THE NEW MULTICHANNEL RADIOSPECTROGRAPH ARTEMIS-IV/HECATE, OF THE UNIVERSITY OF ATHENS

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Abstract. We present the new solar radiospectrograph of the University of Athens operating at the Thermopylae Station since 1996. Observations cover the frequency range from 110 to 688 MHz. The radiospectrograph has a 7-meter parabolic antenna and two receivers operating in parallel. One is a sweep frequency receiver and the other a multichannel acousto-optical receiver. The data acquisition system consists of a front-end VME based subsystem and a Sun Sparc-5 workstation connected through Ethernet. The two subsystems are operated using the VxWorks real-time package. The daily operation is fully automated: pointing of the antenna to the sun, starting and stopping the observations at pre-set times, data acquisition, data compression by 'silence suppression', and archiving on DAT tapes. The instrument can be used either by itself to study the onset and evolution of solar radio bursts or in conjunction with other instruments including the Nançay Decametric Array and the WIND/WAVES RAD1 and RAD2 low frequency receivers to study associated interplanetary phenomena.

Keywords: instrumentation, solar radio astronomy, solar radio bursts, radiospectrograph

1. Introduction

Radio Spectrography of the solar corona at decimeter, meter and decameter waves provides basic information on the origin and early evolution of many phenomena which later extend through the interplanetary medium and can be observed by spacecraft at lower frequencies, below the ionosphere cutoff, and sometimes can be measured *in situ* (cf. McLean and Lambrum, 1985) and references within). Significant problems include the formation of interplanetary shocks, the acceleration of energetic particles from shock waves, and the relation of energetic electrons emitted by active regions to the Heliospheric Current Sheet. All these problems require a close combination of high frequency observations covering the lower

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corona and obtained from the ground with low frequency observations spanning the interplanetary medium and obtained from spacecrafts. The new digital solar radiospectrograph operated at the Thermopylae station, Greece by the University of Athens, covers the range from 110 to 688 MHz using a 7-meter parabolic antenna and two receivers operating in parallel. One is a sweep frequency receiver and the other a multichannel acousto-optical receiver. The sweep frequency analyser covers the full band, while the high sensitivity multi-channel acousto-optical analyser covers with a high frequency resolution and time resolution the critical 270–450 MHz range where several events seem to originate. Furthermore this instrument has been optimized to be operated in conjunction with the WAVES RAD1 and RAD2 low frequency receivers on the Wind spacecraft (Bougeret et al., 1998) in order to provide ancillary data, allowing us to cover, for the first time, the frequency band from 8 Hz to 688 MHz. The ARTEMIS-IV/HECATE was designed and built by the Space Research Department (DESPA) of Paris Observatory and the University of Athens. It is installed at the OTE (Hellenic Telecommunications Organization) Ground Satellite Station at Thermopylae, Greece and it is operated by the University of Athens.

2. System architecture

The overall structure of the system is shown in Figure 1 (cf. also Maroulis et al., 1997). The Artemis-IV/HECATE consists of an *Analogue* and a *Digital* part, described below.

2.1. The analogue part

The analog part receives and filters the solar radio emission and, finally, transmits it to the digital part. It also contains the electro-mechanical devices that move and point the antenna. The radio emission is collected by a 7-meter parabolic antenna (Figure 2, left panel). The antenna has a typical equatorial mounting. It can be rotated around two axes using motors and tracks the sun in Declination and Hour Angle. The main difficulty is to design and build an antenna with a large bandwidth. Imperfections in the impedance matching result in large variations of the sensitivity as a function of the frequency. The focal system in use is made of two crossed log-periodic antennas which do not measure polarisation. After collection, the signal goes through a filtering stage where rejection filters tuned in the most intense parasite frequency range prevent intermodulation effects, which may reduce amplification and sensitivity. Follow a pre-amplification, and a compensation amplification stage. Finally there is a last amplification stage, responsible for matching the signal to the input specifications of the spectrum analyzers. This arrangement leads to a high signal to noise ratio.

Two receivers, with 128 frequency channels each, share the incoming signal (Figure 2, right panel):

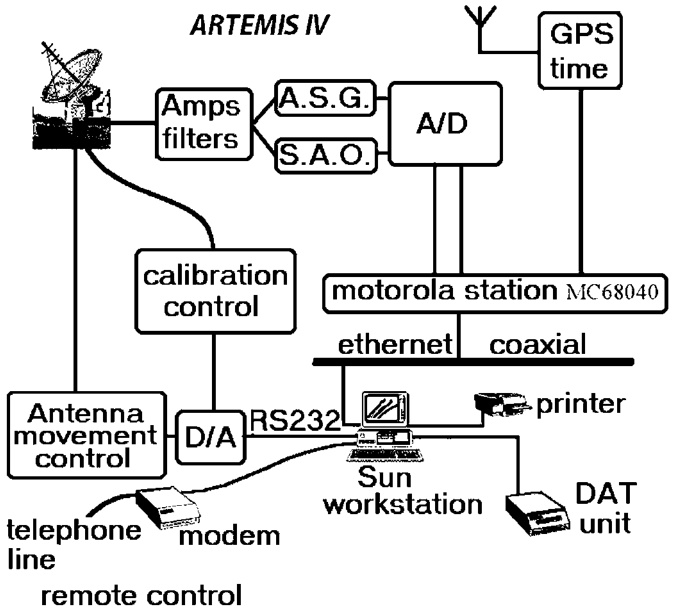

Figure 1. Block Diagram of the ARTEMIS-IV architecture

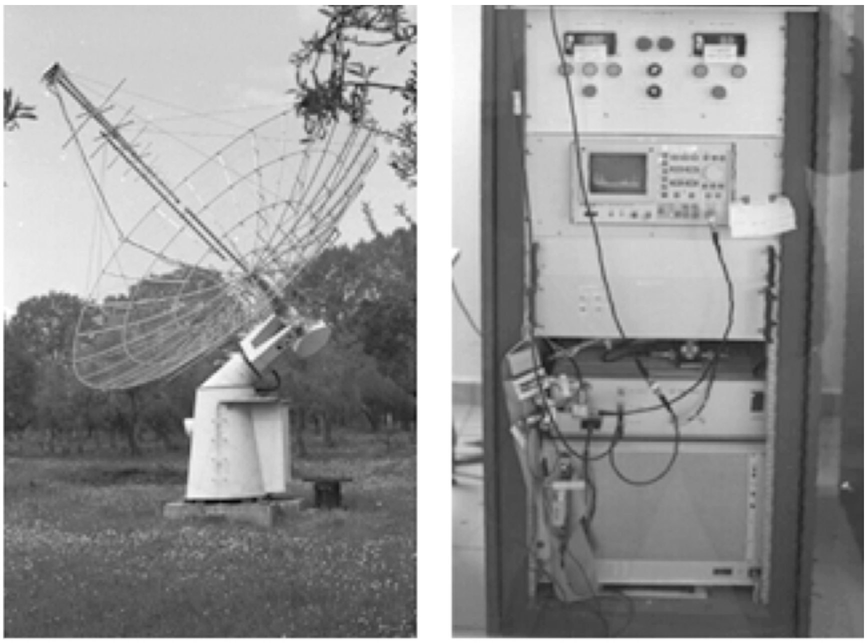

Figure 2. The Artemis-IV radiospectrograph. The 7-meter parabolic antenna is shown in the left panel. In the rack (right panel) the two receivers and the front-end subsystem are mounted.

1. The sweep frequency receiver (Analyseur de Spectre Global or ASG), which covers the range of 110–688 MHz at 10 samples/sec, with a dynamic range of 70 db.
2. The Acousto-Optical receiver (Spectrographe Acousto Optique or SAO), which covers the range of 270–450 MHz at 100 samples/sec, with a dynamic range of 25 db.

The calibration of the system is performed at least twice a day, at the beginning and the end of the observation period in the following way: The receiver is disconnected from the antenna and connected to a noise source of known temperature (10 400 K). Moreover, in order to correct for non-linearities of the image of the receiver, we record its response to a noise source with an intensity varying in steps of 1 db. These data are recorded with the observations.

2.2. THE DIGITAL PART

The digital part consists of two modules with a well defined interface between them: a front-end VME based subsystem and a Sun Sparc-5 workstation connected through 10 Mbps Ethernet. This approach allows easier maintenance and offers greater flexibility for future expansion. The two modules are operated using the VxWorks real-time package.

1. The *front-end module*, which digitizes the analog receiver output using a 12 bit A/D converter, controlled by an MC68040 Motorola microprocessor clocked at 25 MHz. The digitized data are transmitted to the main module by means of the above mentioned Ethernet connection.
2. The *main-module*, which receives digitized data over the ETHERNET connection and removes periods of solar inactivity using a *silence suppression algorithm* (cf. Dumas et al., 1982; Maroulis et al., 1993) and archives periods of solar activity. Furthermore it controls the automated operation of the entire instrument. It is based on a Sun Sparc-5 workstation, running the Solaris Operating System.

An important aspect of the instrument is the capability of unattended operation, without any human attendance apart from a very few functions such as the replacement of the DAT tapes. The complexity of these functions has been kept to a minimum thus eliminating the requirement for trained personnel.

2.3. THE DATA COMPRESSION

At an aquisition rate of 100 samples/sec, the raw data flow from the 128 channels of SAO is 150 kbits/sec resulting in approximately 1 Gbyte of data daily. In order to significantly reduce this amount of data a compression algorithm has been adapted from the multichannel radiospectrograph ARTEMIS-1 of Nançay (Maroulis et al., 1993). The principle of this *burst detection* algorithm is as follows, for one channel:

The digital signal is divided into successive *sentences* of a given constant number N of data points x_{ij} where i and j denote the current timing indices of the data

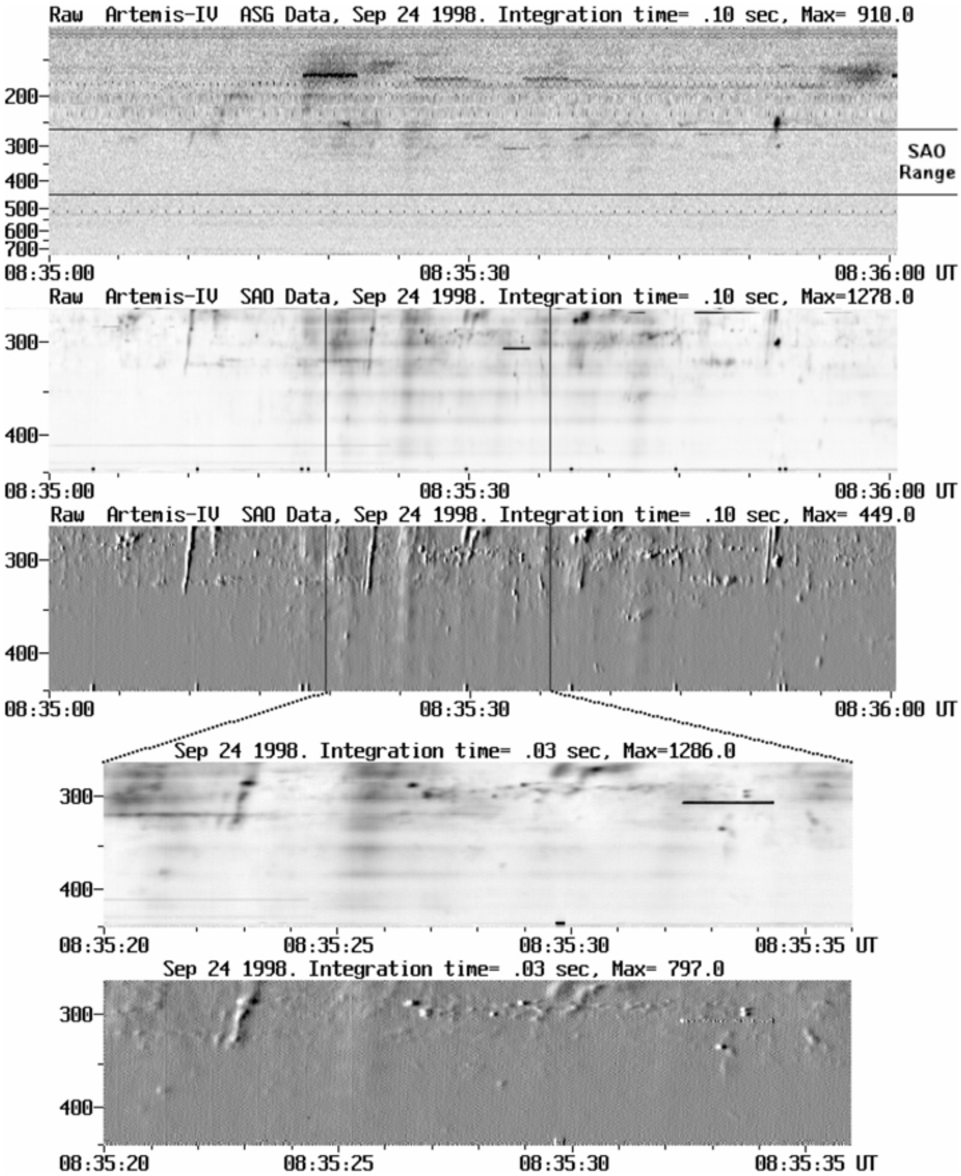

Figure 3. Comparison of ASG and SAO dynamic spectra. Top panel: ASG dynamic spectrum with 0.1 sec resolution in the 110–688 MHz range. Second panel: SAO dynamic spectrum with 0.01 sec resolution in the 270–450 MHz range. Third panel: Differential SAO spectrum with the same time and frequency resolution as panel 2. Fourth and fifth panel: Detail expansion of the SAO intensity and differential spectra from panels 2 and 3, respectively.

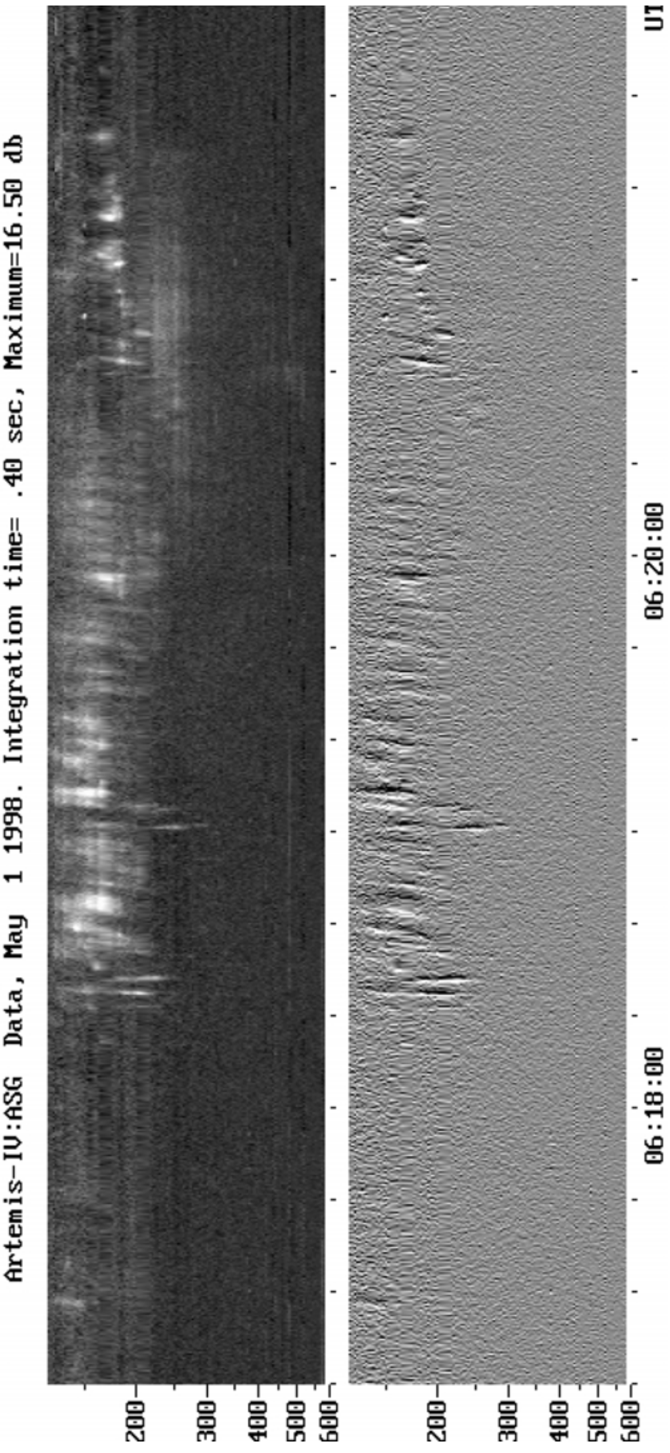

Figure 4. Dynamic spectrum of a type III Group (III-GG), observed on 1 May 1998. The upper panel shows the flux and the lower its time derivative.

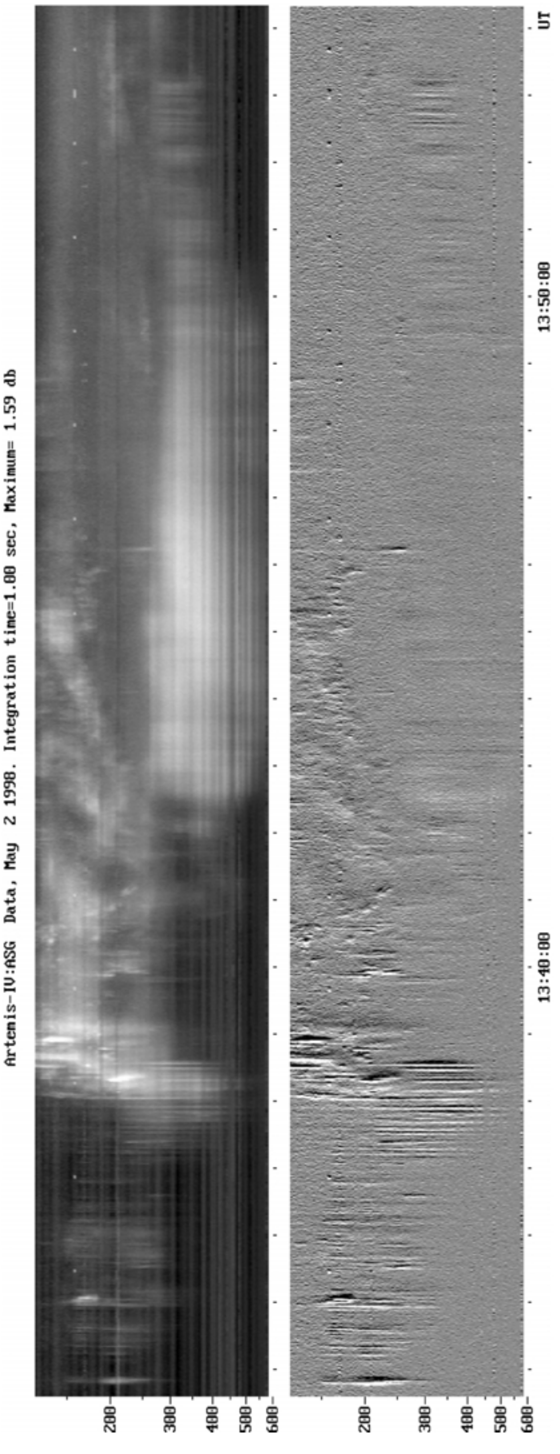

Figure 5. Dynamic spectra of type II event followed by a type IV continuum observed on 2 May 1998. The upper panel of each spectrum shows the flux and the lower its time derivative.

points and of the sentence, respectively. Let m_j be the arithmetic average of the N data points in sentence j. If the *mean absolute deviation* $\mu = \Sigma|x_{ij} - m_{j-1}|$ computed in the *j*th sentence is larger than a predefined threshold σ, then the channel is considered to be *active* over that sentence.

This test is performed on a number of *master channels*. A block of data is considered to be *active* if at least one of the master channels is active. The system retains or rejects blocks according to the following rule: a block is retained if it is active or if it immediately precedes or follows an active block. The average m_j over a block of all the 128 channels are always recorded, whether the block is retained or not. The raw data are currently archived on CD-ROM and DAT tapes.

3. Observations and early results

Compared to classic sweep-frequency receivers, the SAO has a much higher sensitivity and much lower noise, although its dynamic range is rather limited. Figure 3 shows dynamic spectra over an one-minute interval. The top panel shows the ASG spectrum, with the sampling rate of 0.1 sec. The next two panels show the corresponding SAO spectrum (direct and differential display) integrated over 0.1 sec (10 samples). The lower two panels show the SAO data in an expanded time scale (integrated over 33 msec or 3 samples). There is a wealth of weak, small time scale as well as narrow band features that become visible at this resolution.

The ASG still gives very good results in strong, broad band events, such as type III groups (Figure 4) and type II/type IV bursts (Figure 5).

A simple processing of the digital data has been performed in order to enhance small fluctuations and features which are usually undetected because they are superimposed on high level activity. In Figures 3, 4 and 5, the top panels show examples of this processing. Each top panel shows the grey scaled dynamic spectrum, on a logarithmic intensity scale. The intensity has been calibrated for instrumental effects, as described in the previous section, and the quiet Sun background has been subtracted from each channel. The next panel shows the time derivative of the intensity for each frequency channel. Positive derivatives are coded in black, negative in white and all intermediate grey levels have been adjusted to obtain an optimal presentation of the events. Since the original intensity scale for the ASG is logarithmic, this technique provides a differential logarithmic detection, while for SAO it provides differential detection. In Figure 4, we present a type III group dynamic spectrum (upper panel), where the details of individual events are clear in the differential spectrum (lower panel). Moreover in Figure 5 we present a type IV following a type II event. The differential spectrum emphasises the details of the explosive phase as well as the type III precursor, yet it suppresses the type II slowly varying intensity and the type IV continuum which lacks fine structure in this case.

Finally an example of an interesting event can be found in Figure 1 in Bougeret et al. (1998) which shows the first joint observation results, in conjunction with the Nançay Decametric Array, the WIND/WAVES RAD1 and RAD2 low frequency receivers, and the Odrejov radiospectrograph.

4. Conclusions and perspectives

This instrument is characterized by its very high time and frequency resolution, by its capability of autonomous operation and, last but not least, by the use of real time silence suppression on the received data. From this instrument, we expect high quality data which will be used in improving our understanding of solar radio bursts as well as of the underlying physics. The common data analysis of the ARTEMIS-IV/HECATE observations with the data from the WAVES receivers, covering the frequency band from 8 KHz to 688 MHz, will provide a comprehensive description of the solar corona and heliosphere up to the Earths orbit.

The use of industry standard hardware and the modular architecture of the system provide a significant potential for further expansion. In the future we plan to extend the frequency coverage of the radiospectrograph using three Acousto-Optic receivers. We also intend to develop and integrate elaborate processing algorithms for supervised learning and pattern recognition, in an attempt to minimize recording of inactive periods and to automate classification of observational data.

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