M-dm Spectrographs in Europe

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Outline

- Introduction
- Types of ground-based instruments
- Features of radio spectrographs
- Conclusions

Observational requirements

The ideal radio telescope should be able to measure $I(f,x,y,t)$ & $V(f,x,y,t)$ with very low Δf, Δxy, Δt over the entire sun, over the entire radio spectrum, with low noise and wide dynamic range over an unlimited period of time.

However, there are limitations

- No spatial resolution, moderate to high temporal resolution at fixed frequencies (*total flux instruments*)
- Moderate to high spatial resolution at fixed frequencies, moderate temporal resolution (*radio heliographs*)
- Broad band, high spectral resolution moderate to high temporal resolution (*radio spectrographs*)

Total Flux Radio Telescopes

Hiraiso	2.8 GHz	
IZMIRAN	169, 204, 3000 MHz	1000 ms
Crimea	2.5, 2.85 GHz	
Ondrejov	3 GHz	10 ms
Bern (no longer in operation)	3.1, 5.8,8.4,11.8,19.6, 35.0, 50.0 GHz	100 ms
Trieste	237, 327, 408, 610 MHz	1 ms
	1420, 2695 MHz	
Itapetinga	5 bands, 10 – 94 GHz	20 ms

Radioheliographs

Nobeyama	17, 34 GHz	10 – 5 "
SSRT	5.7 GHz	20 "
Guaribidanur	40-150 MHz	300 – 100 "
Nançay	Several freq. in 100s of MHz	90 – 30 "

Non-solar imaging instruments

WSRT	5, 1.4, 0.6 GHz	36 – 3 "
VLA	74 MHz – 40 GHz	24 – 0.05 "
RATAN-600	0.96 – 18 GHz	90 – 30 "
GMRT	6 bands (50 – 1420 MHz)	60 – 2 "

Spectrographs (I)

Huairou	1 – 2, 2.6 – 3.8, 5.2 –7.6 GHz	
ETH Zurich	100 – 4000 MHz	0.5 – 1000 ms
ETH Zurich	50 – 850 MHz	
Ondrejov RT4	2.0 – 4.5 GHz	100 ms
Ondrejov RT5	0.8 – 2.0 GHz	100 ms
Hiraiso (3)	25 – 2500 MHz	2000 ms
Oporto	150 – 650 MHz	60 ms

Spectrographs (II)

ARTEMIS	30 – 630 MHz	100 ms
ARTEMIS	265 – 450 MHz	10 ms
Potsdam (4)	40 – 800 MHz	100 ms
IZMIRAN	25 – 270 MHz	40 ms
Nançay decam.	10 – 100 MHz	1000 ms
RSTN (Palehua, Holloman, San Vito, Learmonth)	75 – 180 MHz	3000 ms
Culgoora	18 – 1800 MHz	3000 ms

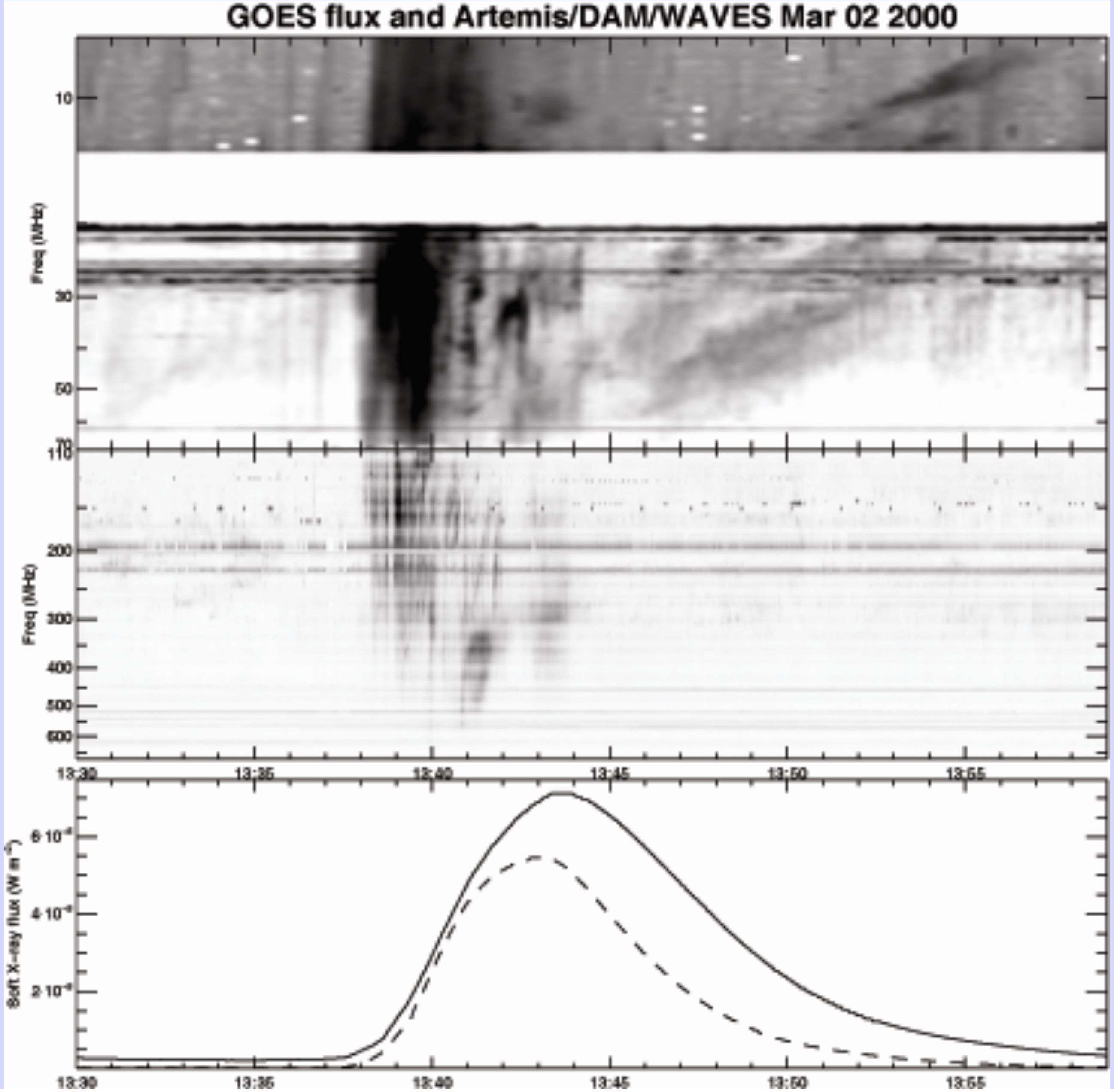
Spectrographs (III)

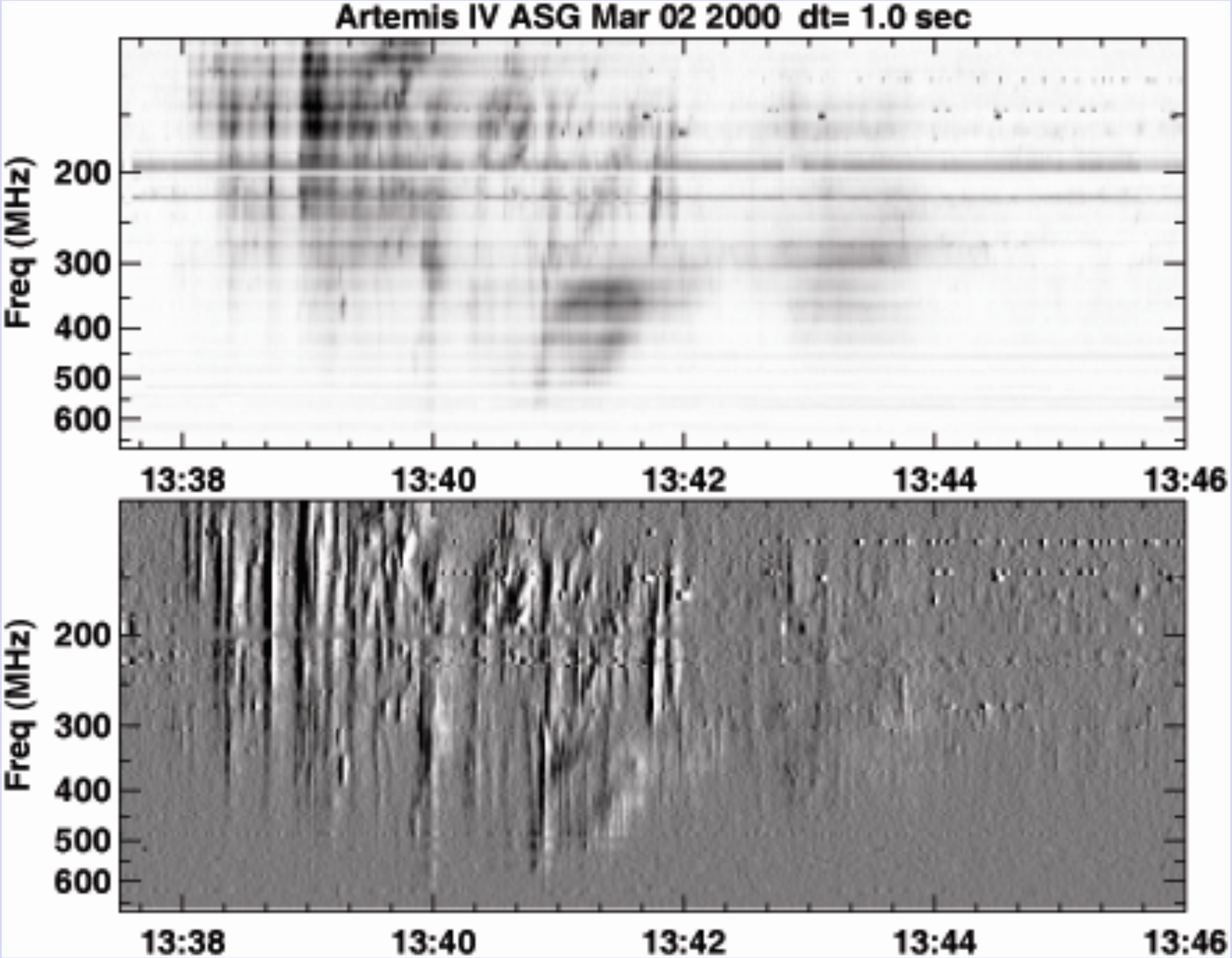
Green Bank	18 – 70 MHz	
Bruny Island	3 – 20 MHz	

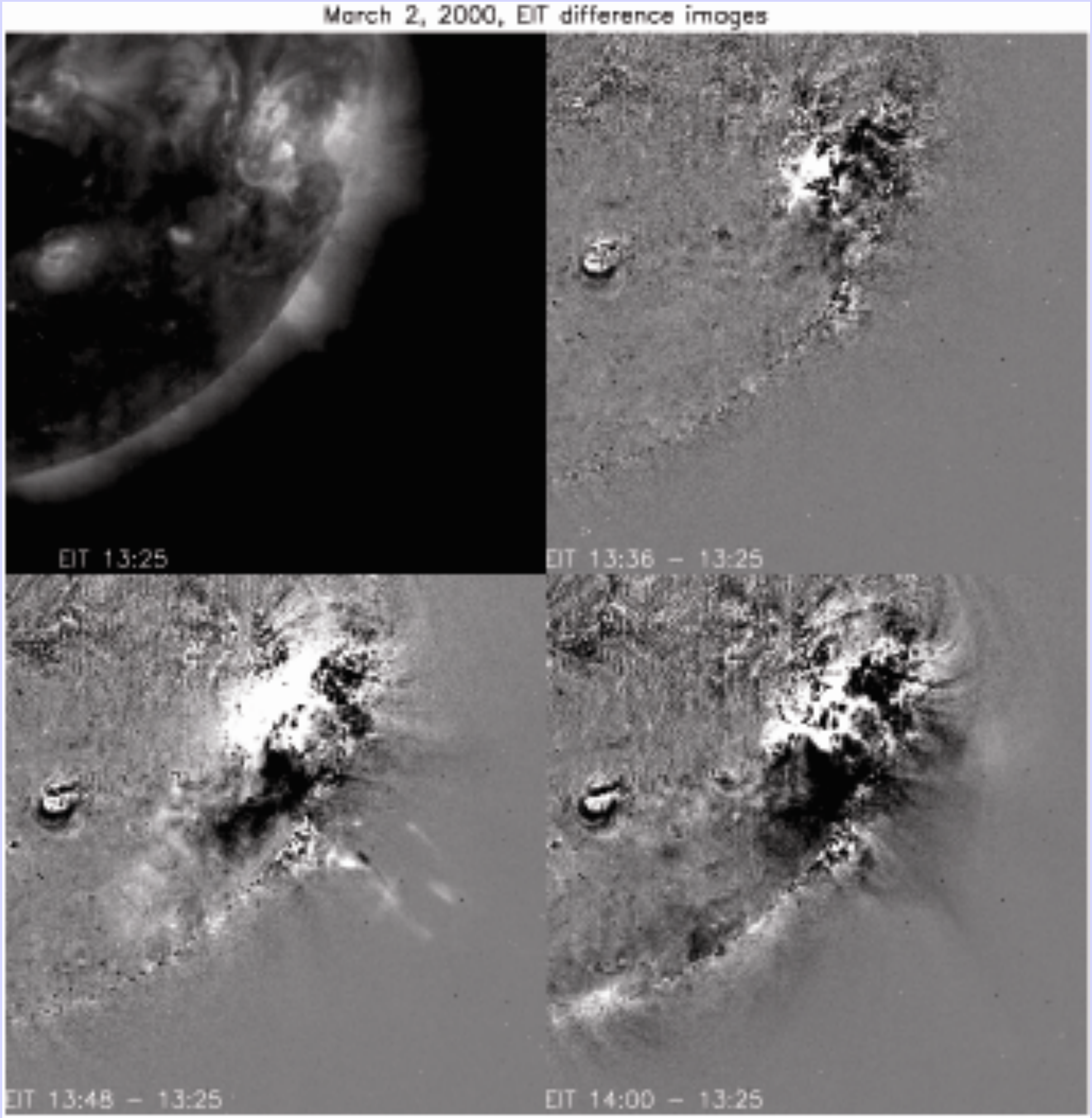
Radio emissions from the inner heliosphere

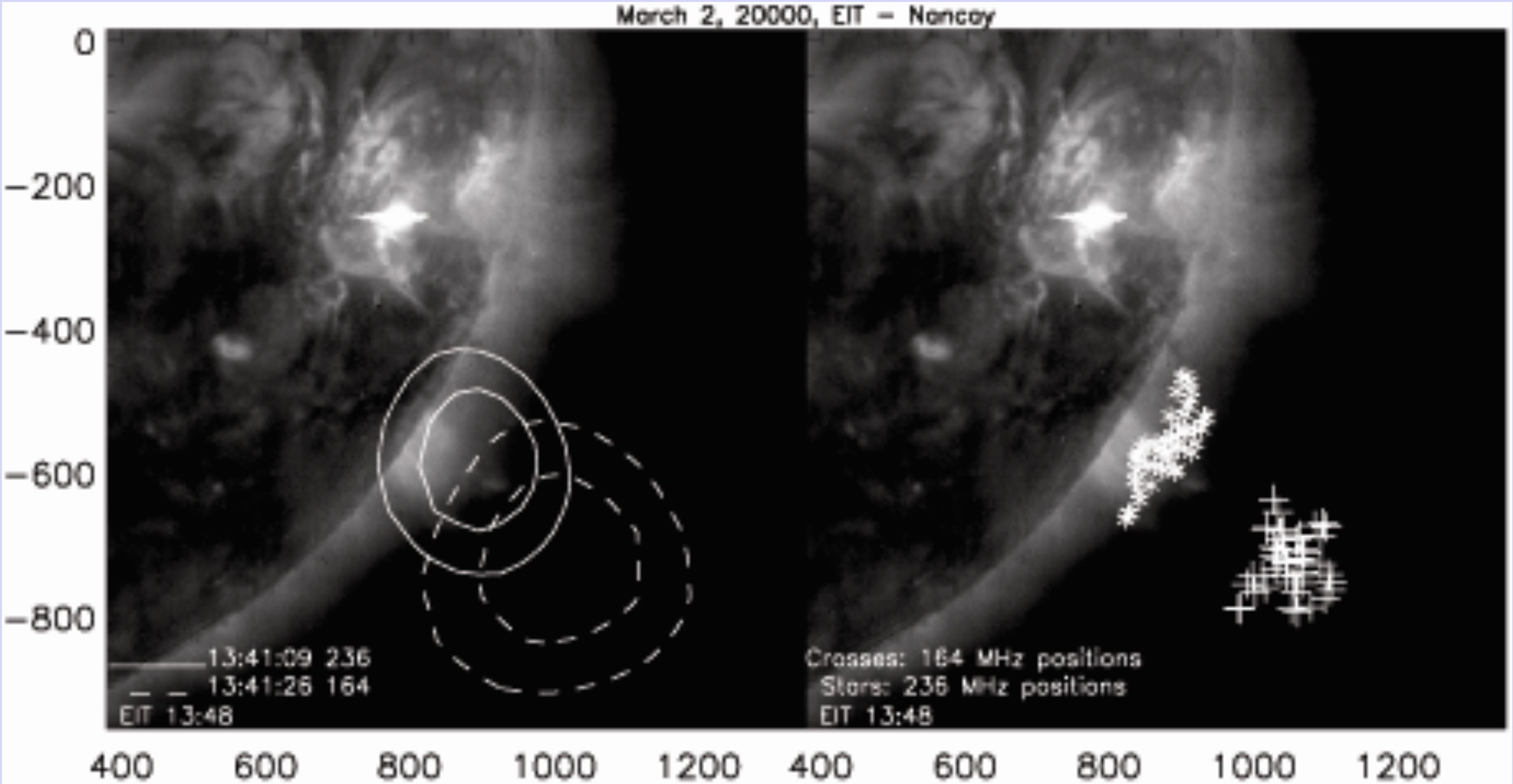
	N_e (cm^{-3})	f_p
low corona	$\geq 10^8$	$\geq$ 100 MHz
$\sim 10\ R_\odot$	$\sim 10^4$	~ 1 MHz
$\sim 30\ R_\odot$	$\sim 1.5\ 10^3$	~ 300 kHz
~ 1 AU	~ 10	~ 30 kHz

Need wide frequency range coverage



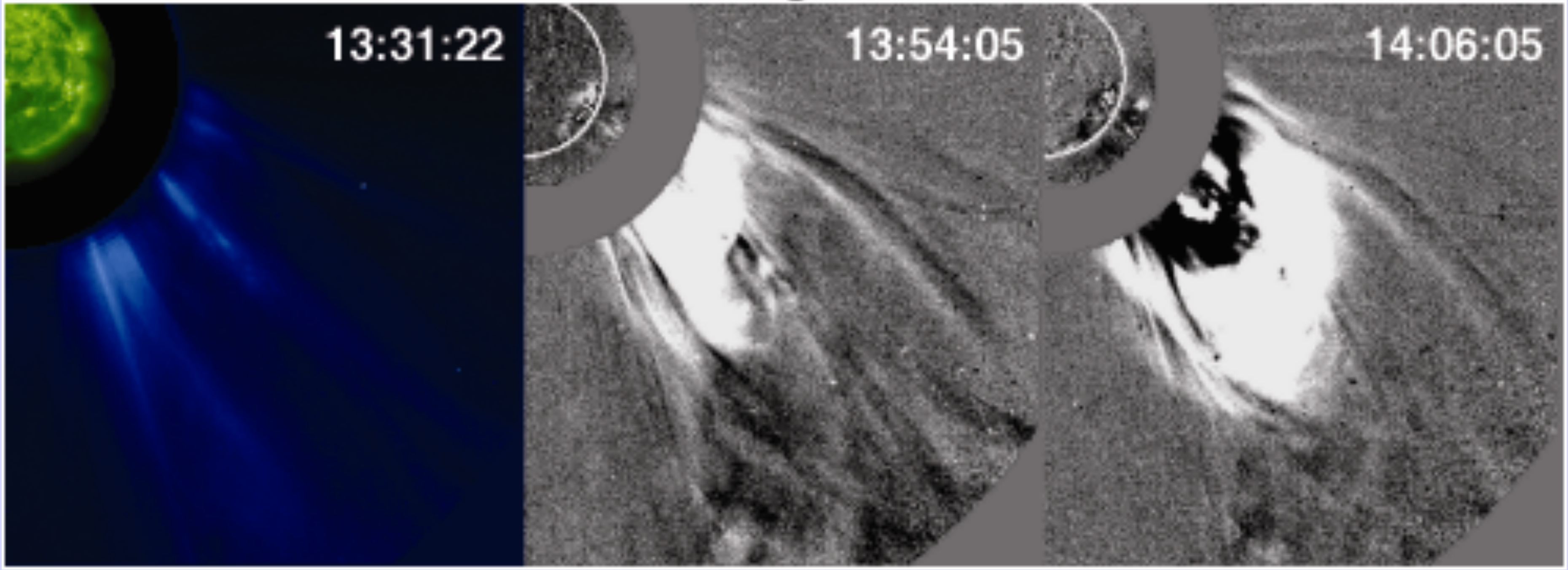

Artemis IV ASG Mar 02 2000 dt= 1.0 sec
Freq (MHz)
200
300
400
500
600
13:38
13:40
13:42
13:44
13:46
Freq (MHz)
200
300
400
500
600
13:38
13:40
13:42
13:44
13:46

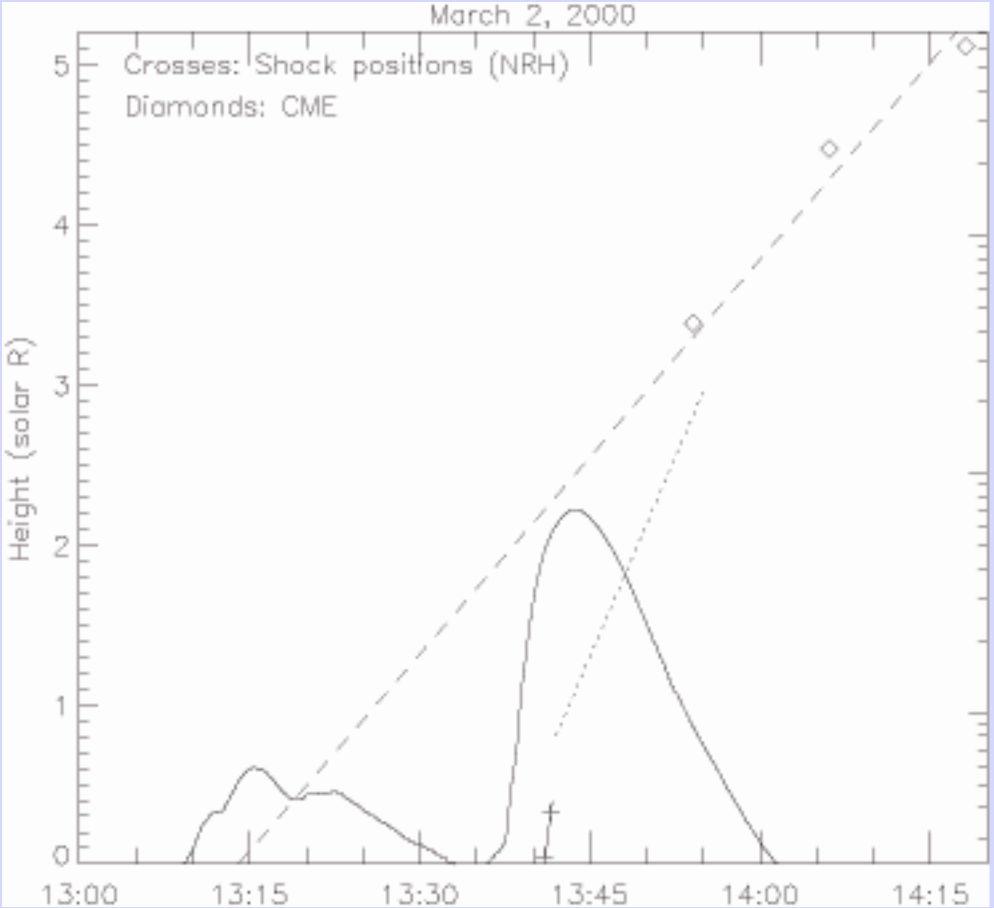

March 2, 2000, EIT difference images
EIT 13:25
EIT 13:36 − 13:25
EIT 13:48 − 13:25
EIT 14:00 − 13:25



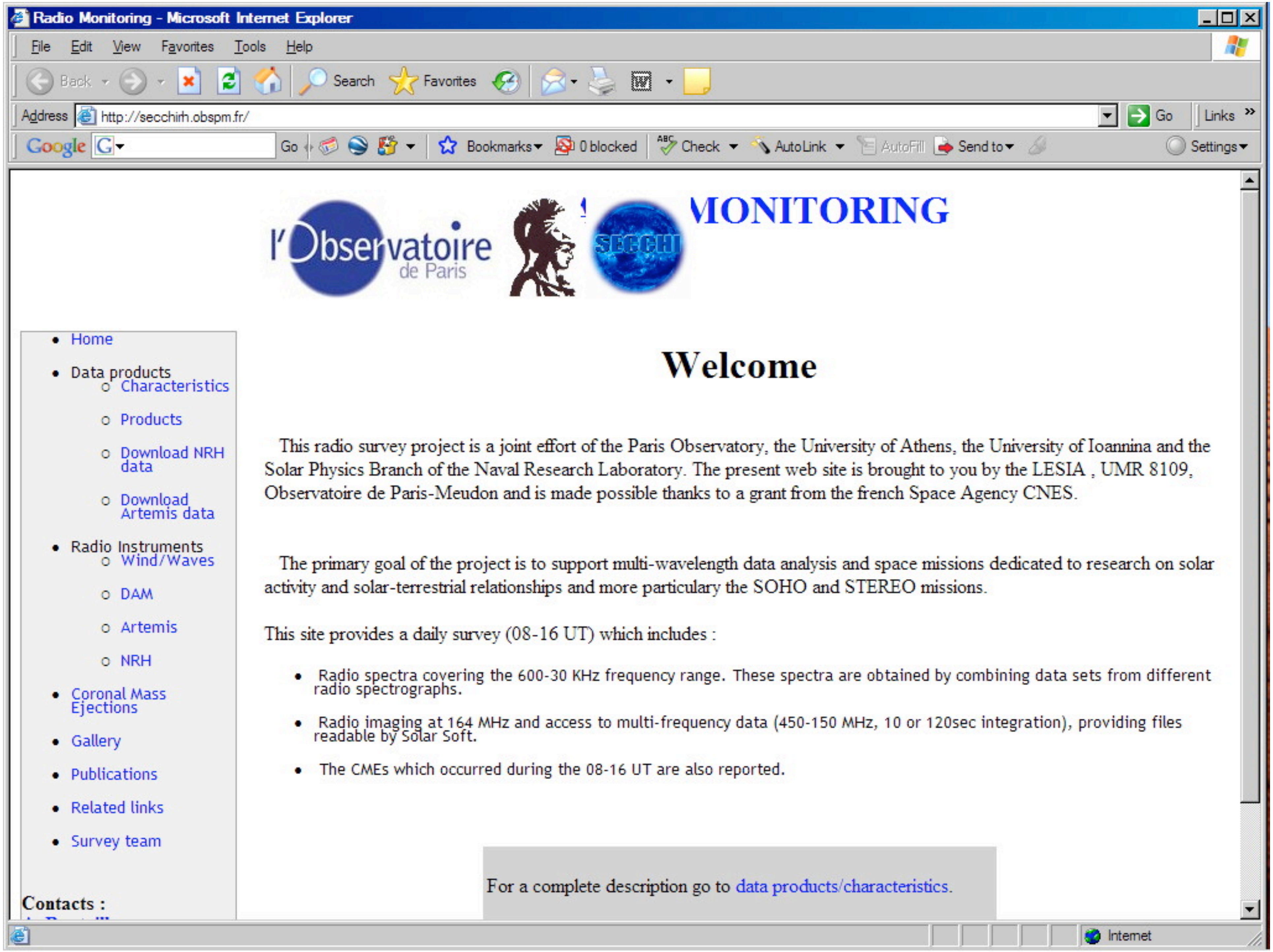
Solid contours: NRH image of the type II at 236 MHz
Dashed contours: NRH image of the type II at 164 MHz
Stars: Centroids of all NRH sources of the type II at 236 MHz
Crosses: Centroids of all NRH sources of the type II at 164 MHz

LASCO C2 images 2000 Mar 2





Crosses: Shock positions from NRH
Diamonds: CME (LASCO)
Solid line: height-time trajectory for the high-frequency shock
Dotted line: height-time trajectory for the low-frequency shock
Dashed line: linear fit to the CME height-time measurements


Radio Monitoring - Microsoft Internet Explorer
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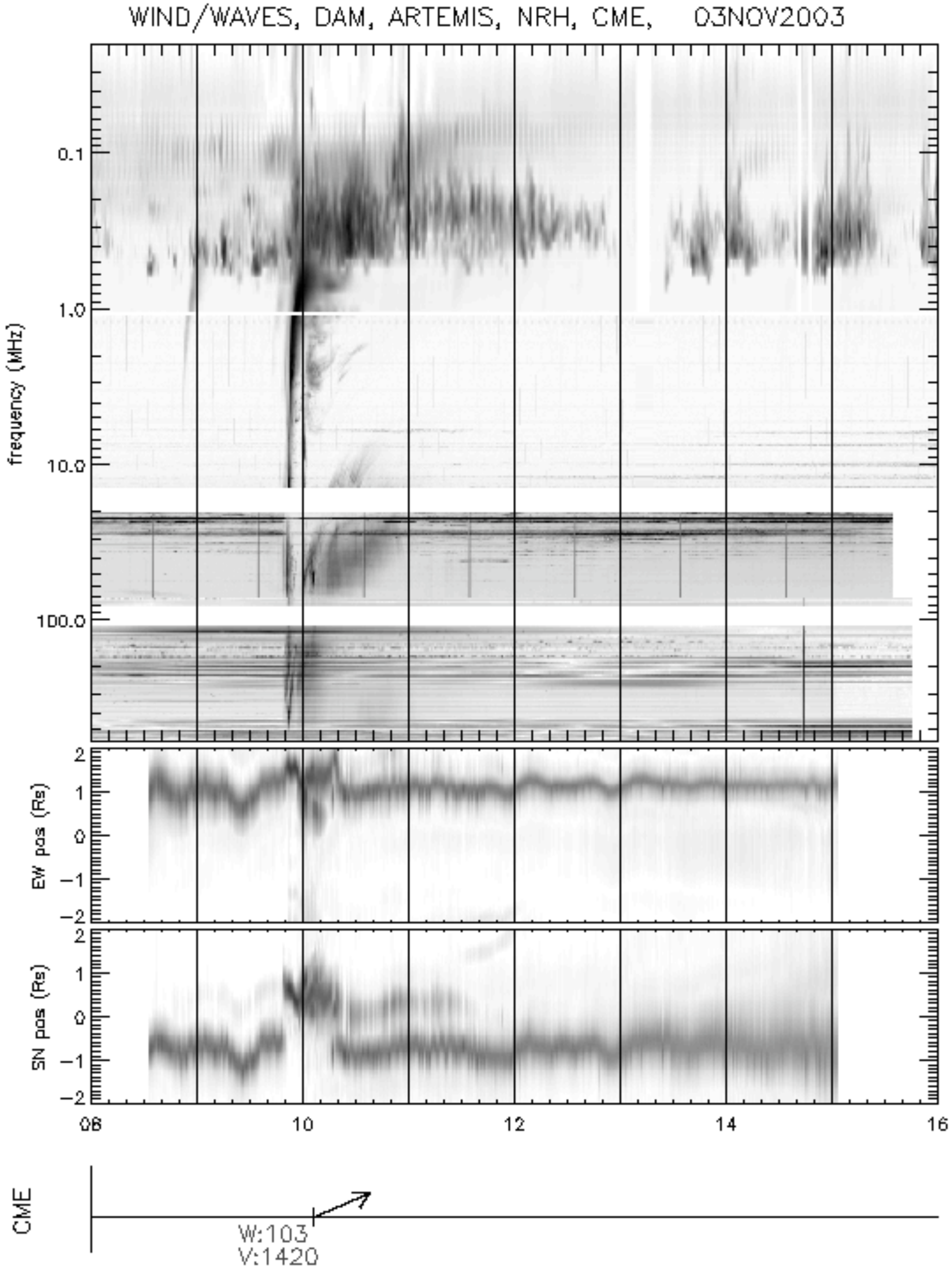
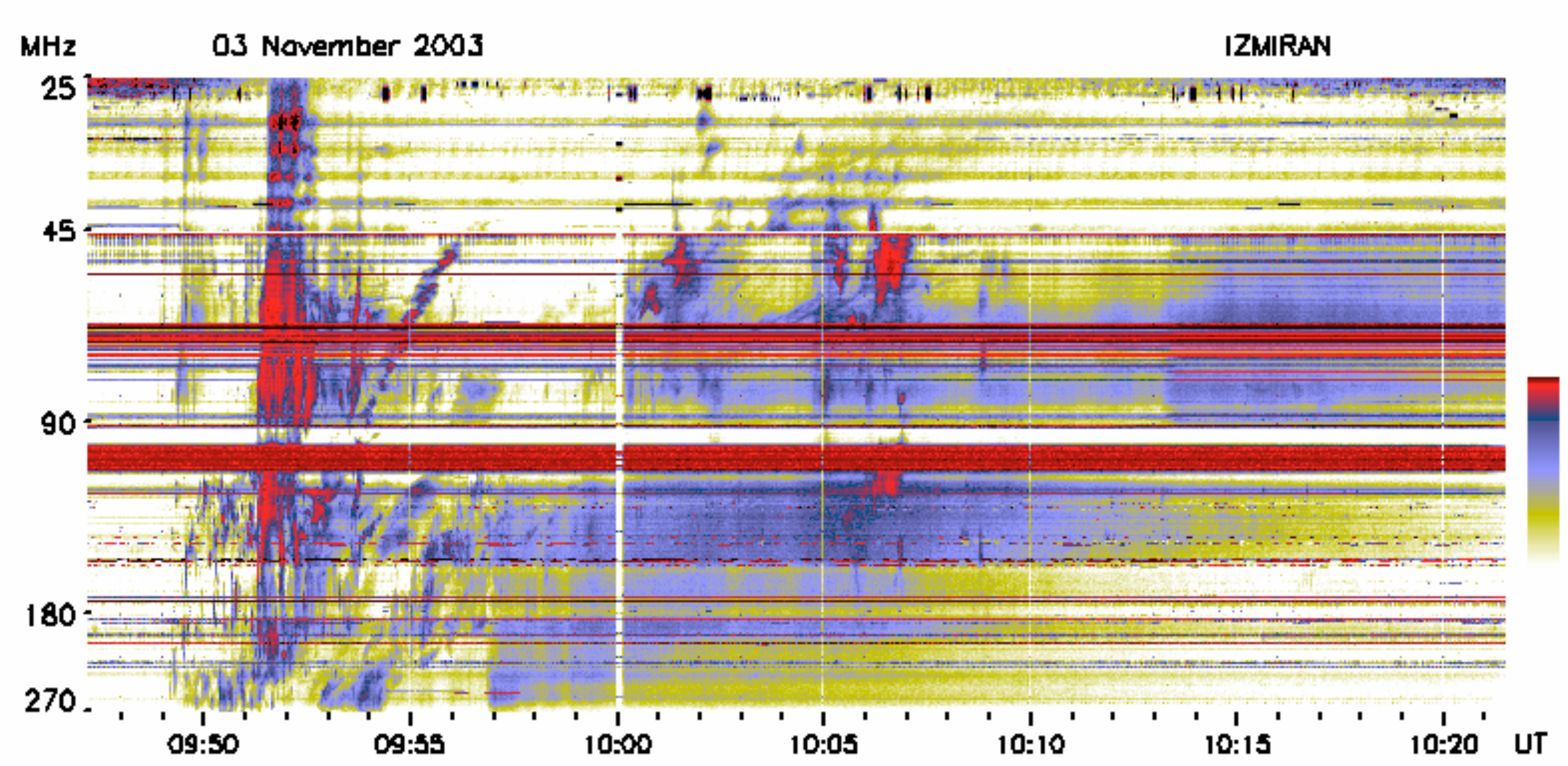
Welcome
This radio survey project is a joint effort of the Paris Observatory, the University of Athens, the University of Ioannina and the Solar Physics Branch of the Naval Research Laboratory. The present web site is brought to you by the LESIA , UMR 8109, Observatoire de Paris-Meudon and is made possible thanks to a grant from the french Space Agency CNES.
The primary goal of the project is to support multi-wavelength data analysis and space missions dedicated to research on solar activity and solar-terrestrial relationships and more particulary the SOHO and STEREO missions.
This site provides a daily survey (08-16 UT) which includes :
Radio spectra covering the 600-30 KHz frequency range. These spectra are obtained by combining data sets from different radio spectrographs.
Radio imaging at 164 MHz and access to multi-frequency data (450-150 MHz, 10 or 120sec integration), providing files readable by Solar Soft.
The CMEs which occurred during the 08-16 UT are also reported.
For a complete description go to data products/characteristics.
Internet

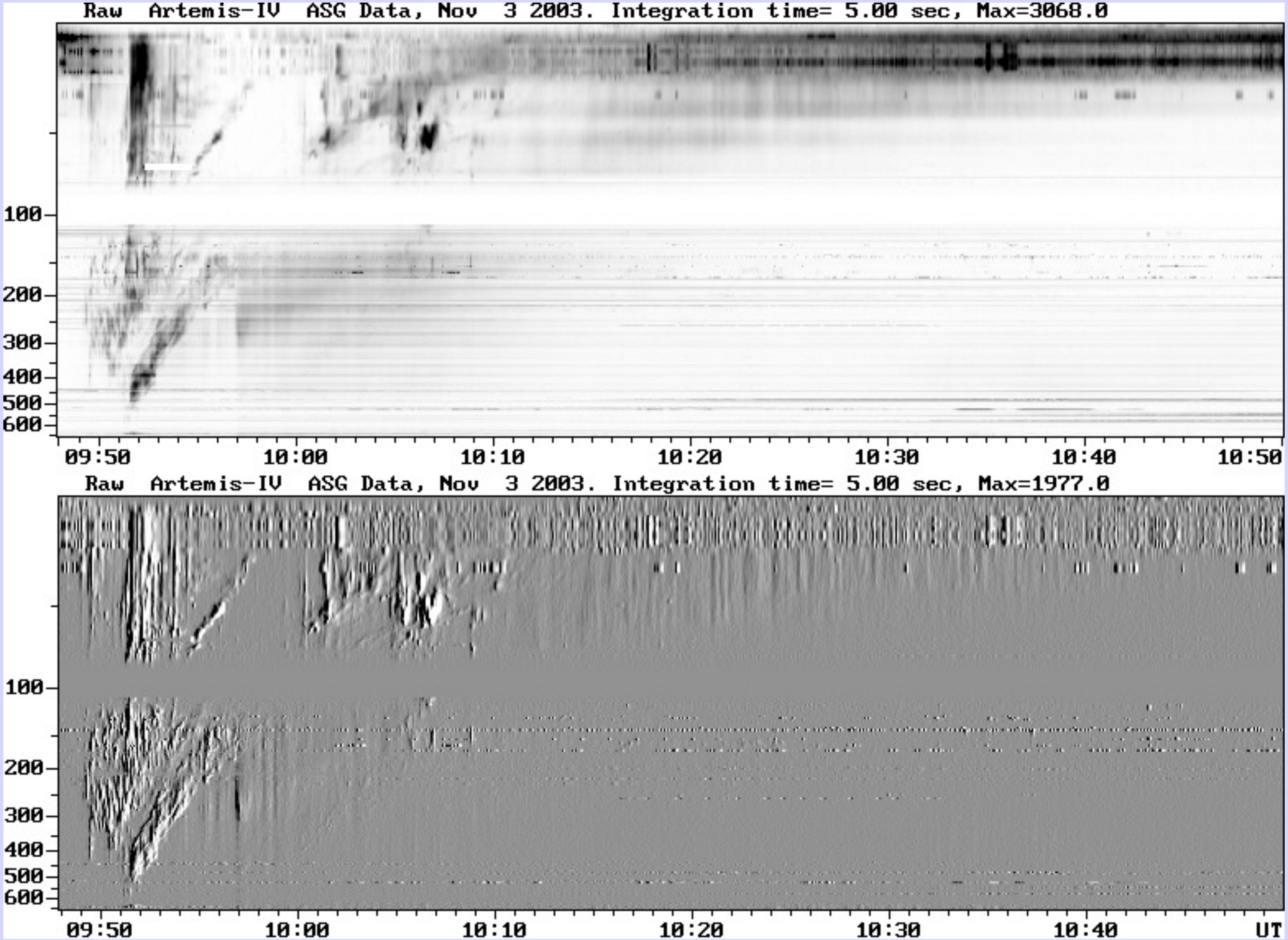


WIND/WAVES, DAM, ARTEMIS, NRH, CME, 03NOV2003
frequency (MHz)
0.1
1.0
10.0
100.0
EW pos (Rs)
SN pos (Rs)
2
1
0
−1
−2
08
10
12
14
16
CME
W:103
V:1420

A complex event as observed by IZMIRAN



The same event as observed byARTEMIS

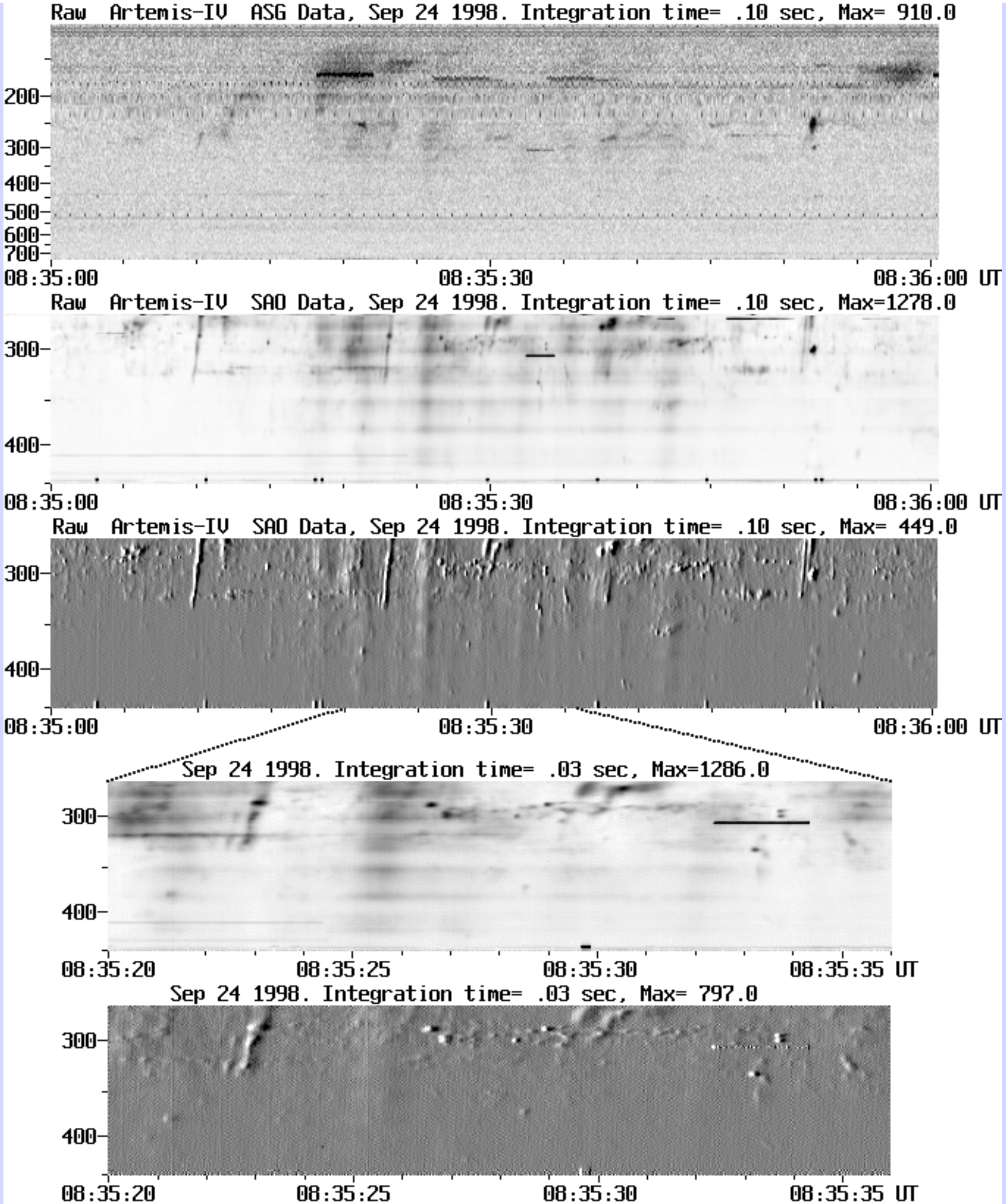


Interference

- Problem especially at low frequencies (< 2 GHz).
  - Very powerful transmitters (TV and FM) (emitters ~100 kW)
  - Low power transmissions and GSM (emitters of 10 - 100 W)
  - Satellites
  - Protected (for radio astronomy) bands are very few and difficult to keep free of interferences:
  - 151, 327, 408, 610, 1400 MHz… with bandwidth from 3 to a few ten MHz.
  - Satellite emissions may occur very close (149.9 MHz) to astronomy band
  - Antennas provide usually a poor rejection (10 db)
- Strong interference: level too high for digital filtering & interference excision → Site quality is very important.
- Mean-level interference (<40 db above QS): digital interference excision will require high dynamic, high resolution spectra and filters.

Sensitivity

- Usually in frequency-agile systems frequency channels are measured sequentially.
- Sensitivity can be improved by multi-channel spectrometers, which measure multiple frequency channels simultaneously.
- → Development of acousto-optic receiver.
- BUT their dynamic range is limited → vulnerable to terrestrial interference



(a) Dynamic spectrum (flux) from sweep frequency receiver (ARTEMIS/ASG)

(b) Dynamic spectrum (flux) from acousto-optical receiver (ARTEMIS/SAO)

(c) Differential display (time derivative) of (b)

(d) Detail expansion of the spectrum from (b)

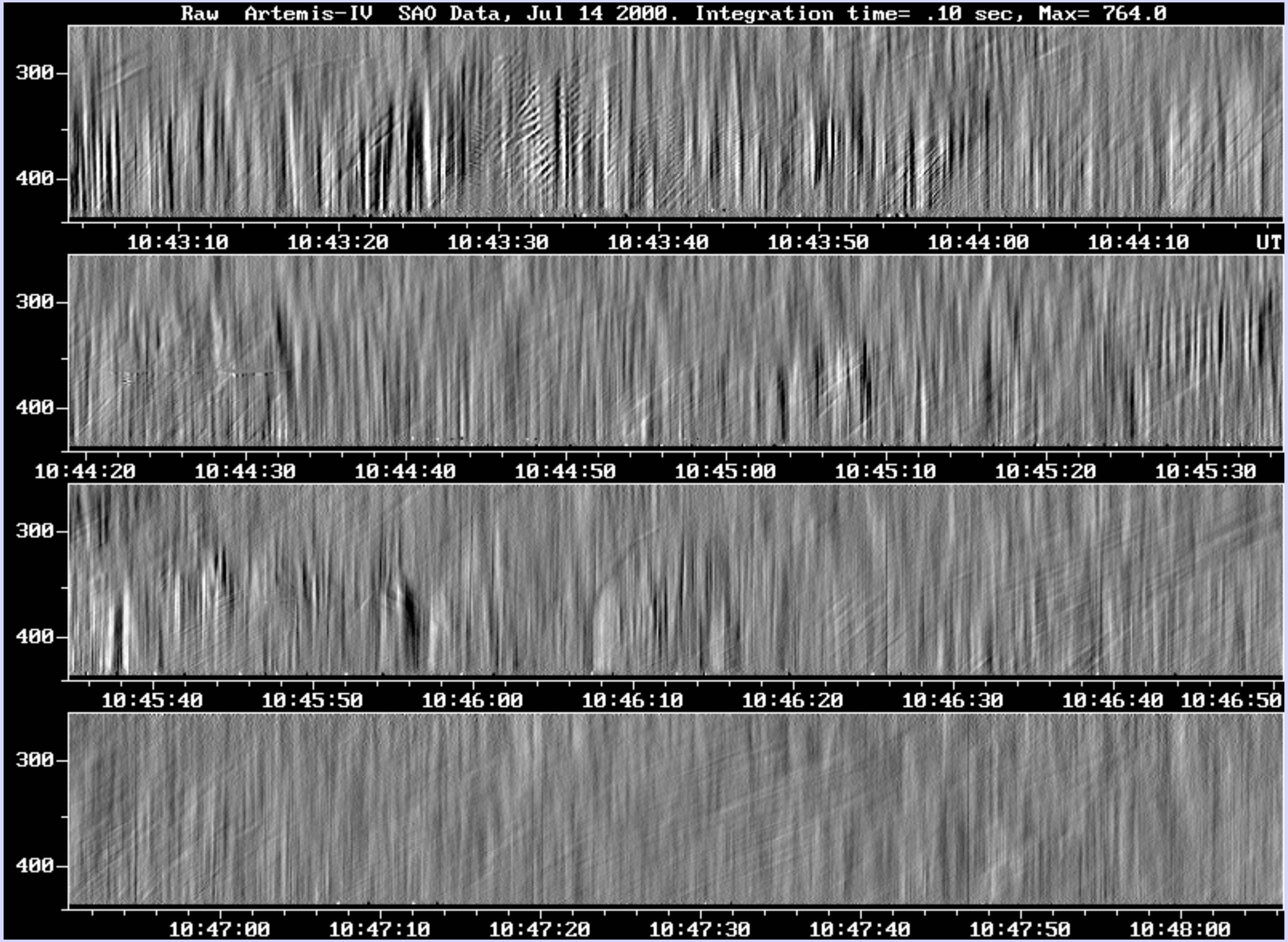
(e) Differential display (time derivative) of (d)

(from Caroubalos et al. 2001a)

Dm-m fine structure

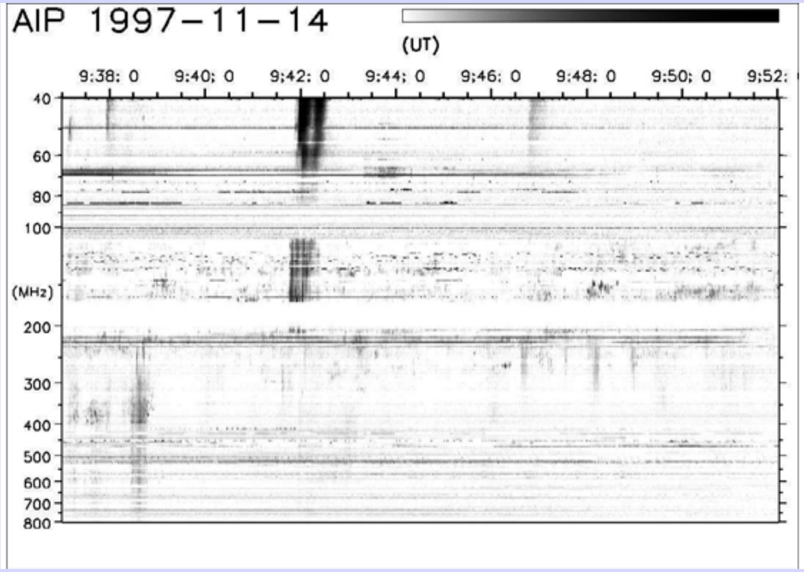
- BBP: associated either with either MHD oscillations of the source of radio emission or w/ periodic regimes of particle acceleration.
- Pulsations w/ drifting high- & low-frequency boundaries: associated w/ SXR blob ejections. They can be understood by repeated electron beam injection or by magnetoplasma blob oscillations.
- Fiber bursts: the radio signature of whistler waves excited after their coalescence w/ Langmuir waves in loops w/ an unstable distribution of nonthermal electrons. Alternatively, Alfven solitons have been invoked.
- Narrow-band dm spikes: signatures of accelerated particles at the primary energy release site? Represent signature of fragnented energy release in flares? Not related to the acceleration site? Relation w/ CMEs?
- Spike properties → ECM emission produced by energetic electrons w/ loss-cone pitch-angle distribution. Source of spike cluster: loop w/ local inhomogeneities forming traps where p/a anisotropy is stronger → strong local wave amplification as a result of negative GS absorption.

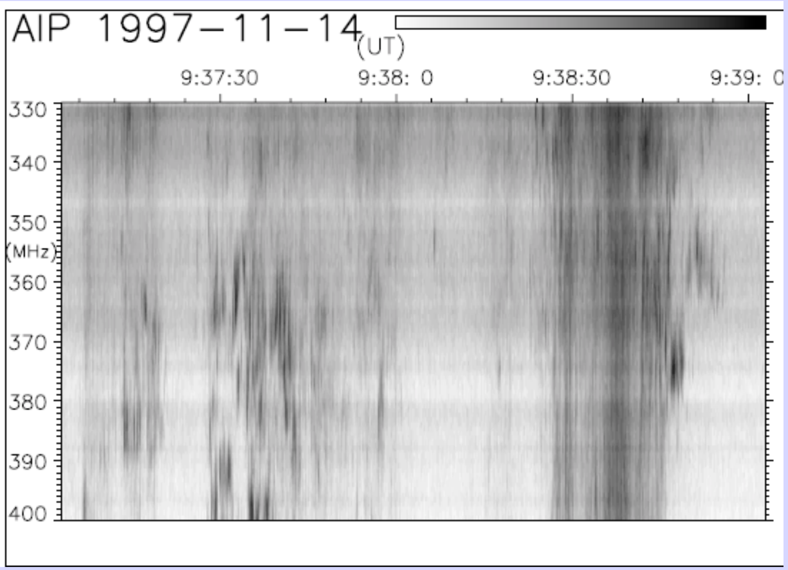
The need for high spectral & temporal resolution

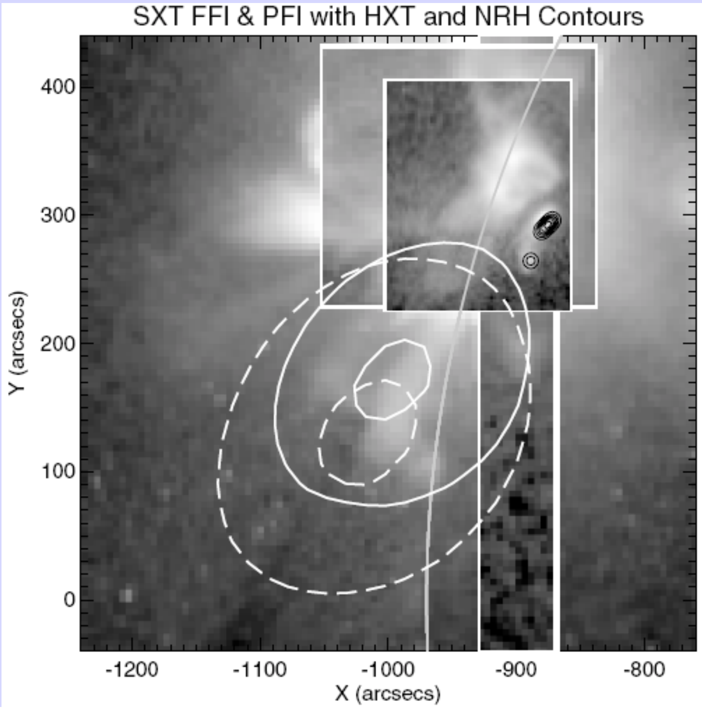


(Pulsations and fiber bursts Caroubalos et al, 2001b)

Narrow-band spikes



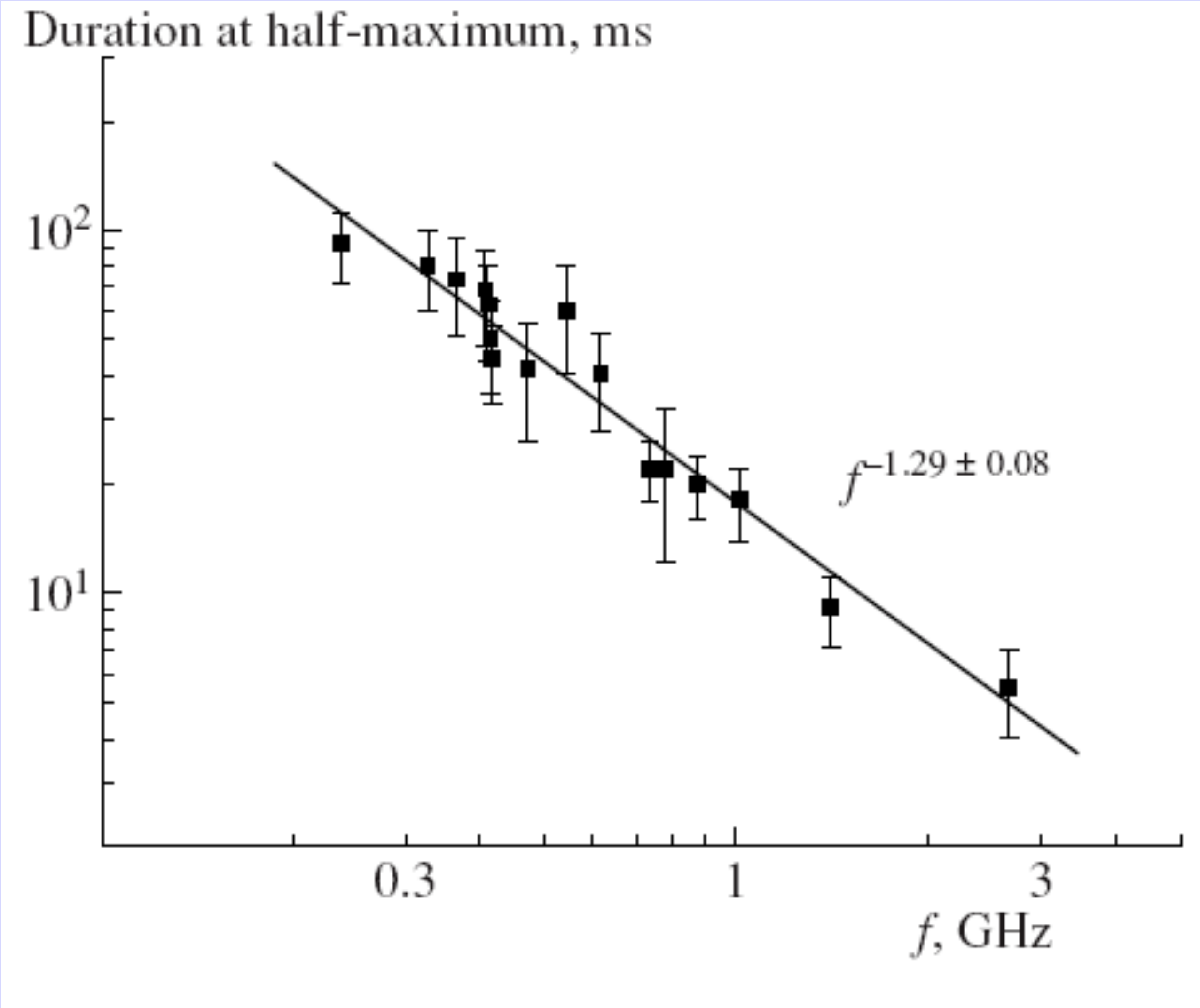




Black contours: HXT 14-23 keV image
Dashed white contours: NRH image of the spike @ 327 MHz
Solid white contours: NRH image of the spike @ 410 MHz

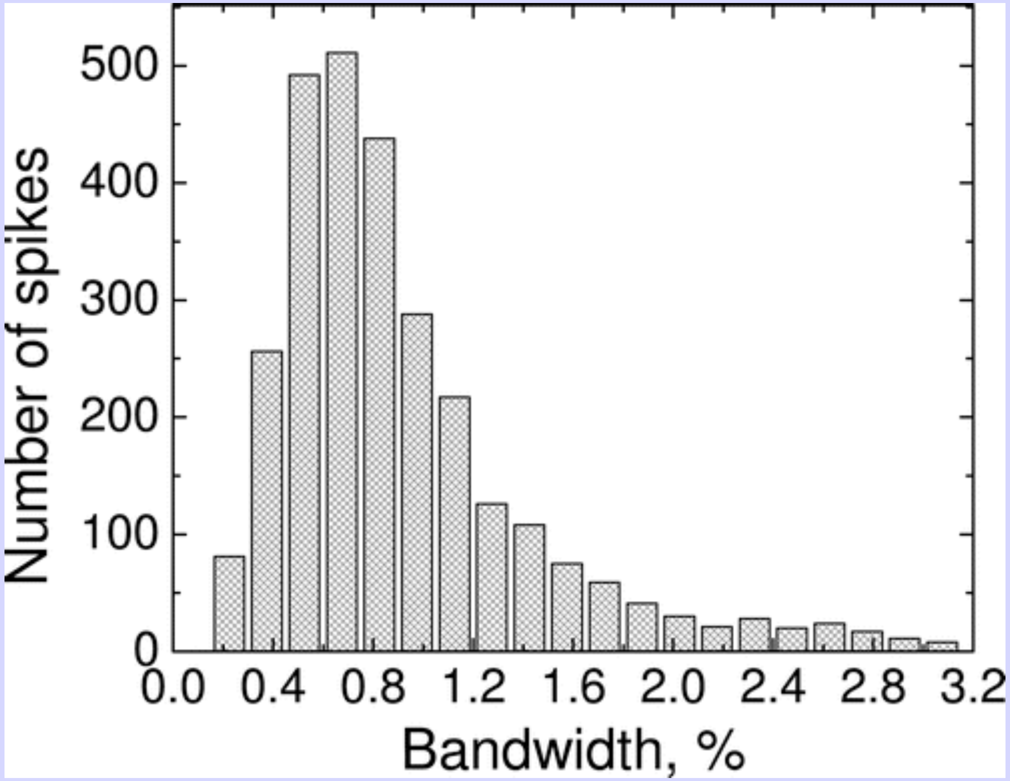
(from Khan & Aurass 2006)

Frequency dependence of the duration of spike bursts



(from Sirenko & Fleishman 2009)

- Minimum bandwidth of narrow-band dm spikes: FWHM bandwidth at 0.17-0.41% of the center frequency (Messmer & Benz 2000).
- These values were close to the 1 MHz resolution of their instrument.



(from Rozhansky et al. 2008)

•Possible lower limit: natural bandwidth of the ECM emission in standard coronal conditions: $\Delta f/f \sim 0.1\% - 0.4\%$ (Fleishman 2004)

Conclusions (I)

For the development of future spectrographs, we need:

- Frequency coverage: 20-650 MHz
- Around the clock observations from identical instruments
- Confront strong interference with careful site surveys
- For the fine structure, sensitivity provided by sweep-frequency receivers not adequate.
- $\tau \sim$ 1-5 msec
- $\Delta f/f \sim 0.1\% - 0.4\%$

Conclusions (II)

- The development of broad-band, high-sensitivity, interference-resistant spectrometers with high temporal and spectral resolution is still a *“desideratum”*.
- Spectrometers are necessary to identify the nature of coherent solar radio emission. Their data need to be combined with positional information of the radio sources from RHs and coronal images of the thermal plasma.
- Spectrometers will be needed in the future to complement interferometers.