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Digitization of 20 years of decametric observations of the Sun and Jupiter in Nançay between 1970 and 1990

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ABSTRACT

Since 1970, decametric observations of the Sun and Jupiter have been acquired on a daily basis from the radio observatory of Nançay, France. The resulting database now forms the worldwide largest set of low frequency observations of the Solar Corona between 10 and 100 MHz and of the Jovian magnetosphere between 10 and 40 MHz. The Nançay Decameter Interferometer (NDI), a two-antenna interferometer, acquired pioneer observations from 1970 to 1978, using analog radio receivers tested on the Arecibo giant radiotelescope. The large Nançay Decameter array (NDA), a phased array of 144 helical antennas, was then constructed in the late 1970s as a ground-based support to the Voyager mission and started routine observations in January 1978 in replacement of the NDI, using similar spectrometers. The NDA is still in operation today and its observations, recorded in a digital format since 1990, are public and daily made accessible to the heliospheric and magnetospheric communities at <https://www.obs-nancay.fr/reseau-decametrique/>. Before 1990, though, the Nançay decametric observations were recorded on analog devices, such as 35-mm films, magnetic tapes and other paper supports, physically archived at the Observatory of Paris, on its site of the Observatory of Meudon, where they could only be accessed on demand. The NDA team recently undertook a multi-year effort to inventory all the Nançay decametric archives, to refurbish and digitize them in order to preserve and promote this historical data collection, most notably by extending the current public database over the 1970-1990 time interval. We digitized the full collection of 35-mm films, corresponding to a total film length of ~ 45.5 km, with a specific high resolution scanner. Each roll was scanned by a series of pixel-to-pixel contiguous images recorded in TIF format with adequate metadata and naming convention. The final ~ 40 Tb data volume was archived at Paris Astronomical Data Centre and the physical films were refurbished to be archived in a perennial way. We also digitized the associated observations sheets. Finally, we took advantage of this project to also digitize a sample of 35-mm films extracted from four other historical solar data collections hosted at the Observatory of Paris and dealing with two distinct Nançay radiotelescopes and two Lyot heliographs located at the Observatories of Meudon and Haute-Provence. The digitized, documented, Nançay decametric archives have been publicly released to the community in 2020 at <http://archives-decametriques.obspm.fr>. After having described the instruments, the data collections and the digitization pipeline, this article ends with a few scientific case studies, focussing on the search for Jupiter-satellite decametric emissions. This work is a concrete example of how historical astronomical measurements can be preserved and archived along the IAU recommendation, to the benefit of the astronomical community.

Keywords: Decametric radioastronomy – Archives – Solar Corona – Jupiter’s magnetosphere

1. INTRODUCTION

Created in 1956 in the Sologne forest (France) under the responsibility of the Observatory of Paris, the radio observatory of Nançay has hosted since then a variety of radiotelescopes covering a wide spectral range from a few MHz to several GHz. The exploration of the low frequency sky, ranging from the terrestrial ionospheric cutoff of ~ 10 MHz to 120 MHz (decameter wavelengths) rose in the early 1960s under the impulsion of the Meudon research group of decametric radioastronomy of André Boischoat.

While developing low frequency radio receivers, which were tested at the giant parabola of Arecibo in 1970 Boischoat et al. (1971), the group led the construction and operation of two successive decameter radiotelescopes in Nançay, devoted to the quasi-daily monitoring Sun and Jupiter. Between 1970 and 1978, a 2-antenna interferometer, hereafter referred to as the Nançay Decameter Interferometer (NDI), acquired pioneer observations Boischoat (1974). After Jan. 1978, solar system observations were acquired by the Nançay Decameter Array, a phased-array with a larger effective area, designed as a sensitive ground-based support to the Voyager mission Boischoat et al. (1980) and still in operation today. Pictures of these instruments are displayed in Figure 1.

Altogether, this 52 years-long Nançay decametric database now forms what appears to be the worldwide largest set of low frequency observations of the Solar Corona between 10 and 100 MHz, and of the Jovian magnetosphere between 10 and 40 MHz, sampling ~ 4.7 solar cycles and ~ 4.2 jovian revolutions, with high resolution observations acquired with a series of receivers of increasing performances. The NDA data are acquired in digital format since 1990, and the observations obtained with its Routine (survey) receiver are daily publicly released to the heliospheric and magnetospheric communities at <https://www.obs-nancay.fr/reseau-decametrique>. This digital 32 years-long database has continuously fed in research efforts on heliospheric radio emissions and the unique length of the database yielded pioneer statistical analyses of Jovian and Solar radio bursts. Recent examples include the detection of new decametric emissions induced by Ganymede, Europa or unrelated to satellites from a 26-30 years-long catalog of NDA observations of Jupiter Marques et al. (2017); Zarka et al. (2018); Jácome et al. (2022) or the characterization of solar type III bursts automatically tracked over half a solar cycle Zhang et al. (2018).

However, the NDA/NDI measurements collected between 1970 and 1990 were recorded analog devices, such as 35-mm films, magnetic tapes and other paper supports. These archives were conserved at the Observatory of Paris on its site of the Observatory of Meudon, where they could only be accessed on demand Lamy et al. (2017). This situation prevented from a wide scientific use of pioneer measurements. The conservation state and duration of analog archives was also unknown with a significant risk of loss of historical measurements. In this article, we present a multi-year effort recently undertaken by the NDA team to inventory all the Nançay decametric archives, to refurbish and digitize them in order to preserve and promote this historical data collection, most notably by extending the current public database over the 1970-1990 time interval.

The importance and urgency of the preservation and digitization of historical observations has been acknowledged recently by the XXXth General Assembly of the International Astronomical Union (IAU) in its Resolution B3: "on preservation, digitization and scientific exploration of historical astronomical data" International Astronomical Union (2018), which starts by stating that *historical observations provide irreplaceable information regarding changes in the Sun, stars, and other objects of astronomical interest and thereby allow researchers to investigate the time domain and the nature of those transient, evolutionary or recurring changes across a far greater interval than is possible from the relatively short time-span of modern-age (born digital) observations alone.*

Hereafter, section 2 describes the concerned radiotelescopes and section 3 the associated inventoried collections of analog decametric archives. We present in section 4 how we digitized the full collection of 1492×35 -mm films at high spatial resolution and intensity dynamics together with the associated observation sheets. Section 5 indicates how the data can be accessed and used scientifically, while section 6 presents a few scientific case studies, focussing on the search for Jupiter-satellite decametric emissions. Finally, section 7 presents 10 digitized films extracted from four other 35-mm data collections of radio and visible solar observations also conserved at the Observatory of Paris, corresponding to decades of measurements acquired by two other Nançay radiotelescopes and two solar heliographs respectively located at the Observatories of Meudon and Haute-Provence (France).

2. THE RADIOTELESCOPES

2.1. The Nançay Decameter Interferometer (NDI)

The NDI was a two-antenna decameter interferometer (Fig. 1, left), originally designed for solar observations (and therefore also sometimes called solar interferometer) but which rapidly also targeted Jupiter. It operated between 1970 and 1978 Boischoat (1974) with daily observations before to be supplied by the NDA.

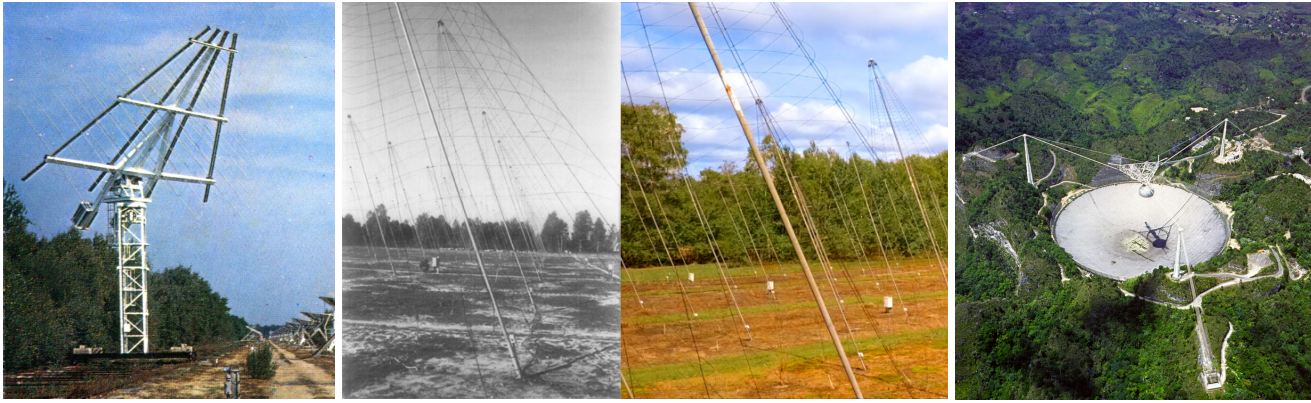


Figure 1. Pictures of (left) the Nançay Decameter Interferometer (NDI), (middle) the Nançay Decameter Array in 1980 and in 2017 and (right) of the Arecibo parabolic dish.

Its two antennas were mounted on top of 10-m high mobile towers able to track moving targets. Each antenna was made of 4 log-periodic dipoles, sensitive to the 20 – 80 MHz range with a 10 dB gain. One antenna was settled at a fixed position and the other one along a 1500-m long East-West tail track, yielding variable baselines for interferometric purposes, although the interferometric mode was rarely used.

The sensed signal was recorded by various radio receivers specifically developed for the radio observatory of Nançay. Two swept-frequency spectrographs measured the signal over the 20-40 and 40-80 MHz ranges, with spectral bandwidth of 20 kHz and 100 kHz, respectively, at a variable sweeping rate within 1-500 Hz. Alternately, two swept-frequency receivers using the same sweep-generators and recording devices could be used in interferometric mode. One multi-channel receiver sampled a 1 MHz band (within the 10-110 MHz range), with 50×20 kHz-wide adjacent channels. Four fixed-frequency spectrographs measured the signal at 30, 36, 60 and 72 MHz over a 250 kHz bandwidth.

The devices used to collect the data included magnetic tapes, 35-mm films, fac-similés and foldable paper, as illustrated in Figure 2, reproduced from [Leblanc & Groupe de Radioastronomie Décamétrique \(1975\)](#).

The scientific research conducted with NDI observations has been early reviewed by [Boischoot \(1974\)](#).

2.2. Decametric observations of the Sun at Arecibo

Between 15th July and 25th August 1970, the decametric research team of Meudon conducted solar observations with the giant parabola of Arecibo (Puerto Rico). This observing program, requested to the director of the Arecibo observatory, aimed at detecting the quiet solar corona at decameter wavelengths [Boischoot et al. \(1971\)](#).

The observations were carried out with the swept- and fixed-frequency receivers described above, namely two swept-frequency receivers covering the 20-40 and 40-80 MHz ranges and sensitive to two polarizations, and fixed-frequency spectrographs at 29, 36 and 60 MHz sensitive to one polarization. The signal was collected with a specifically-conceived feed antenna placed at the focal point of the 300-m large dish and made of two perpendicular log-periodic antennas sensing either both right- and left-handed circularly polarized emissions or two perpendicular linearly polarized ones.

The observations were executed from 16th July to 16th August, with 50 h of solar observing time spread over 18 days, complemented by 12 h for calibration sources (pulsars) and 5 h to observe the moon. The data were recorded on magnetic tapes (which benefit the best, 40 dB, dynamics) and on 35-mm films.

The fixed-frequency measurements of the Sun were for instance analyzed by [Aubier et al. \(1971\)](#) who proposed that wave scattering by the inhomogeneous corona affects the solar decametric brightness, or by [Aubier & Boischoot \(1971\)](#) to measure the temporal profile of type-III bursts and infer coronal temperatures.

The scientific research conducted with NDI observations has been early reviewed by [Aubier & de La Noe \(1971\)](#); [Boischoot \(1974\)](#).

2.3. The Nançay Decameter Array (NDA)

The NDA, also known as the large decameter array, is a steerable phased-array with an effective area of ~ 7000 m² at 25 MHz, a maximal gain of 25 dB and a wide main lobe ($\sim 6 \times 10^\circ$). It is made of 144 Tee-Pee log-periodic broadband fixed antennas sensitive to the 10-120 MHz range, inspired by those of the Clark Lake Observatory [Erickson & Fisher \(1974\)](#) except that they have been inclined by 20° southward to facilitate the tracking of solar systems targets. These

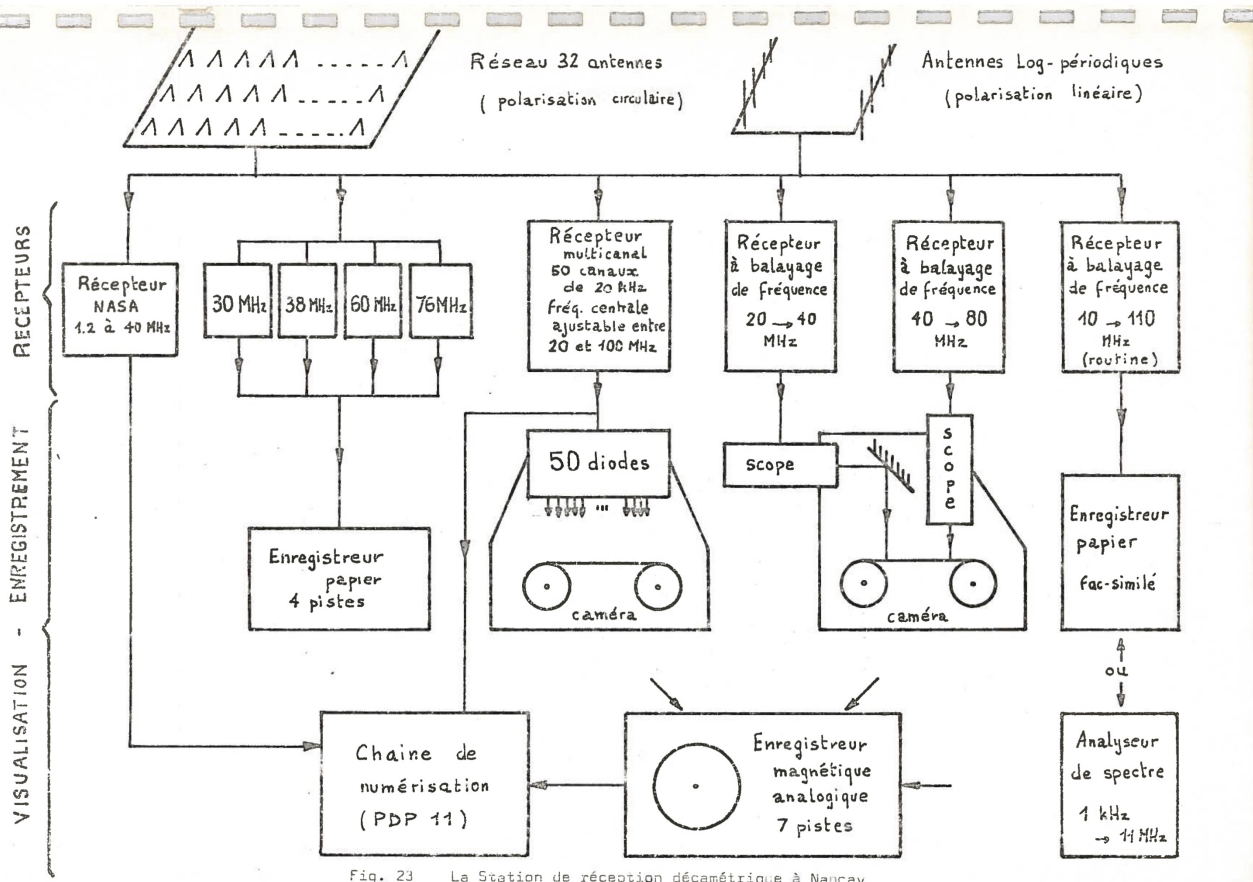


Fig. 23 La Station de réception décimétrique à Nançay

Figure 2. Data acquisition pipeline for the NDI and NDA (in its early 32-antennas configuration) instruments. Data were recorded on 35-mm films, magnetic tapes, fac-similés and paper sheets. Reproduced from Fig. 23 of [Leblanc & Groupe de Radioastronomie Décimétrique \(1975\)](#).

conical antennas form 2 sub-arrays respectively sensitive to right-handed and left-handed circularly polarized emissions [Boischot et al. \(1980\)](#); [Lecacheux \(2000\)](#).

The NDA has been originally conceived as a ground-based stereoscopic support to the exploration probes which based the experiment known as STEREO-MJS 77 (for Mariner-Jupiter-Saturn 1977) which ultimately became the Voyager mission [Leblanc & Groupe de Radioastronomie Décimétrique \(1975\)](#). The latter observed heliospheric radio emissions with the Planetary Radio Astronomy (PRA) experiment, the spare model of which has been lent to the radio Observatory of Nançay for stereoscopic observations with the same receiver [Aubier et al. \(1978a\)](#); [Boischot et al. \(1981\)](#). The NDA was therefore built between 1975 (the primary set of 32 antennas array is displayed in Figure 2) and late 1977. It has been observing since then the Sun and Jupiter on a daily basis, together with other intense radiosources, with a series of successive radio receivers which were analog before 1990 and digital beyond [Lamy et al. \(2017\)](#). A tentative summary of the spectrometers employed by the NDI and the NDA is provided in table 1.

The NDA analog data were recorded on the same devices as those employed for the NDI, as illustrated in Figure 2.

Overall, the results obtained from the analysis of NDA measurements, published in ~ 200 articles, have been successively reviewed in [Lecacheux \(2000\)](#); [Zarka \(2011\)](#); [Lamy et al. \(2017\)](#).

3. THE DECAMETRIC ARCHIVES

From 2016 to 2018, the NDA team conducted an exhaustive inventory of the decametric archives conserved at the Observatory of Paris on the site of the Observatory of de Meudon (which was merged with the Observatory of Paris in 1926). The archives, stored in different buildings, overall consisted of collections of 35-mm films, of fac-similés, of foldable papers, of observation sheets together with some handwritten catalogs. This inventory unfortunately revealed that the magnetic tapes mentioned above had all been lost.

Receiver	Acronym	Type	Measurements	Characteristics	Data storage	Data availability	Reference
Spectrograph		Swept-freq.	1 channel	10-110 MHz	Fac-Similés	1975-1987	Boischot (1974)
Spectrographs	S	Swept-freq.	RR, LL RR, LL	20-40 MHz with $\delta f = 20$ kHz 40-80 MHz with $\delta f = 100$ kHz	Films, Magn. tapes	1978-1990	Boischot (1974)
Spectrograph		Swept-freq.	2 channels	Interferometric mode	Films	Data lost	Boischot (1974)
Spectrographs		Fixed-freq.	1 channel $\delta f = 250$ kHz	$f = 30, 36, 60$ and 72 MHz	Sefram	1977-1079	Boischot (1974)
Multi-channel spectrometer	MCX	Multi-freq.	RR, LL	1 MHz band, $\Delta t = 100+$ msec	Films, Magn. tapes	1977-1981	Lecacheux & Rosolen (1975)
Routine	R	Swept-freq.	RR, LL		Films, Magn. tapes	1979-1989	Boischot et al. (1980)
Planetary Radio Astronomy	PRA	Swept-freq.	2 channels	main mode POLLO	Films, Magn. tapes	Data lost (1979-1983)	Warwick et al. (1977)
Acousto-optical Spectrometer 1	SAO	Acousto-optic.			2 Films	1983-1984 (other data lost)	
Routine-New (now Routine)	RN	Swept-freq.	RR, LL	$\delta f = 30$ kHz, $\delta t = 0.87$ msec	Films, Magn. tapes	1990-1991	
Rou	Rou			10-40 MHz : 0.5 sec \times 75 kHz	Digital	Since 1990	Lecacheux (2000)
Analysseur de spectre numérique	ASN			10-80 MHz : 1.5 or 2.5 sec \times 250 or 125 kHz			
Analysseur de spectre à balayage)	ASB			10-40 MHz, $\Delta t = 10$ msec and $\delta f = 30$ kHz			
Digital spectropolarimeter	POLAR	Swept-freq.	I, Q, U, V	1.5 or 2.5 sec \times 250 or 125 kHz	Magnetic tapes	Data lost (1990-?)	Lecacheux et al. (1991)
Acousto-optical Spectrometer 2	SAO2	Acousto-optic.	RR, LL	24 MHz band : $3+$ msec \times 11.7 kHz	Digital	Data lost (1997-?)	Lecacheux (2000)
Digital Signal Processor	DSP	Filters bank	RR, LL, LR	12.5 MHz band : $1+$ msec \times 12.2 kHz	Digital	Data lost (1997-?)	Kleewein et al. (1997)
Reconquete	RDH	FFT	RR, LL, LR	12.5 MHz band : $1+$ msec \times 12.2 kHz	Digital	Test observations (2004-2009)	Weber et al. (2005)
Domaine Hertzien	NR	FFT	RR, LL, LR	FFT, 3-500 msec \times 49 kHz	Digital	Since 2012	Lamy et al. (2017)
News-Routine	M	FFT	RR, LL		Digital	Since 2014	Lecacheux et al. (2013)
Meristo			10-35 MHz : 100 msec \times 80 kHz				
Juno-Nançay	J	FFT Waveform	RR, LL, LR	6-56 MHz : $2.6+$ msec \times $3.05+$ kHz	Digital	Since 2016	Lamy et al. (2017)

3.1. *Films*

We retrieved a total of 1492×35 -mm rolls, each long of ~ 30.5 m in average, yielding a total film length of ~ 45.5 km. These rolls sub-divide in three different sets : 601 rolls correspond to NDI observations, 13 to the Arecibo campaign and 878 to NDA measurements. The rolls were generally in good conservation state. They were stored in metallic boxes showing frequent traces of rust, themselves conserved in metallic cabinets. Each box was labelled with a sticker indicating the number of the roll in a given data collection (a data collection consisting of a combination of an instrument with a receiver, see below), the observing date, the target and the acronym of the receiver, as illustrated in Figure 3. This basic information enabled us to classify the films precisely.

The NDI archives can be separated into 3 data collections : 436 rolls obtained with the 'S' (Spectrograph) receiver, 149 rolls with the 'MCX' (Multi-Channel) one and 16 rolls corresponding to tests (unused rolls, duplicated ones, tests of instrumental modes etc.).

The Arecibo campaign was treated as a single data collection made of 13 rolls, obtained with different receivers.

The NDA, largest, set of films consists of 4 data collections : 682 rolls acquired with the 'S' receiver between 1978 and 1980 (most likely the same receiver as that used with the NDI), 154 rolls obtained with the 'R' (Routine) receiver between 1979 and 1989, 40 rolls obtained with the 'RN' (Routine-New) from 1990 to 1991 and 2 rolls obtained with the 'SAO' (Spectrographe Acousto-Optique or Acousto-Optical Spectrograph) in 1983.

The structure of a given film generally consists of several separated observations each made of 1 or 2 dynamic spectra with the frequency (y) axis perpendicular to the roll direction and the time (x) axis along it. Handwritten notes were sometimes found directly on the film (to mark events of interest, the start of an observation, a change in instrumental mode). The NDI/NDA observations exclusively deal with quasi-daily observations of Jupiter and the Sun, most of the time recorded in alternance with long (up to 8 h) observations. Different time and frequency markers, depending on the inspected data collection, were visible on the films, providing references for both axes. The Arecibo observations contained dynamic spectra together with time series of the recorded signal at fixed frequencies. They targeted the Sun, the moon and historical pulsars such as CP-1919, the first pulsar discovered only 3 years earlier before the observing campaign.

The overall structure of 35-mm films, the nature of the recorded signals and the coding of the time/frequency markers were understood by comparing the films (either by eye or with historical visualization devices) with the 35-mm data published in the literature, such as in Boisshot et al. (1971); Aubier et al. (1978b); Boisshot et al. (1980), as illustrated in Figure 4. Interestingly, we noticed at several occasions some perforations marked with colored sewing threads corresponding to published observations.

3.2. *Observation sheets*

We also retrieved and inventoried a total of 10219 individual paper sheets, displayed in Figure 5, stored in pasteboard boxes. Each sheet describes an individual observation executed with both the NDI and the NDA over the time interval ranging from 1st Sept. 1977 to 14th Nov. 1997. This time interval does not coincide with the NDI lifetime, either because such observations sheets were not in use or have been lost before 1977. Interestingly, they have been produced on a daily basis up to 1997, covering 7 years of NDA observations also acquired in digital format, which will be helpful for the scientific validation of NDA analog data.

Such observations sheets contain handwritten essential information for the understanding of the recorded decametric observations such as the name of the observer, the date and duration of the observation, the target, the pointing parameters (manual or automatic, tracking, scan or transit mode), the used receiver and the employed instrumental mode together with the data outputs (number of channels, analog device on which the data were recorded).

Four different models of observation sheets have been identified, all being displayed in Figure 5 (right).

3.3. *Paper-based data records*

In addition to the observation sheets, we also retrieved two types of paper-based data records.

3.3.1. *Fac-similés*

The first type consists of so-called Fac-similés, which are 30 cm large paper print-out rolls long of a few meters (up to 12 m) aimed at plotting specific data intervals at high resolution.

We inventoried 812 individual rolls from Dec. 1975 until June 1987, stored in pasteboard boxes. Each roll was labelled with a sticker describing the content of the roll (source, observation interval, and handwritten comments on



Figure 3. Collection of Nançay decametric archives stored on 35-mm rolls in their original metallic boxes. (a-c) Pictures of the NDI, Arcibo and NDA sub-collections. The different acronyms refer to the receivers used for the observations. (e-d) Original metallic storage cabinets and inventoried films before digitization.

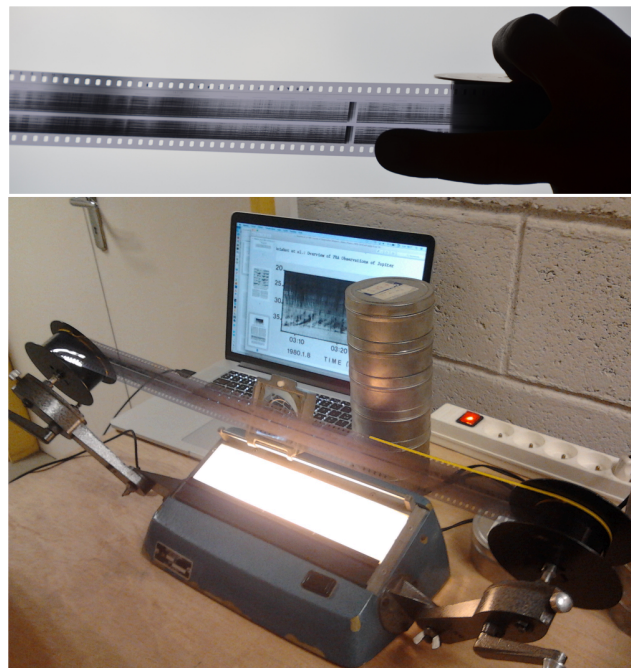


Figure 4. Visual inspection of 35-mm films. (Top) Data recorded through two channels with time markers, vertical radio frequency interferences and a calibration sequence. (Bottom) Comparison with a published dynamic spectrum Boisshot *et al.* (1981).

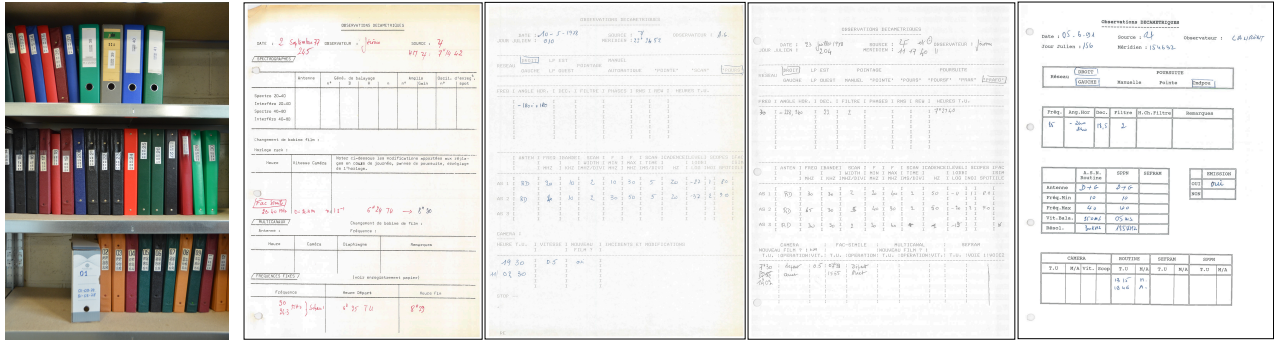


Figure 5. (Left) Decametric observation sheets stored in boxes, ranging from 1st Sept. 1977 to 14th Nov. 1997. (Right) Four models of observation sheets have been successively employed to described the NDI/NDA daily measurements.

the nature of observed emissions). Most of the rolls where in good state. Figure 6 shows pictures of this collection. All these archives deal with Jupiter and the Sun, except one which corresponds to one observation of Cassiopea A.



Figure 6. Fac-similés rolls on which were drawn high resolution decametric observations.

3.3.2. Foldable papers

The second type of paper-based archived measurements consists of foldable sheets of paper, sometimes referred to as Sefram (as the name of the company producing those). The signal recorded on this medium corresponded to fixed-frequency measurements of transiting radiosources at high cadence. We inventoried 17/8 individual foldable sheets for the NDA RH/LH polarized observations obtained from 4th Nov. 1977 to 14th March 1979 and from 22th Feb. 1977 to 25th Feb. 1979, respectively. The targeted sources were Cygnus A, Cassiopea A, Taurus A and Virgo A. These observations, matching the construction timeline of the NDA, were devoted to calibration purposes as indicated by handwritten notes. An example of foldable paper record is displayed in Figure 7.

4. DIGITIZATION

Once inventoried, the digitization of the above-described archives became an obvious priority of the NDA team Lamy et al. (2017); Cecconi et al. (2018).

4.1. The 35-mm collection

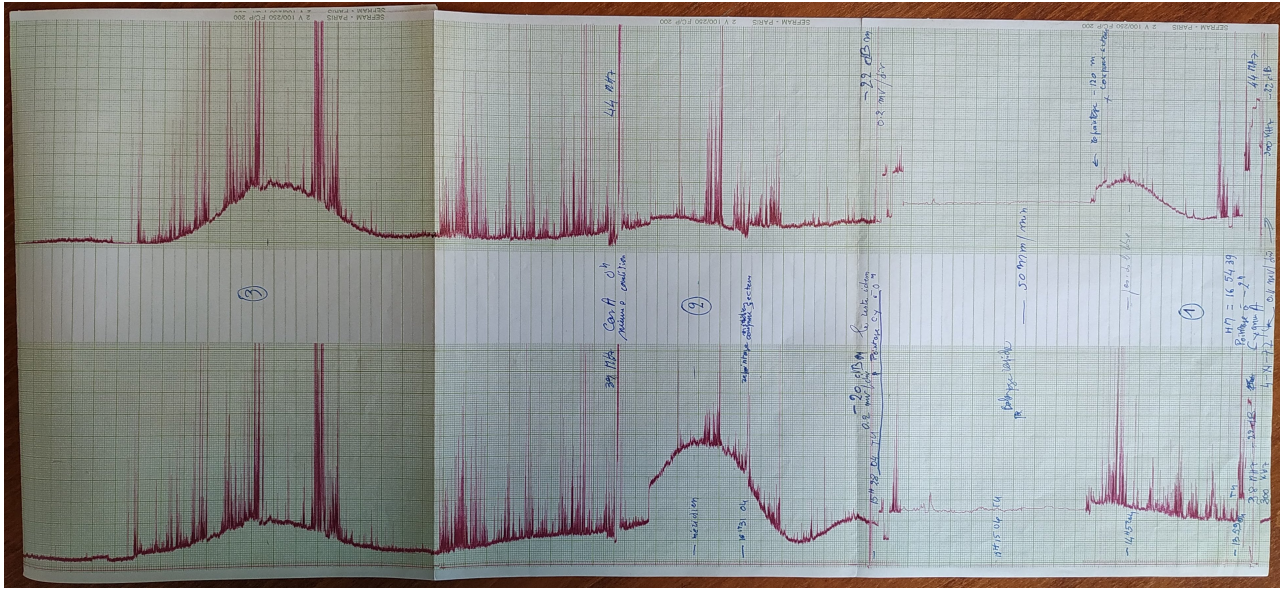


Figure 7. Picture of data recorded on a Sefram foldable paper sheet showing transit observations of Cas A.

The digitization of the large collection of 35-mm rolls, corresponding to a total film length of 45.5 km, required a substantial work. This work was achieved in several steps between 2018 and 2020 including most notably : drafting a digitization project, applying to funding calls to assemble the required budget (~ 100 k€, including the cost of the digitization process, of the required digital storage volume and the full time of an archivist for a period of 9 months), the publication of an open call with the digitization requirements, the selection of a digitization company equipped with an adequate, high performance, scan, the testing and validation of scanning parameters on a subset of rolls, the digitization of the full dataset itself, the storage of the digitized observations together with the cleaning, refurbishment and final archiving of the physical 35-mm rolls.

4.1.1. Digitization parameters

The employed scanner was a CS 8850 WW model of the Wicks & Wilson 8800 series. It enabled to digitize the 35-mm rolls with the following characteristics. Each roll was first cleaned and uncharged from static electricity by a broom preceding the scan. The flatness of the film was ensured by a mechanical tension imposed by two 10 cm-distant supports. The roll was continuously read and scanned with a theoretical 8-bits dynamics in intensity. In practice, the final dynamics was slightly adjusted to sample both the background and most intense pixels without saturation, resulting in a loss of ~ 0.5 dB. The obtained scans were recorded in the TIF format as 15744×5408 pixels images. They covered the full extent of the film across the rolling direction (y-axis or spectral direction), therefore including the perforations. They were also strictly adjacent in the rolling direction (x-axis or temporal direction) with a 1 pixel precision. Overall, a ~ 30.5 m-long film in average was entirely scanned through a total of ~ 320 TIF images. Examples of the quality of the digitization process are displayed in Figure 8. The x and y axes were not necessarily constant along a full film, because of some intrinsic variability linked to the camera used to plot the data onto the film. This variability was generally related to a change of instrumental mode (it was for instance possible to adapt the speed at which the film was printed) or a change of observation. The x and y axes could nonetheless be fairly precisely located within a given sequence of observation.

4.2. Digital conservation

The final set of TIF images represents a ~ 40 Tb total volume. These images were stored by data collection onto a server of the Observatory of Paris maintained by the Paris Astronomical Data Centre (PADC) and accompanied by a Data Management Plan. We kept the definition of a data collection as the observations obtained with one instrument (*e.g.* the NDA) and one receiver (*e.g.* the S receiver).

The individual TIF images were accompanied by standard metadata and labelled with a specific nomenclature, which we describe below on the basis of the following example : `FR751142302_RDN_S_0416_1982_0243.tif`. The FR751142302

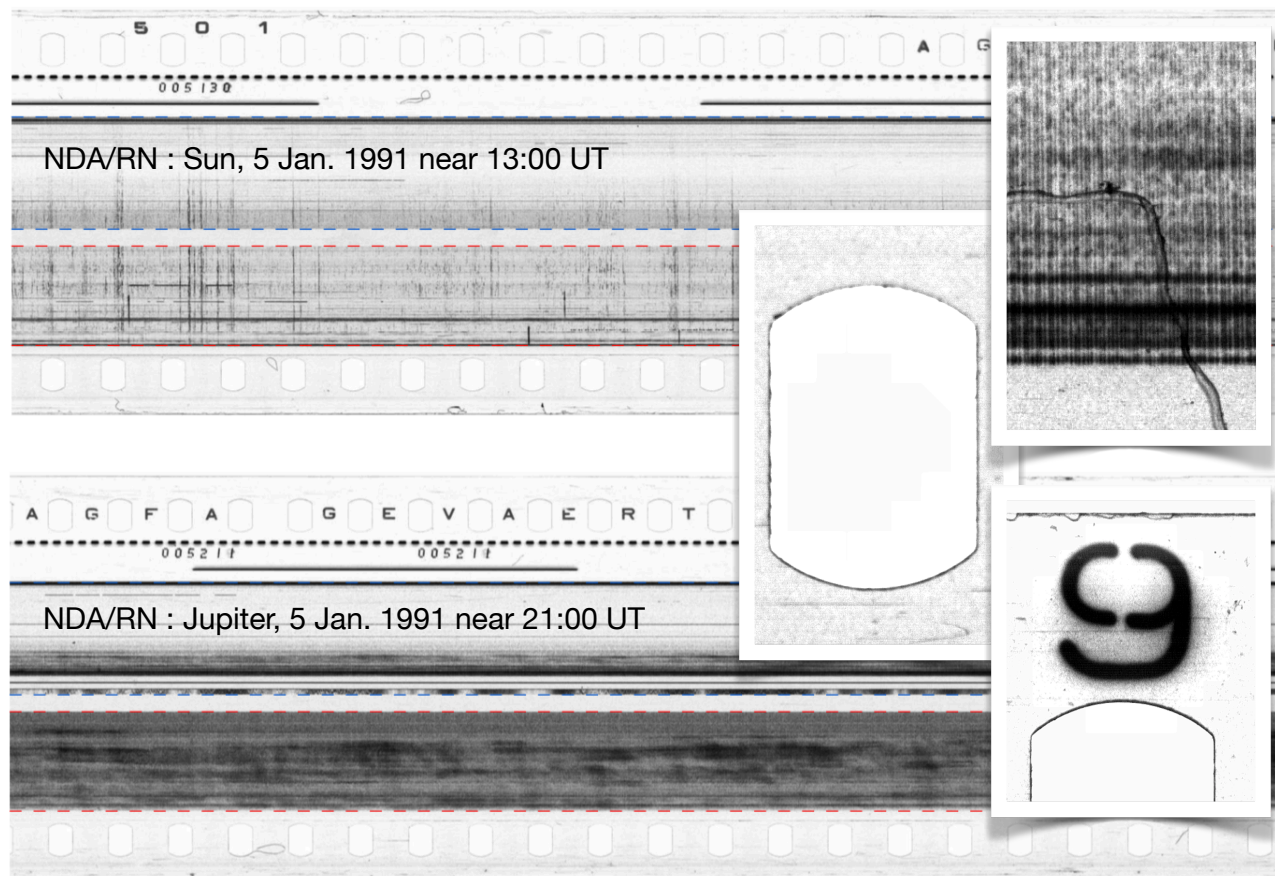


Figure 8. (Left) Test images of digitized observations of Jupiter and the Sun together with (right) full resolution extracts.

code identifies the library of the Observatory of Paris, where the data collection is hosted. The RDN code refers to the french acronym (Réseau Décimétrique de Nançay) for the NDA, and could be alternately IDN (for NDI) or Arcibo. The 'S' letter refers to the used receiver and could be alternately R, RN, M, SAO or TEST (for test observations). 0416 identifies the roll number within a data collection (here RDN_S). 1982 corresponds to the starting year for the scanned roll. Finally, 0243 indicates the number of the scan for a given roll.

4.3. *Preservation of physical archives*

The original storage of 35-mm films used metallic devices (rolling core and storage box) not adapted to long-term conservation. Once digitized, each scanned film was re-rolled around a plastic core and stored in an individual acid-free paper box compliant with the current policy of archive conservation. Both the the roll and its associated box were labelled with the unique identifier of the film within a data collection. The refurbished films were ultimately packed by groups and definitely inventoried for long-term archiving at the Observatory of Paris and stored in a dedicated archiving room on the site of the Observatory of Meudon. Figure 9 displays examples of refurbished rolls after digitization.

4.4. *Observation sheets*

The observation sheets have been straightforwardly digitized individually with a standard digital photocopier. All the information that they contain have additionally been manually extracted and used to construct a digital base of metadata.

4.5. *Other paper records*

Although we tested the digitization of at least one Fac-similé roll, we chose not to digitize the collections of paper records. As these were precisely inventoried, a list of those is nevertheless available and, as for the other decametric physical archives, can be accessed on demand to the NDA team.

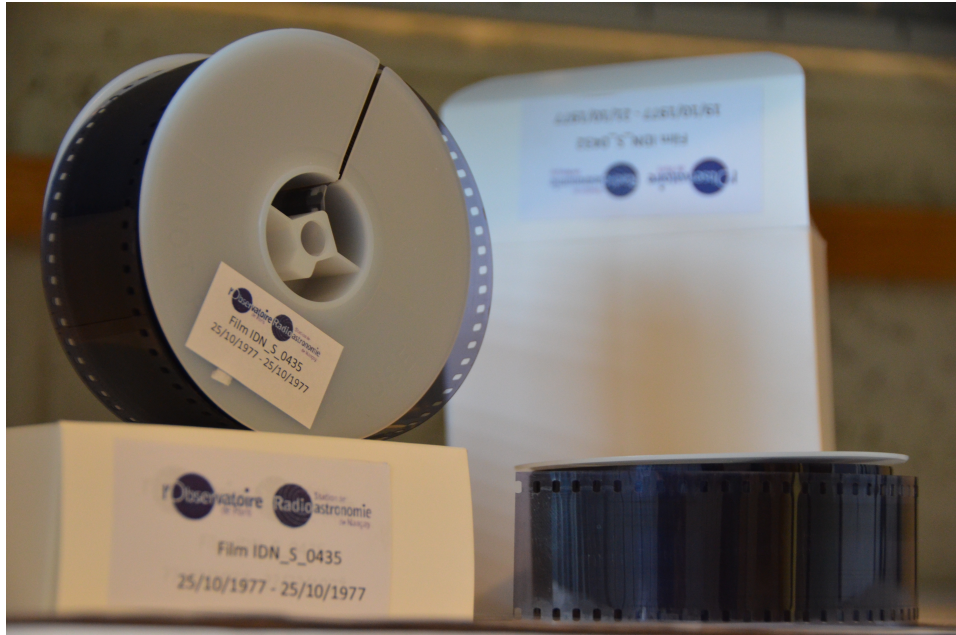


Figure 9. Refurbished 35-mm rolls after digitization.

5. DATA AVAILABILITY

In order to release the digitized Nançay decametric archives to the scientific community, we created the online portal <http://archives-decametriques.obspm.fr>, which both describes the digitization project and provides access to the digitized data with an associated documentation.

The 35-mm digitized dataset, which decomposes into 8 separated data collections, is distributed under the Creative Commons-BY-4.0 licence format and is referenced as Lamy et al. (2020). The digitized observation sheets are accessible together with the 35-mm data and referenced as Debisschop et al. (2020), with an online documentation describing how to read them with usecases. Intensity calibration of the NDA data can be performed by using the hourly calibration sequences with noise diodes of known flux (one example of which is seen on Figure 2, top), exactly as for digital data.

Interestingly, the NDA decametric archives of Jupiter obtained between 1978 and 1990 were specifically cataloged in the literature throughout a series of articles successively published by Leblanc et al. (1981, 1983, 1989, 1990, 1993), likely because the NDA team realized that analog records of the observations could not be easily re-used. These catalogs consist of time-frequency boxes in which Jovian decametric bursts were detected. However, the published versions were only available as raster scans which prevented the community from easily utilizing easily them. This issue motivated a recent, parallel, digitization effort of (Cecconi et al., to be submitted to the Planetary and Heliospheric Radio Emissions IX proceedings). The digitized catalogs in their original formatting are now also accessible online together with the Jovian digitized data they refer to and referenced as Leblanc & et al. (2020a,b,c,d,e). A final catalogue, referenced as Cecconi et al. (2020), compiles all of them, while fixing a few events and adding more contextual metadata (such as the phase of non-Io moons).

6. SCIENTIFIC USE CASES

We used the digitized set of NDA archives to perform the preliminary comparisons and data analyses presented below.

6.1. Comparison with published observations

No observations sheets were retrieved for the Arecibo campaign, for which only the handwritten notes found on top of the films helped us to figure out the content of the records. Nonetheless, we retrieved the solar observation published by Boisshot et al. (1971) in their Figure 2, replicated on top of Figure 9. The original caption mentions two types of solar radio bursts, together with a vertical lightning flash but the original display of the Figure has a poor dynamics which prevents from tracking finely the behaviour of the bursts, despite the huge sensitivity of the Arecibo dish.

Figure 9, bottom shows the portion of the digitized film corresponding to this observation. We can immediately notice the gain in dynamics and identify fainter radio bursts near 46 MHz before the vertical lightning flash which could not be tracked from the original Figure. The bottom portion of the film additionally shows a dynamic spectrum at higher frequencies which reveal continuous solar emission during the observed interval.

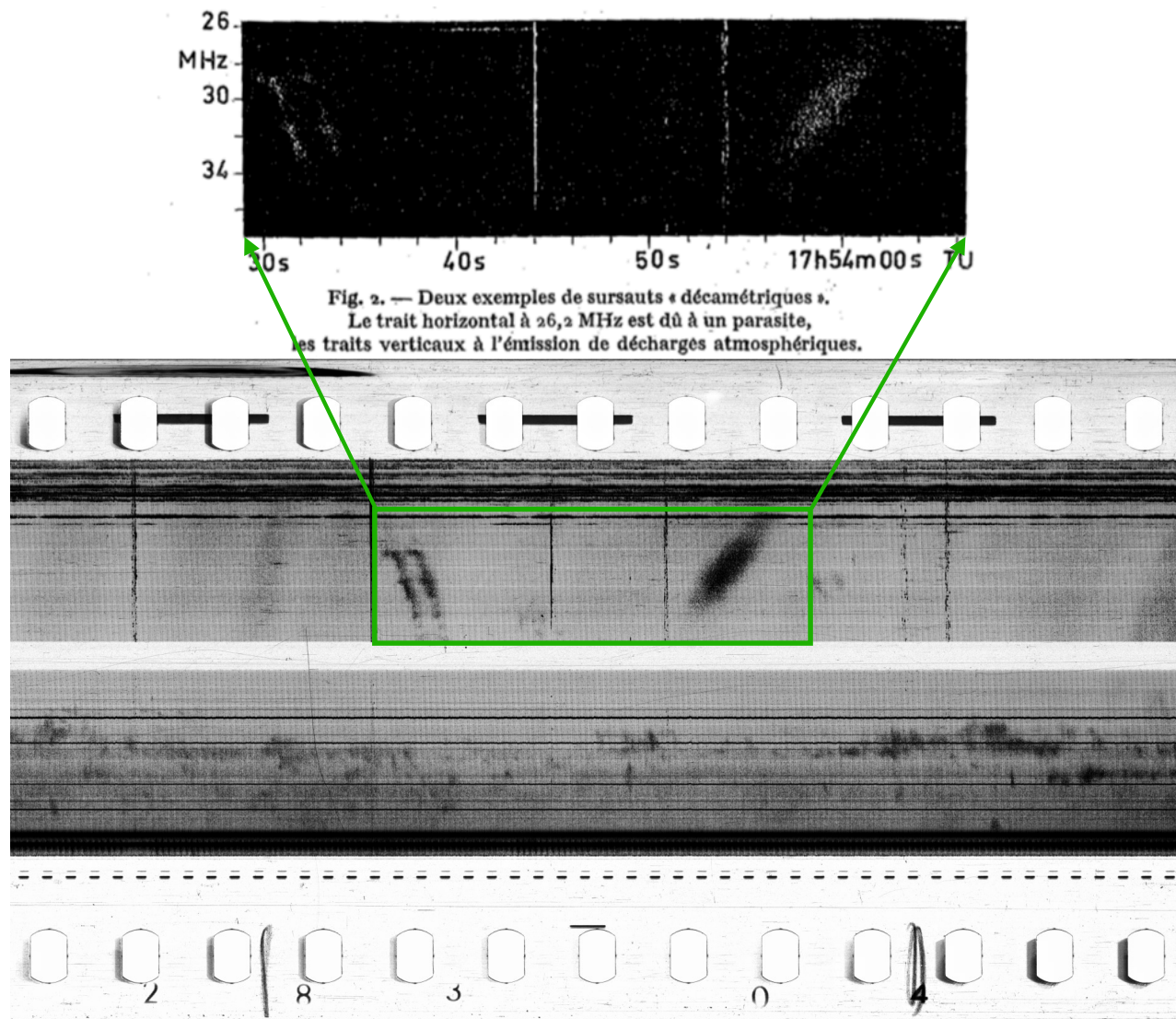


Figure 10. (Top) Dynamic spectrum of Boisshot et al. (1981).

6.2. Jupiter-satellite decametric emissions

Figures 11 and 12 display full resolution dynamic spectra reconstructed from the NDA Jupiter observations of 3rd and 5th Feb. 1978 respectively, as the very first observations of the completed array. The two observations were indeed recorded on the first and second roll of the NDA/S data collection. The observation sheets confirmed the use of the S receiver with the RH sub-array and provided the observed spectral range for both channels. The data are of excellent quality and displayed decametric emission with high dynamics and high temporal and spectral resolution.

The observed intervals were chosen specifically as they correspond to the first two records of Jupiter emissions cataloged by Leblanc et al. (1981). The corresponding time-frequency boxes are superimposed on the data by dashed white boxes. While fairly matching the bursts, some weak emission can also be identified outside the boxes.

The emission visible in Figure 12, vertex-late and RH-polarized, reaching frequencies as high as 28 MHz, is characteristic of the Io-A component. We checked with the online Jupiter probability tool recently developed by the NDA team (Cecconi et al., in prep.) at <https://jupiter-probability-tool.obspm.fr> that this actually corresponds to the Io-A' type of emission statistically identified by Marques et al. (2017) from a catalog of 26 years of digital NDA/Routine observations.

The weaker bursts visible in Figure 11, vertex-late and RH-polarized and barely reaching 20 MHz are a non-Io emission. Surprisingly, the Jupiter probability tool shows that it is consistent with a Ganymede-A emission, which was only very recently statistically detected by Zarka et al. (2018) from the analysis of the 26 years-long catalog of NDA/Routine observations of Jupiter mentioned above. It is thus striking to realize that the first recorded NDA observation of Jupiter was likely a Gan-A event while such emissions were unambiguously identified 40 years later. By itself, this example shows the interest of long-term databases and the value-added of digitized historical datasets.

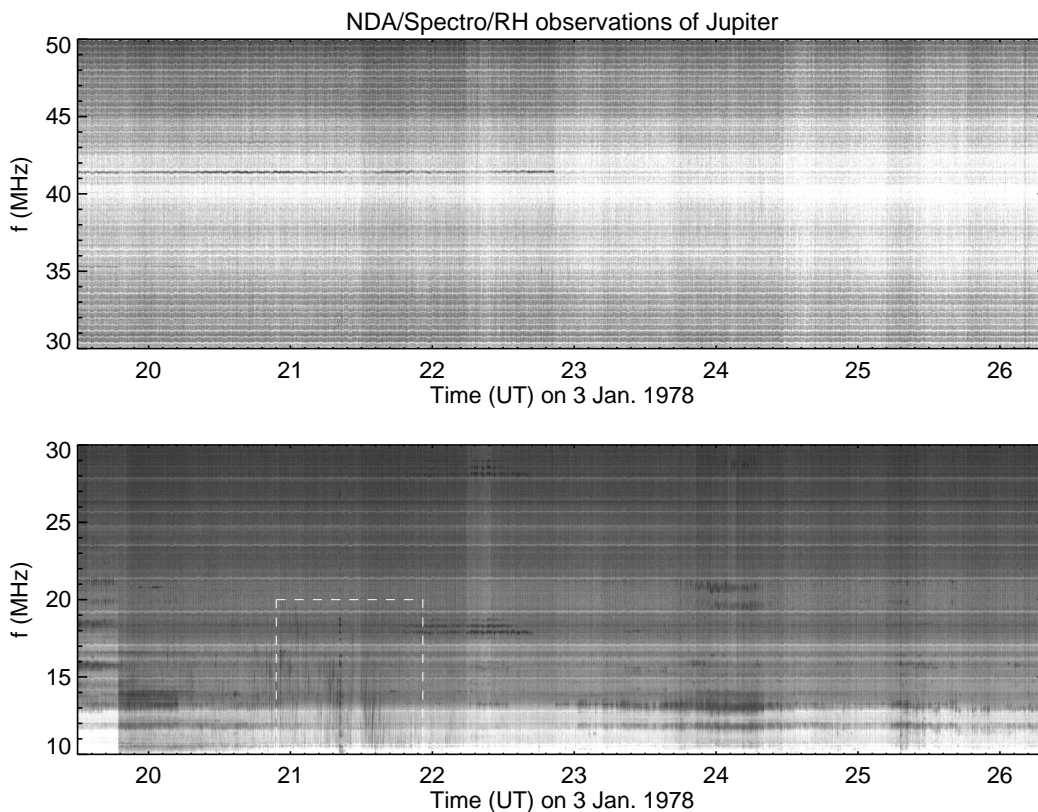


Figure 11. NDA/S dynamic spectra of Jupiter acquired with the RH sub-array on 3rd Feb. 1978 from 10 to 50 MHz. The white dashed box corresponds to the first reported detection of Jupiter in the NDA catalog of Leblanc et al. (1981). The vertex-late, RH polarized emission is consistent with a Ganymede-A decametric emission.

The full 12 years-long digitized catalog of NDA archived observations of Jupiter provides an occasion to check the persistence of planet-satellite decametric emissions from 1978 to 1990 and to extend the results of Marques et al. (2017); Zarka et al. (2018) obtained over the 1990-2016 interval. Figure 13a plots the Jupiter cataloged emissions as a function of the Io phase and the longitude of the observer. As expected, the distribution reproduces that already published by Leblanc et al. (1993) (with the same dataset but over the 1978-1988 interval only). The emissions clustered within the colored regions defined by Marques et al. (2017) are attributed to Io with some differences, though. For instance, the

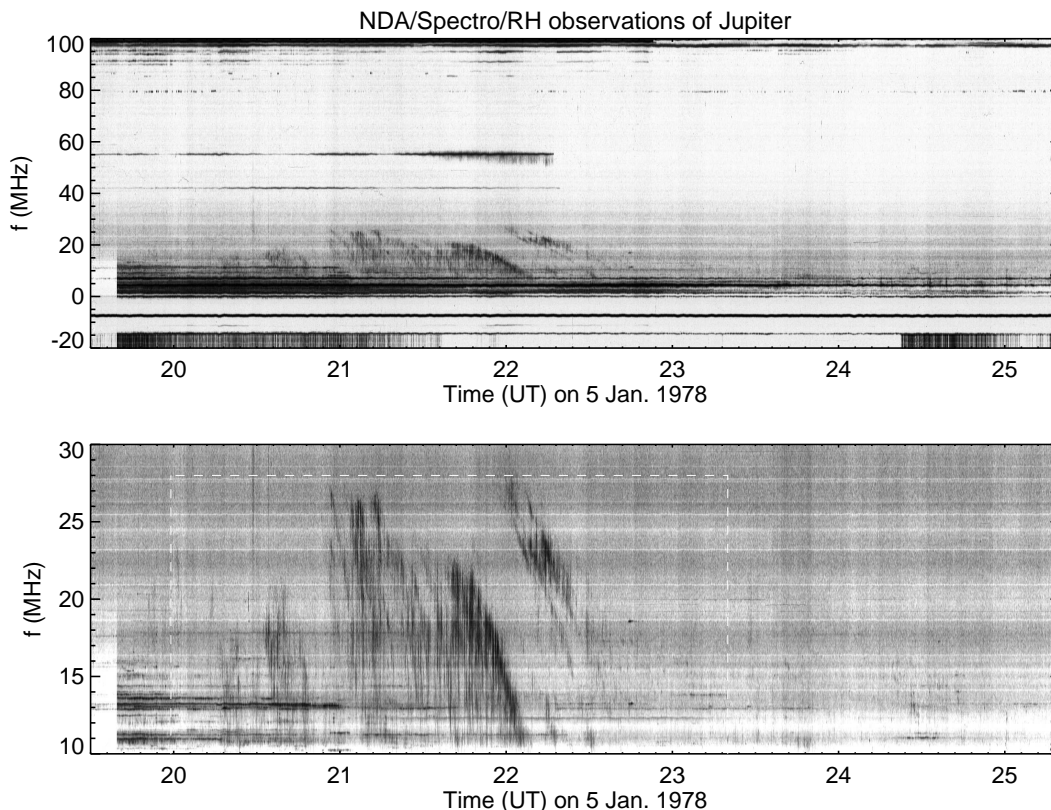


Figure 12. NDA/S dynamic spectra of Jupiter acquired with the RH sub-array on 5th Feb. 1978 over two spectral ranges covering 10-100 MHz. The white dashed box corresponds to the second reported detection of Jupiter in the NDA catalog of [Leblanc et al. \(1981\)](#). The vertex-late, RH polarized emission is consistent with a Io-A decametric emission.

Io-B (Io-D, resp.) component near the bottom left blue (red, resp.) box was more (less, resp.) visible than in [Marques et al. \(2017\)](#). The comparative occurrence of the various Io components within the 1978-1990 and 1990-2022 intervals is left for future analysis. Once the Io components were removed, we plotted the rest of the emissions as a function of the phase of the satellites Europa, Ganymede and Callisto as an attempt to track decametric emissions induced by those moons [Zarka et al. \(2017\)](#). A modest cluster consistent with the Gan-A and B emissions identified by [Zarka et al. \(2018\)](#) is visible on Figure 13b. No obvious cluster consistent with the Europa emissions recently identified by [Jácome et al. \(2022\)](#) appears on Figure 13c, though. These results are likely affected by the poorer resolution of the boxes defined in the 1978-1990 catalog when compared to the polygons employed in the 1990-2020 but might also reveal an additional long-term trend. A more detailed analysis of the long-term occurrence of Jupiter-satellite emissions is beyond the scope of this paper.

7. OTHER 35-MM DATASETS ARCHIVED AT THE OBSERVATORY OF PARIS

In parallel to the above-described work of the NDA team on decametric archives, the ‘archive and legacy’ commission from the scientific council of the LESIA laboratory has identified four other collections of 35-mm archives conserved at the Observatoire de Paris on its site of Meudon. These consist of two sets of radio observations of the Sun acquired in Nançay (i) with the Radio Spectrographe Multicanal de Nançay (RSMN) over 110-470 MHz, consisting of 758×35 -mm films recorded between 1978 et 1991 [Dumas et al. \(1982\)](#) and (ii) with the Nançay Radio Heliograph (NRH), in operation since 1956, and providing routine images between 150 and 450 MHz [Kerdran & Delouis \(1997\)](#). The two

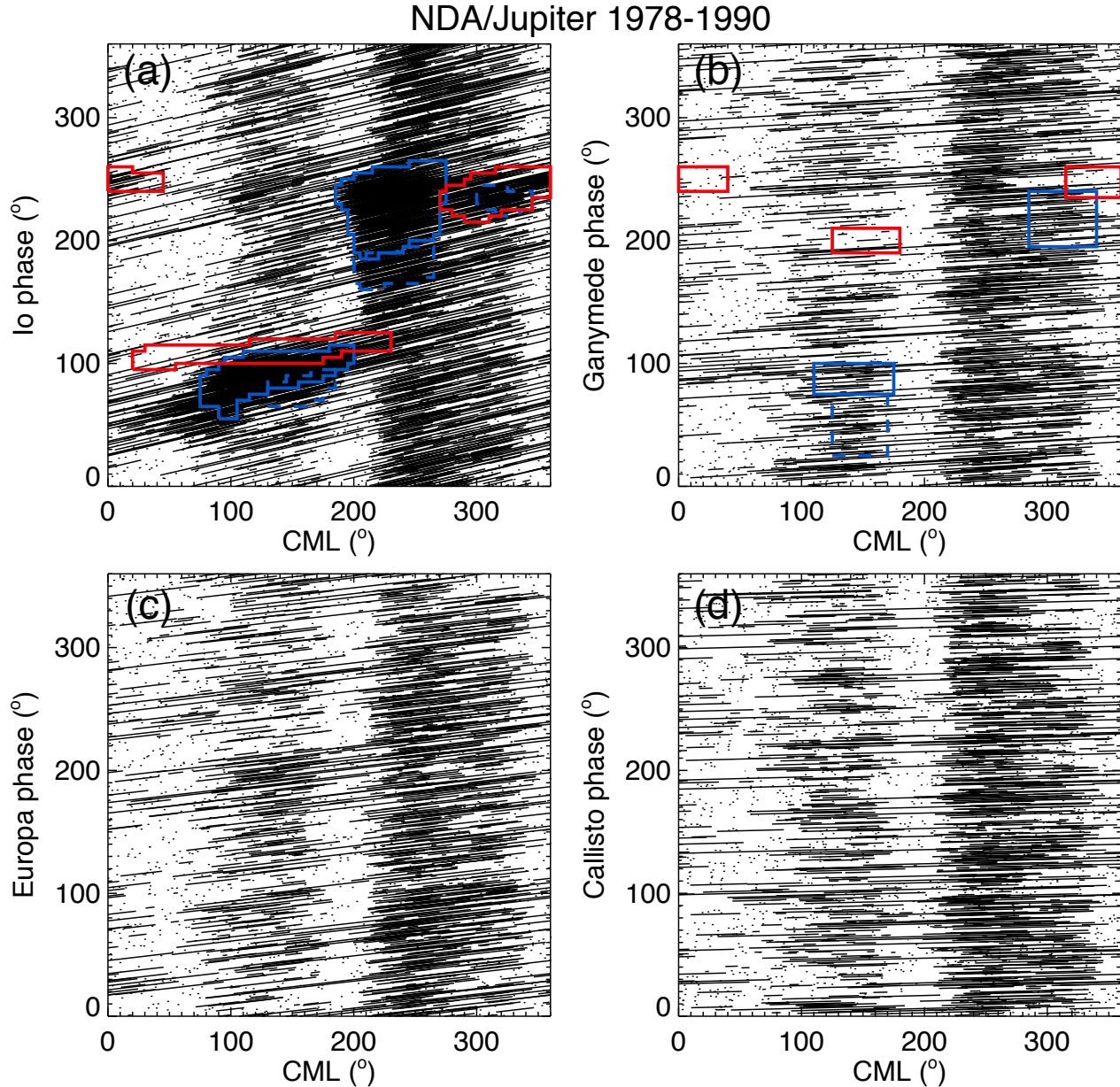


Figure 13. Jupiter emissions recorded with the NDA from 1978 to 1990 plotted as function of the phase of (a) Io, (b) Ganymede, (c) Europa and (d) Callisto and of the central meridian longitude (CML) of the observer. The colored regions in panels (a) and (b) mark the most probable regions for Io- and Ganymede-Jupiter decametric emissions, according to Zarka et al. (2018). Panel (a) displays all NDA/Jupiter records, while panels (b-d) display only those without the Io-Jupiter emissions.

other sets of observations consist of visible, mostly $H\alpha$, sequences of images of the Sun acquired with a series of Lyot Heliographs installed (iii) at the Observatory of Meudon, consisting of 1966 films collected between the 28th May 1956 and the 29th Oct. 1997 (yielding an estimated total of ~ 5.8 millions of individual images) Grenat & Laborde (1954) and (iv) at the Observatory of Haute-Provence, consisting of 1195×35 -mm films obtained between the 30th Apr. 1958 and the 1st Feb. 1995¹.

We took advantage of this project to digitize a sample of each of these four collections, yielding a total of 10 digitized films targeting periods of active solar activity. The radio observations were scanned as the decametric ones. Examples

¹ <https://observations-solaires.obspm.fr/Les-heliographes>

of digitized images are provided at <https://archives-decametriques.obspm.fr/>. The solar images were scanned with a different scanner, whose frequency of acquisition was adjusted on the frequency of images acquired along the film. Figure 14 shows $H\alpha$ images of the Sun acquired at the Observatory of Meudon in 1957 (left) and at the Observatoire de Haute Provence in 1958 (right). Despite a background noise on the film, the quality of the images is excellent and enables one to easily track active regions on the solar surface.

The further analysis of these images and the possible future digitization of the associated 35-mm collections is left to interested colleagues of the solar community.

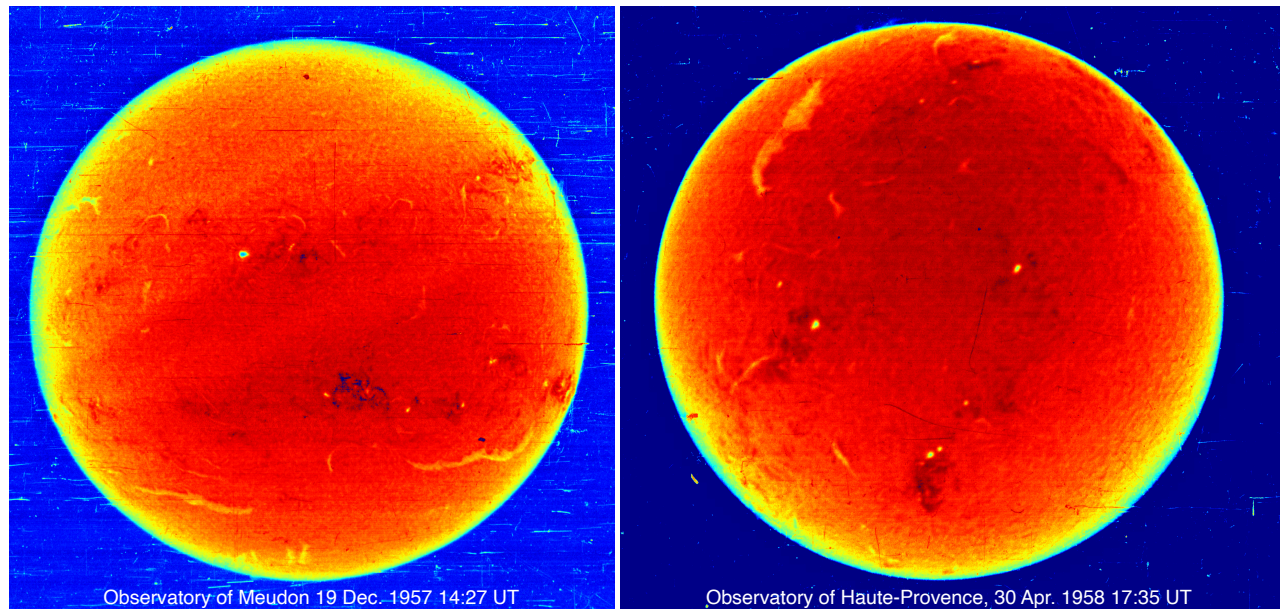


Figure 14. Individual $H\alpha$ images of the Sun acquired with the Lyot Heliographs at the Observatory of Meudon on 19 Dec. at 14:27 UT 1957 (left) and at the Observatory of Haute-Provence on 30 Apr. 1958 at 17:35 UT (right).

8. SUMMARY AND PERSPECTIVES

In this article, we have presented a multi-year effort of the NDA team to fully refurbish the Nançay decametric archives conserved at the Observatory of Paris. These consist of quasi-daily observations of Jupiter and the Sun successively acquired between 1970 and 1990 with three radiotelescopes : the NDI, the Arecibo parabola and the NDA, which is still in operation today.

The observations were recorded on analog devices such as 35-mm films and other paper based supports that we have fully inventoried. We have then digitized and documented the entire 35-mm data collection and the associated daily observation sheets. We have ensured in parallel a long-term preservation of the refurbished physical archives. We have shown how the digitized data can be used for scientific purposes with use cases. A preliminary analysis of the Jovian decametric emissions for instance suggests that the first ever NDA record of Jupiter displays an arc consistent with a Gan-A emission. Interestingly, the statistical occurrence of Jupiter emissions cataloged by the NDA team throughout 1978-1990 supports the presence of Gan-A and B emissions, but no obvious evidence of radio emissions induced by Ganymede or Europa, which needs further investigation.

The digitized, documented, data have been publicly released in 2020 through the online portal <http://archives-decametriques.obspm.fr>. This extends the current 32 years-long NDA digital database with 20 years of novel observations and offers new perspectives to the community for unprecedented long-term analyses of the Solar Corona and the Jovian magnetosphere over half a century.

We have finally presented digitized samples of four other 35-mm solar data collections also conserved at the Observatory of Paris, acquired by two other radiotelescopes of the radio Observatory of Nançay (RSMN and NRH) and two Lyot heliographs which acquired $H\alpha$ images of the Sun at both the Observatories of Meudon and Haute Provence.

This project is a concrete example of how historical astronomical measurements can be preserved and digitized to facilitate their scientific exploration along the IAU recommandation. Its success is thanks to synergistic efforts

between researchers, archivists, data engineers and web designers involving the LESIA laboratory, the library of the Observatory of Paris and the Paris Astronomical Data Centre.

We thank the NDA team and especially P. Zarka and L. Denis for their precious memories. We also thank M.-P. Issartel for her long-lasting inventory work, S. Cnudde for his pictures of the archives and design work of the webpage, C. Colon for her unvaluable work on budgetary aspects, I. Bualé for managing the solar archives in Meudon, C. Briand and S. Corbel for their support and L. Klein and J.-M. Malherbe for useful advice. We also acknowledge the work of the 'archive and legacy' commission at LESIA and PADC. We warmly thank C. Higgins, W. S. Kurth, E. Echer, A. Konovalenko and H. Rucker for their official support to this digitization project.

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REFERENCES

- Aubier, M., & Boisshot, A. 1971, in CESRA-2, Committee of European Solar Radio Astronomers, ed. A. Abrami, Vol. 2, 109
- Aubier, M., & de La Noe, J. 1971, *Astronomy & Astrophysics*, 12, 491
- Aubier, M., Leblanc, Y., & Boisshot, A. 1971, *Astronomy & Astrophysics*, 12, 435
- Aubier, M. G., Boisshot, A., Leblanc, Y., et al. 1978a, in ATP Planétologie
- Aubier, M. G., Leblanc, Y., & Moller-Pedersen, B. 1978b, *Astronomy & Astrophysics*, 70, 685
- Boisshot, A. 1974, *Solar Physics*, 36, 517, doi: [10.1007/BF00151218](https://doi.org/10.1007/BF00151218)
- Boisshot, A., de La Noë, J., Du Chaffaut, M., & Rosolen, C. 1971, *Academie des Sciences Paris Comptes Rendus Serie B Sciences Physiques*, 272, 166
- Boisshot, A., Lecacheux, A., Kaiser, M. L., et al. 1981, *J. of Geophys. Res.*, 86, 8213, doi: [10.1029/JA086iA10p08213](https://doi.org/10.1029/JA086iA10p08213)
- Boisshot, A., Rosolen, C., Aubier, M. G., et al. 1980, *Icarus*, 43, 399, doi: [10.1016/0019-1035\(80\)90185-2](https://doi.org/10.1016/0019-1035(80)90185-2)
- Cecconi, B., Debisschop, L., & Lamy, L. 2020, A catalogue of Jovian decametric radio observations from January 1978 to December 1990, PADC/MASER, doi: [10.25935/1FQM-FS07](https://doi.org/10.25935/1FQM-FS07)
- Cecconi, B., Lamy, L., Denis, L., et al. 2018, Digitizing analogic spectrograms recorded by the Nançay Decameter Array on 35mm film rolls from 1970 to 1990
- Debisschop, L., Lamy, L., & Cecconi, B. 2020, Nançay Decametric 35mm Film Observations Logs Collection, Observatoire de Paris, doi: [10.25935/QS04-FV42](https://doi.org/10.25935/QS04-FV42)
- Dumas, G., Caroubalos, C., & Bougeret, J. L. 1982, *Solar Physics*, 81, 383, doi: [10.1007/BF00151311](https://doi.org/10.1007/BF00151311)
- Erickson, W. C., & Fisher, J. R. 1974, *Radio Science*, 9, 387, doi: [10.1029/RS009i003p00387](https://doi.org/10.1029/RS009i003p00387)
- Grenat, H., & Laborde, G. 1954, *Annales d'Astrophysique*, 17, 541
- International Astronomical Union. 2018, Resolution B3 on preservation, digitization and scientific exploration of historical astronomical data. https://www.iau.org/static/resolutions/IAU2018_ResolB3_English.pdf
- Jácome, H. R. P., Marques, M. S., Zarka, P., et al. 2022, *Astronomy & Astrophysics*, 665, A67, doi: [10.1051/0004-6361/202244246](https://doi.org/10.1051/0004-6361/202244246)
- Kerdraron, A., & Delouis, J.-M. 1997, in *Coronal Physics from Radio and Space Observations*, ed. G. Trottet, Vol. 483, 192, doi: [10.1007/BFb0106458](https://doi.org/10.1007/BFb0106458)
- Kleweein, P., Rosolen, C., & Lecacheux, A. 1997, in *Planetary Radio Emissions IV*, 349–357
- Lamy, L., Zarka, P., Cecconi, B., et al. 2017, in *Planetary Radio Emissions VIII*, 455–466, doi: [10.1553/PRE8s455](https://doi.org/10.1553/PRE8s455)
- Lamy, L., Cecconi, B., Debisschop, L., et al. 2020, Nançay Decametric 35mm Film Observations Digitized Collection, Observatoire de Paris, doi: [10.25935/QRMQ-X194](https://doi.org/10.25935/QRMQ-X194)
- Leblanc, Y., de La Noe, J., Genova, F., Gerbault, A., & Lecacheux, A. 1981, *Astron. & Astroph.*, 46, 135
- Leblanc, Y., & et al. 2020a, A catalogue of Jovian decametric radio observations from January 1978 to December 1979, PADC, doi: [10.25935/GXZF-ZT33](https://doi.org/10.25935/GXZF-ZT33)
- . 2020b, A catalogue of Jovian decametric radio observations from January 1980 to December 1981, PADC, doi: [10.25935/RAS0-ER93](https://doi.org/10.25935/RAS0-ER93)
- . 2020c, A catalogue of Jovian decametric radio observations from January 1982 to December 1984, PADC, doi: [10.25935/403B-VA51](https://doi.org/10.25935/403B-VA51)
- . 2020d, A catalogue of Jovian decametric radio observations from January 1985 to December 1987, PADC, doi: [10.25935/gh59-py87](https://doi.org/10.25935/gh59-py87)

- . 2020e, A catalogue of Jovian decametric radio observations from January 1988 to December 1990, PADC, doi: [10.25935/cmqb-jj10](https://doi.org/10.25935/cmqb-jj10)
- Leblanc, Y., Gerbault, A., Denis, L., & Lecacheux, A. 1993, *Astron. & Astroph.*, 98, 529
- Leblanc, Y., Gerbault, A., & Lecacheux, A. 1989, *Astron. & Astroph.*, 77, 425
- Leblanc, Y., Gerbault, A., Lecacheux, A., & Boudjada, M. Y. 1990, *Astron. & Astroph.*, 86, 191
- Leblanc, Y., Gerbault, A., Rubio, M., & Genova, F. 1983, *Astron. & Astroph.*, 54, 135
- Leblanc, Y., & Groupe de Radioastronomie Décamétrique. 1975, in Internal report, Observatoire de Paris-Meudon. <https://archives-decametriques.obspm.fr/sites/archives-decametriques/IMG/pdf/leblanc-nda-stereo-mjs-75.pdf>
- Lecacheux, A. 2000, Washington DC American Geophysical Union Geophysical Monograph Series, 119, 321, doi: [10.1029/GM119p0321](https://doi.org/10.1029/GM119p0321)
- Lecacheux, A., Boisshot, A., Boudjada, M. Y., & Dulk, G. A. 1991, *Astron. & Astroph.*, 251, 339
- Lecacheux, A., Dumez-Viou, C., & Klein, K.-L. 2013, in *Journées scientifiques URSI-France*, 73–76
- Lecacheux, A., & Rosolen, C. 1975, *Astron. & Astroph.*, 41, 223
- Marques, M. S., Zarka, P., Echer, E., et al. 2017, *Astron. & Astroph.*, 604, A17, doi: [10.1051/0004-6361/201630025](https://doi.org/10.1051/0004-6361/201630025)
- Warwick, J. W., Pearce, J. B., Peltzer, R. G., & Riddle, A. C. 1977, *Space Sci. Rev.*, 21, 309, doi: [10.1007/BF00211544](https://doi.org/10.1007/BF00211544)
- Weber, R., Viou, C., Coffre, A., et al. 2005, *J. Appl. Signal Proc.*, 16, 2686, doi: [10.1051/0004-6361/201833586](https://doi.org/10.1051/0004-6361/201833586)
- Zarka, P. 2011, in *Ecole CNRS de Goutelas 2007*, Vol. 30, 205–215
- Zarka, P., Marques, M. S., Louis, C., et al. 2017, in *Planetary Radio Emissions VIII*, 45–58, doi: [10.1553/PRE8s45](https://doi.org/10.1553/PRE8s45)
- Zarka, P., Marques, M. S., Louis, C., et al. 2018, *Astronomy & Astrophysics*, 618, A84, doi: [10.1051/0004-6361/201833586](https://doi.org/10.1051/0004-6361/201833586)
- Zhang, P. J., Wang, C. B., & Ye, L. 2018, *Astronomy & Astrophysics*, 618, A165, doi: [10.1051/0004-6361/201833260](https://doi.org/10.1051/0004-6361/201833260)