A new spectrometer for short wave radio astronomy near ionosphere's cutoff

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Radio Interference in Large Bandwidth Observations

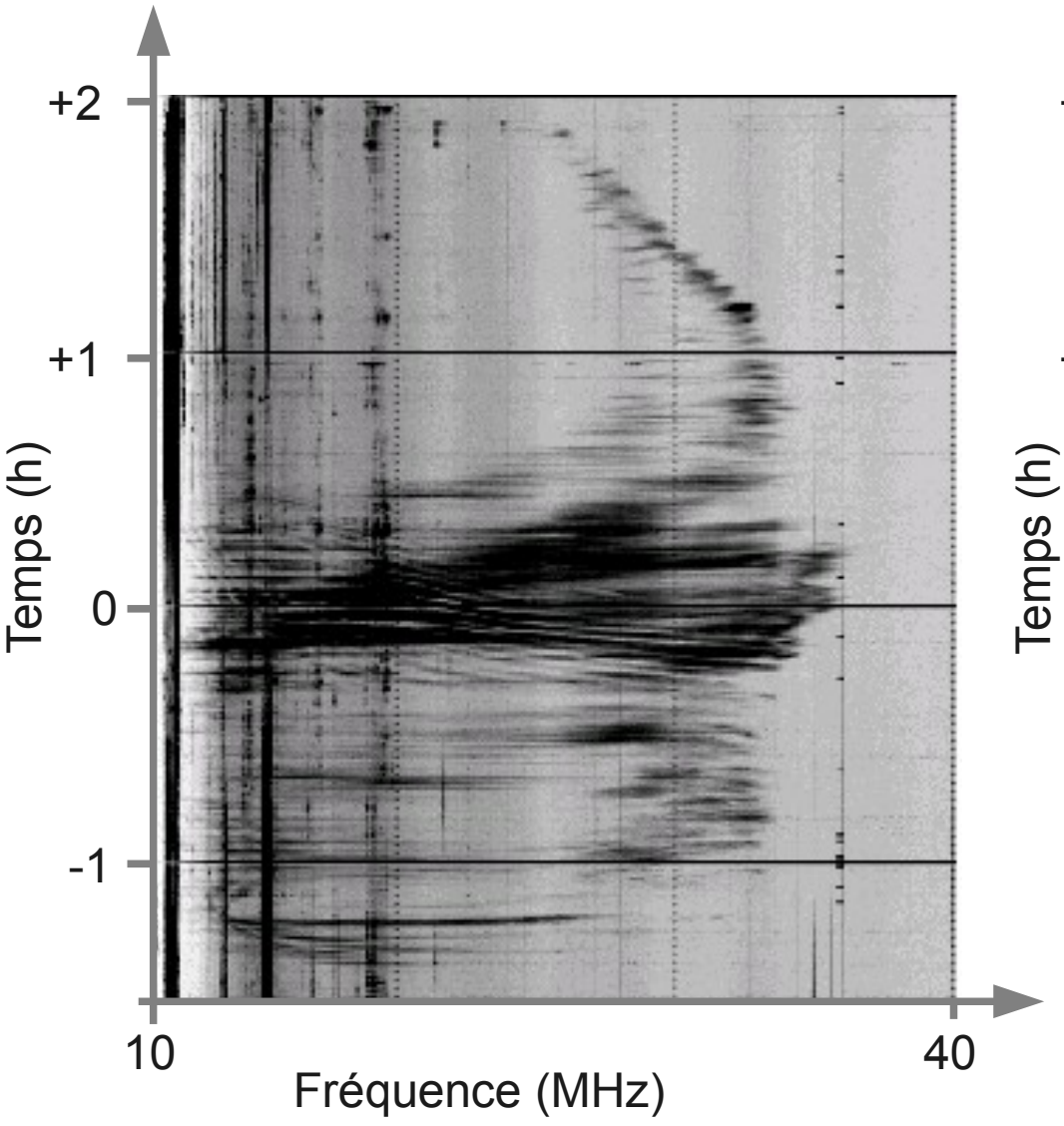
Bonn

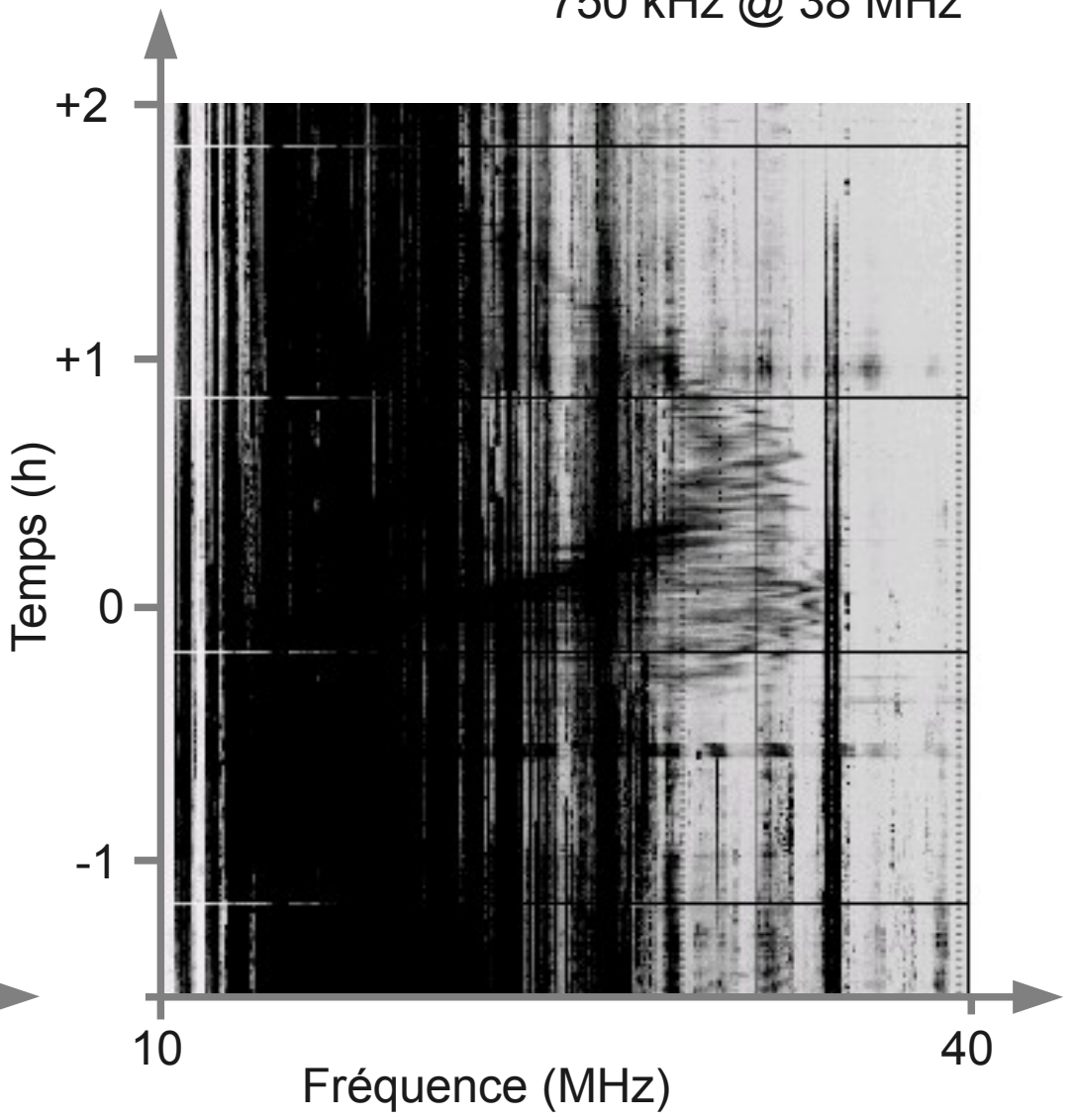
Content

- Context and goal
- Dynamic spectrometry of Sun in the decameter band
- Method
- Implementation
- Results and conclusion

Ionosphere conditions and RFI

RA bands:
50 kHz @ 13 MHz
120 kHz @ 25 MHz
750 kHz @ 38 MHz





Goal

- Process in real-time the analog signal (amplified and filtered) generated by the NDA (Nançay Decameter Array)
- To Provide a continuous dynamic spectrogram of Solar radio-emissions in the Short Wave band (f<40 MHz)

- On-line processing is required to mitigate the effects of the many spurious generators present in this band.

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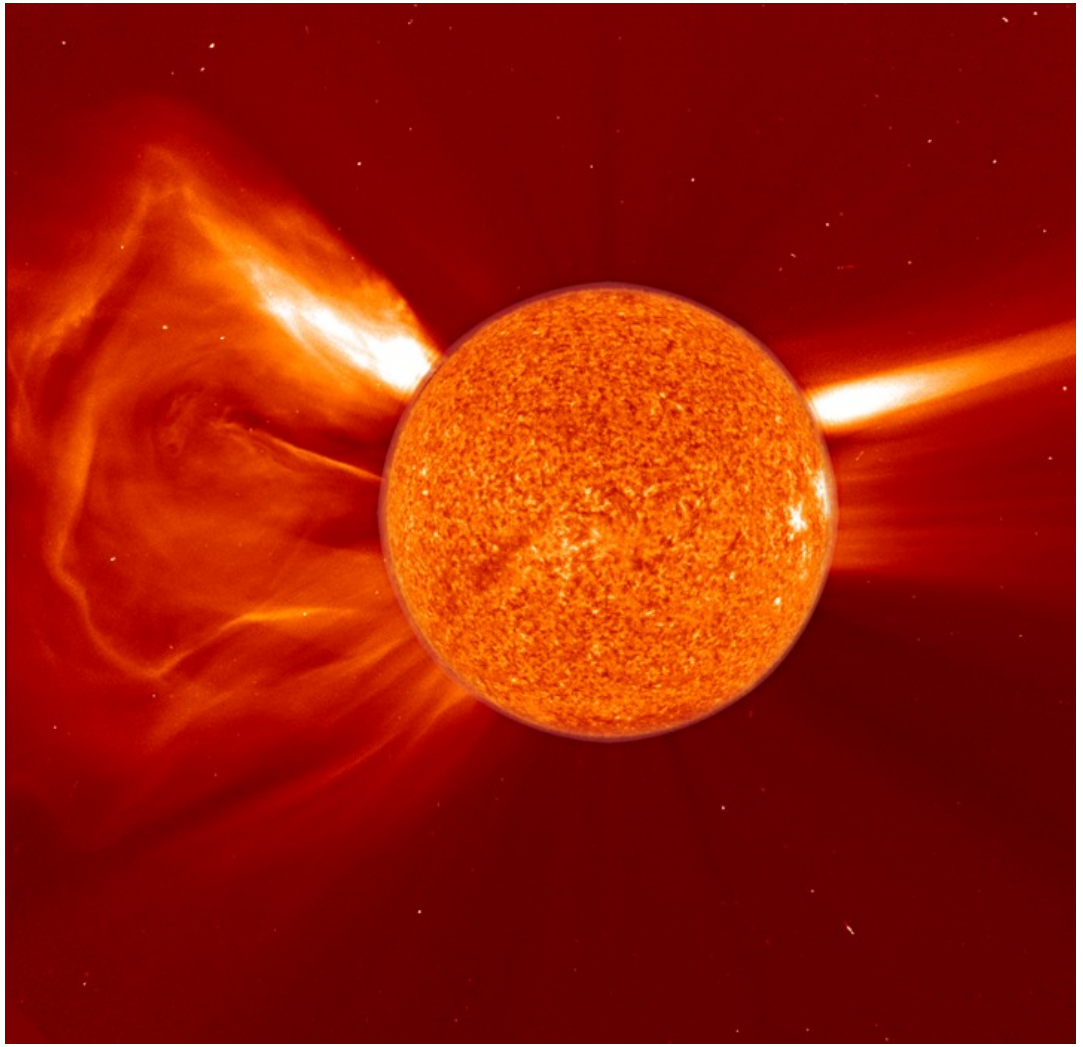
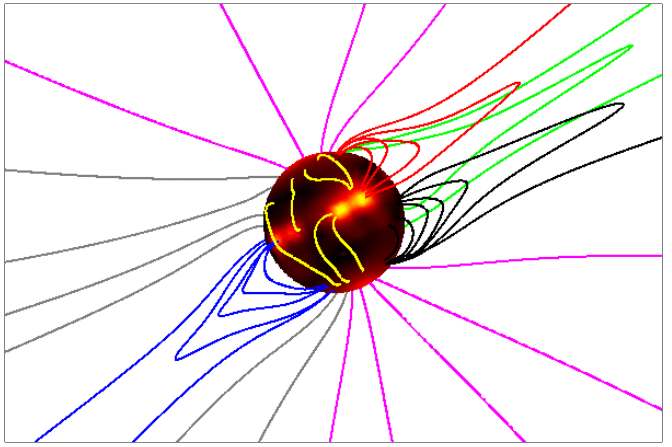
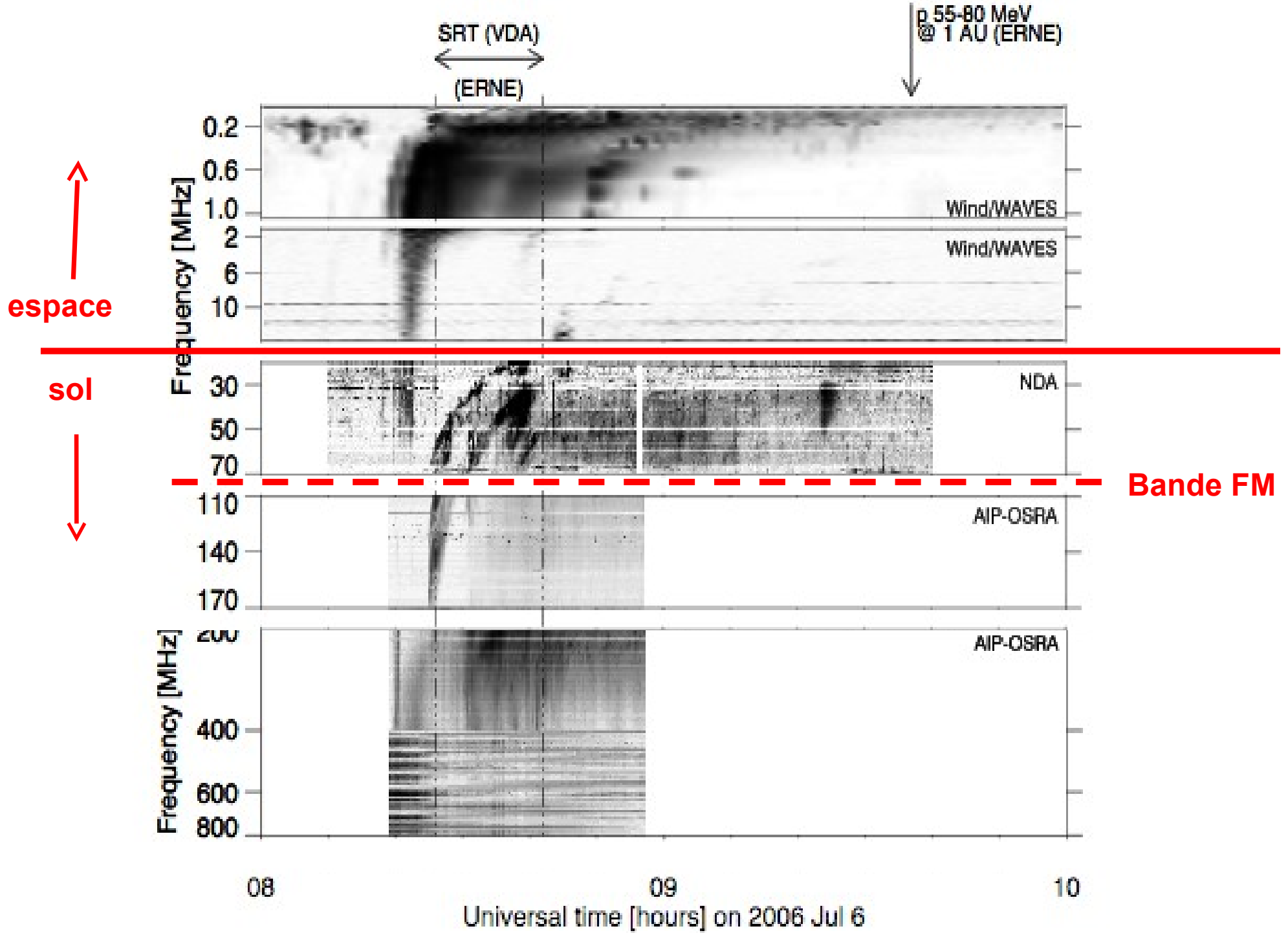
Frequency observation is a function of the altitude over the Sun of sensed signals





$$f_p \propto \sqrt{N_e} \propto R^{-1}$$


SRT (VDA)
(ERNE)
p 55-80 MeV
@ 1 AU (ERNE)
espace
sol
Bande FM
Frequency [MHz]
0.2
0.6
1.0
Wind/WAVES
2
6
10
Wind/WAVES
30
50
70
NDA
110
140
170
AIP-OSRA
400
600
800
AIP-OSRA
08
09
10
Universal time [hours] on 2006 Jul 6

Signal of interest caracteristics

For frequencies < 50 MHz, solar bursts are generated in the corona where diffusion time τ is > 10 ms, leading to a spatial scale $\Delta R = c\tau > 3000$ km.

Since the Fe inverse proportional to altitude over the Sun surface, the required frequency resolution is : $\Delta f / f \sim \Delta R / R_{\odot} \sim 4e\text{-}3$

$\Delta f > 40$ kHz

The “useful” characteristic for a solar low band spectrometer are then:

- Sampling frequency ~ 100 MHz
- 512 channels
- ~10 spectra/s
- 2 channels for the 2 telescope polarisation

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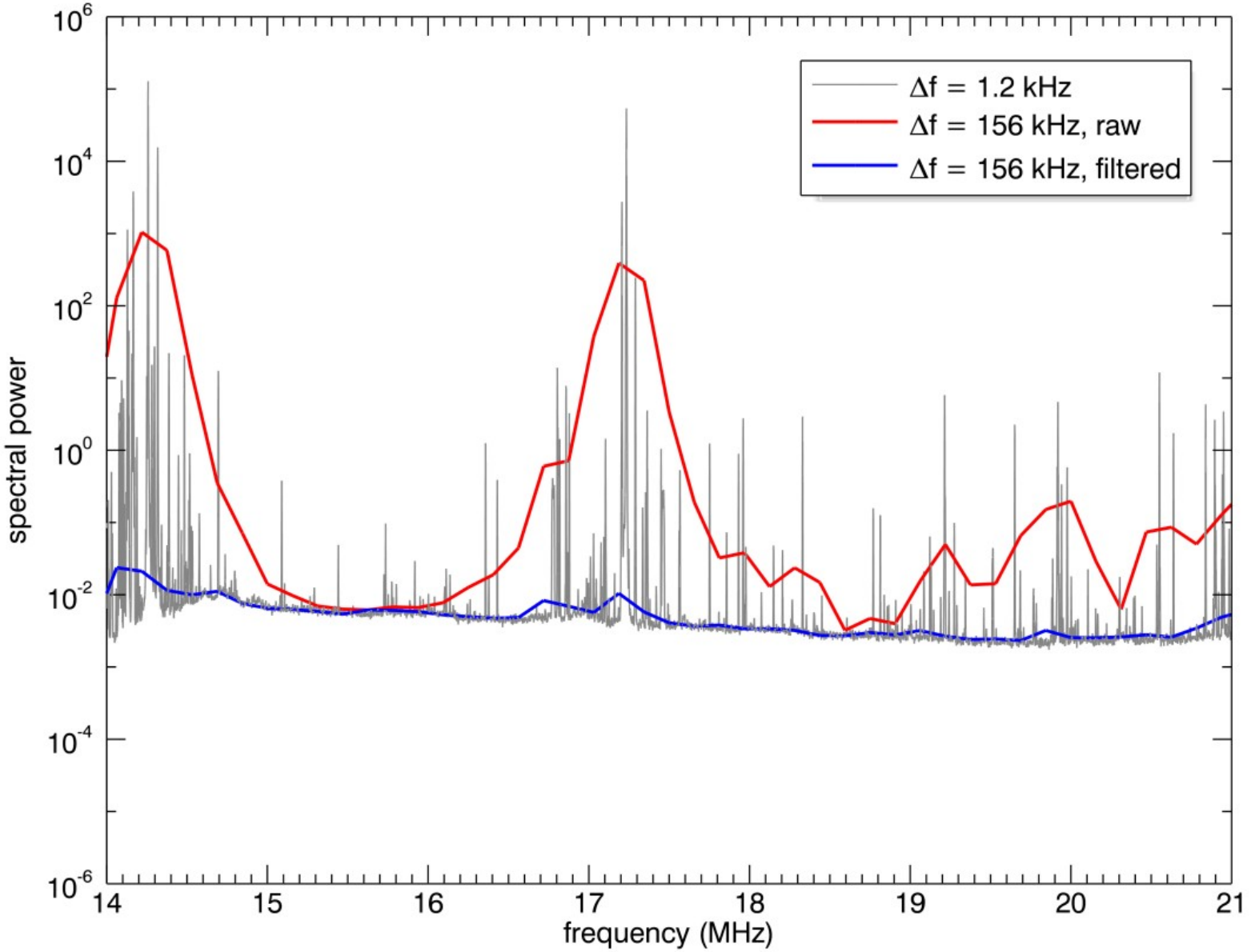
RFI characteristics

The 5-30 MHz band is heavily occupied:

- By many intermittents, narrow band ($\Delta f \sim$ qq kHz) transmitters:
  - Broadcasting
  - Maritime and aeronautical mobile
  - Amateur radio
  - Timing, …
  - Ionospheric sounding
- By impulsive signals (industry and natural events (distant storms))

Example of a spectrum



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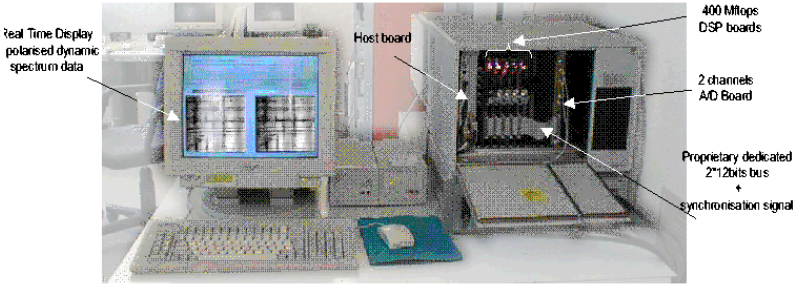
1997-2000

DSP-chip based FFT analyser

- Digital spectrum estimation in real time, from A/D converted waveform (Welch, 1967)
- 12 bits A/D conversion, 32 bits arithmetic
- 50 % temporal overlap
- Radix-4 DFT + Blackman-Harris windowing
- Computation of both auto and (complex) cross spectra
- 2x12.5 MHz bandwidth with 1024 channels requires a computational power of 1.5 10^9 operations/second.

⇒ original, parallel architecture, using commercial chip ADSP 2106x (SHARC)

- Frequency resolution 12 KHz
- Time resolution 1 ms (1 polarisation channel)
  2 ms (full polarisation analysis)
- Dynamic range > 65 dB
- Packaged in a Sun workstation



Digital receiver designed and built at Meudon Observatory

2003-2011 : RDH (FPGA/DSP/CPU)

2012-2013

HPPB board + FMC108 ADC

ALSE (Parisian company)

IO : ~100 Gb/s

Computation : 600 GMAC/s

Memory : 11 Mbits

Description of embedded processing

- Continuous sampling at 80 MS/s (14 bits)
- “High” resolution spectral analysis
  - Blackman-Harris (RFI > 70dB) + 64k-FFT (simultaneous double rfft)
  - Floating point conversion (bus width reduction) and Power
- Narrow band RFI “filtering”:
  - Robust estimation of mean power of adjacent frequency bands
  - 64 channels => 1 channel
- Impulsive RFI “filtering”:
  - Robust estimation of mean power in a channel
  - 128 time samples => 1 sample
- Resulting compression:
  - Input: 10 TB/day
  - Output : 100 MB/day

Robust estimators

- M-estimators:
  - Maximum likelihood principle
  - Influence function to reduce the weight of outlayers
- L-estimators:
  - Combine one or more order statistics (truncated mean, percentiles, median, …)
- We choose the Median
  - Sorting algorithm cheap to implement in FPGA (O(N))
  - Small loss of sensitivity
  - Break-down point of 50%
- Hardware infrastructure ready for other estimators

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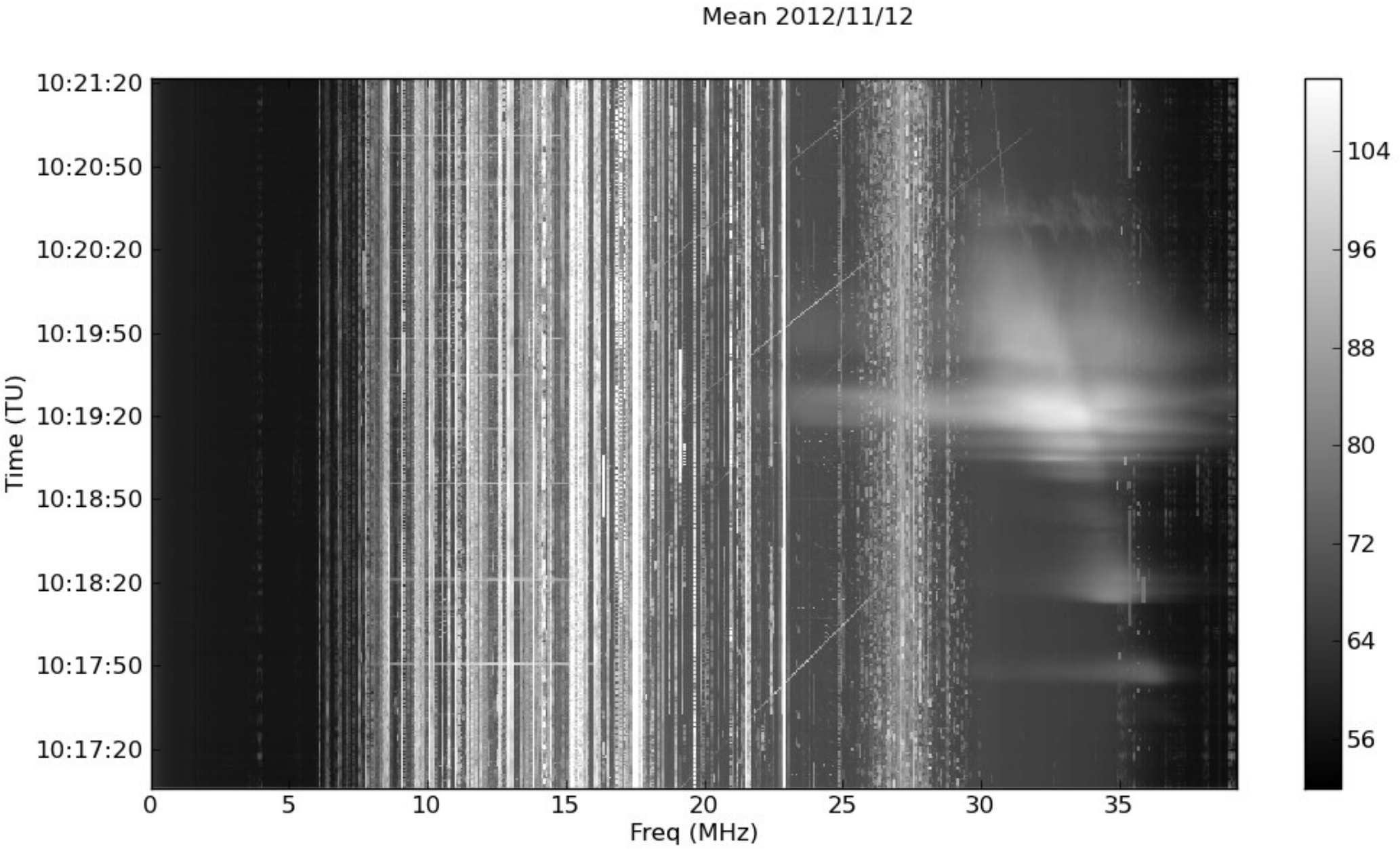
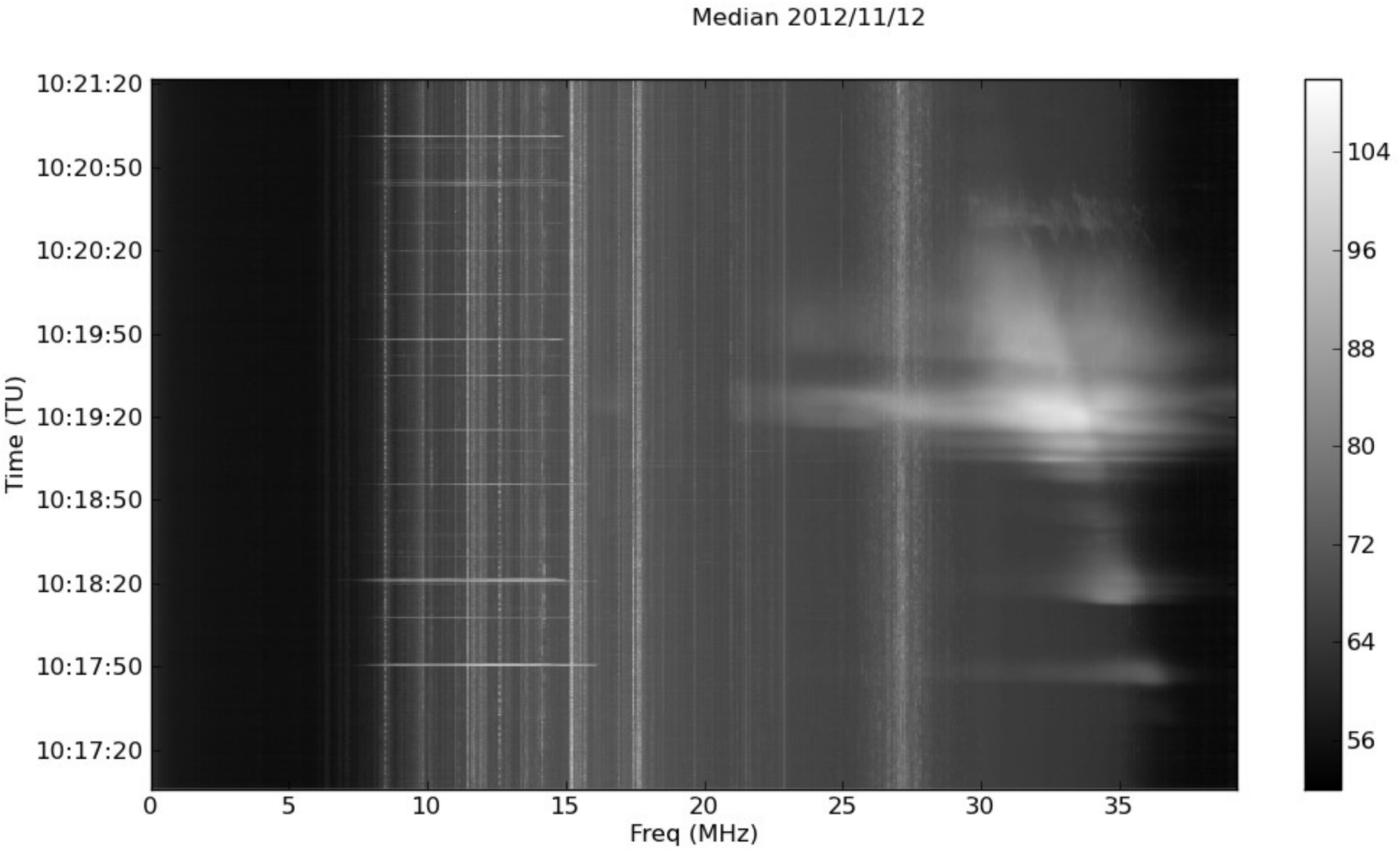

Mean 2012/11/12
10:21:20
10:20:50
10:20:20
10:19:50
10:19:20
10:18:50
10:18:20
10:17:50
10:17:20
Time (TU)
0
5
10
15
20
25
30
35
Freq (MHz)
104
96
88
80
72
64
56


Median 2012/11/12
10:21:20
10:20:50
10:20:20
10:19:50
10:19:20
10:18:50
10:18:20
10:17:50
10:17:20
Time (TU)
0
5
10
15
20
25
30
35
Freq (MHz)
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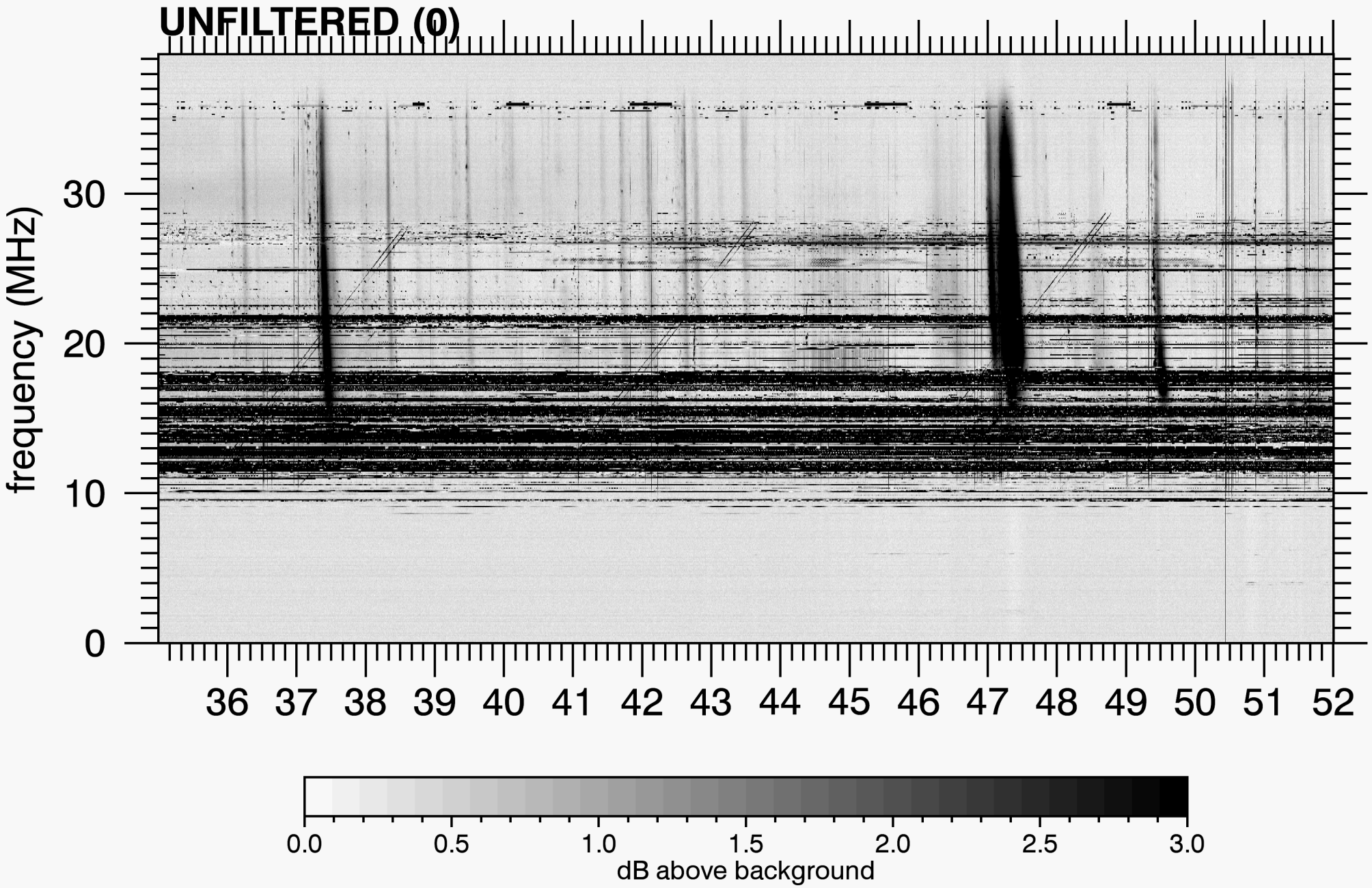
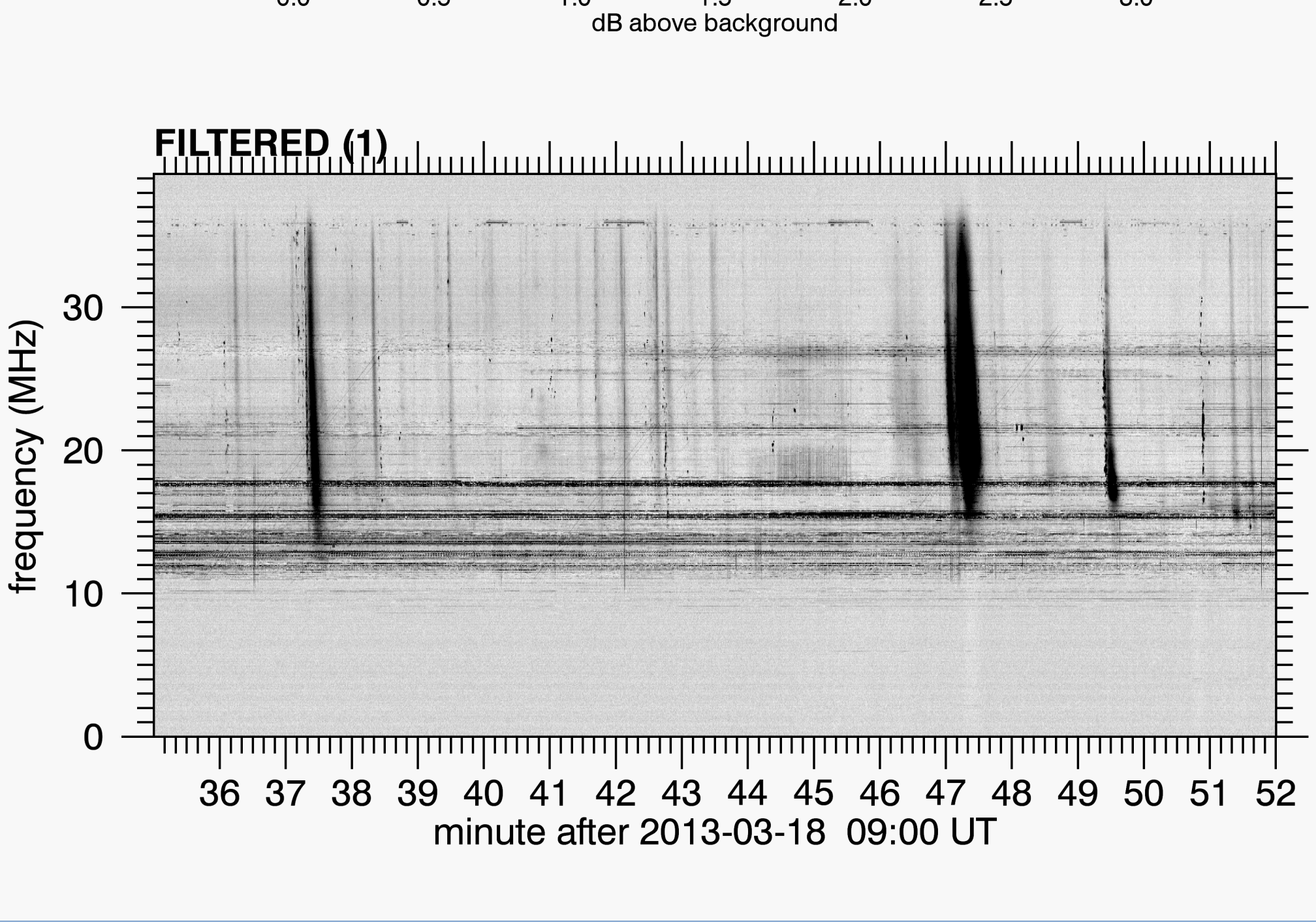
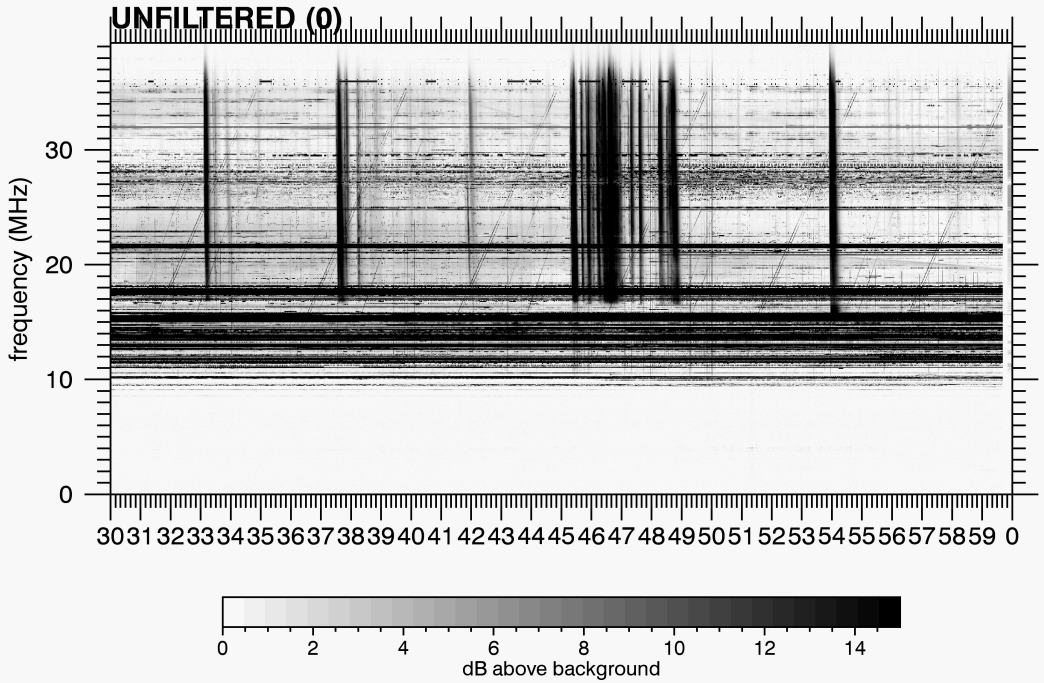
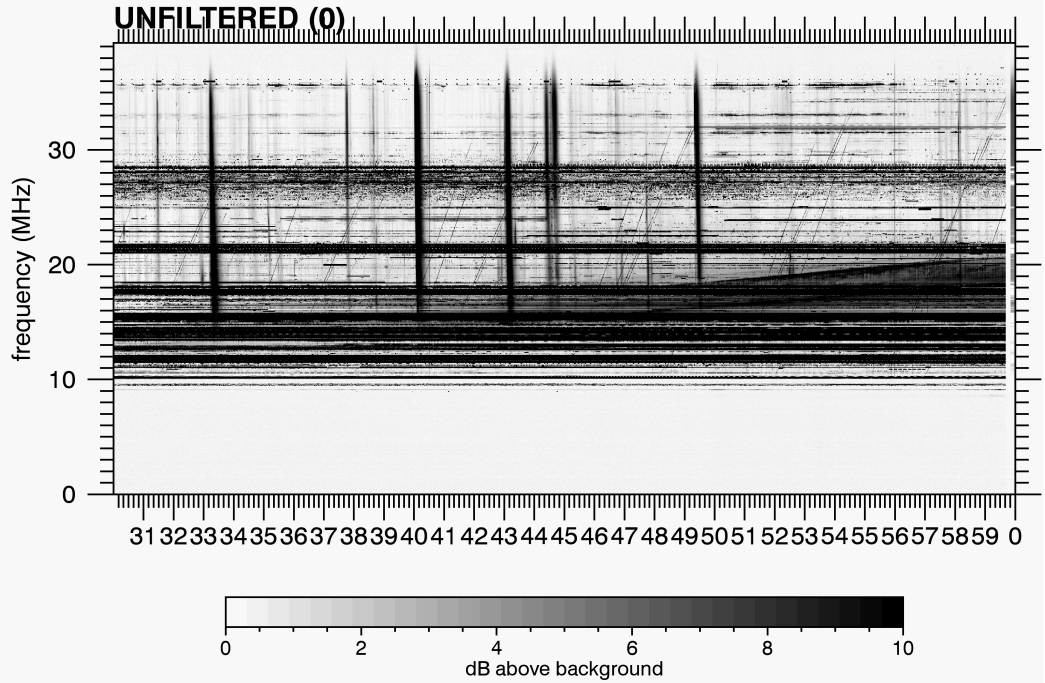
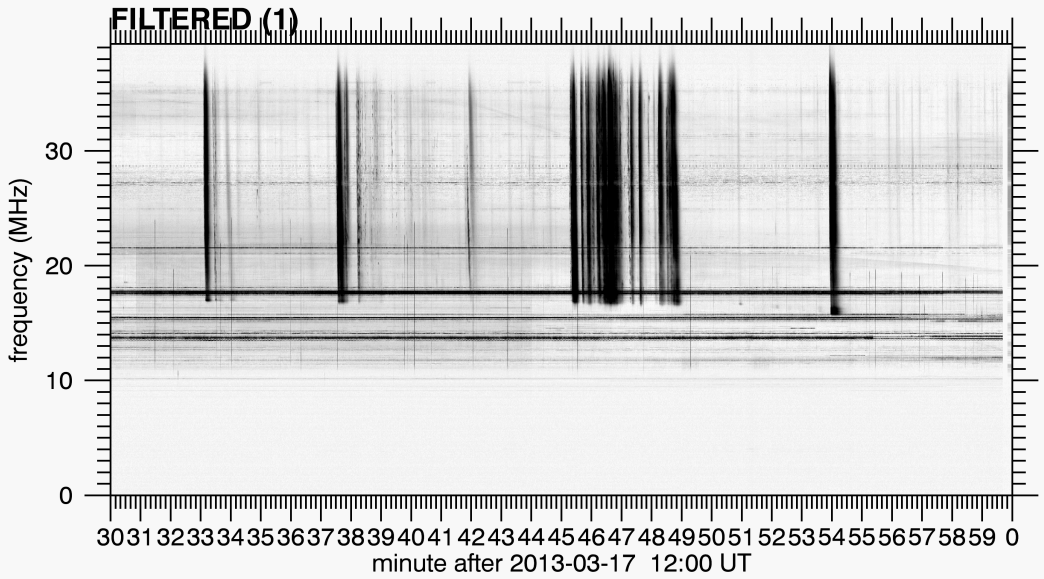
56

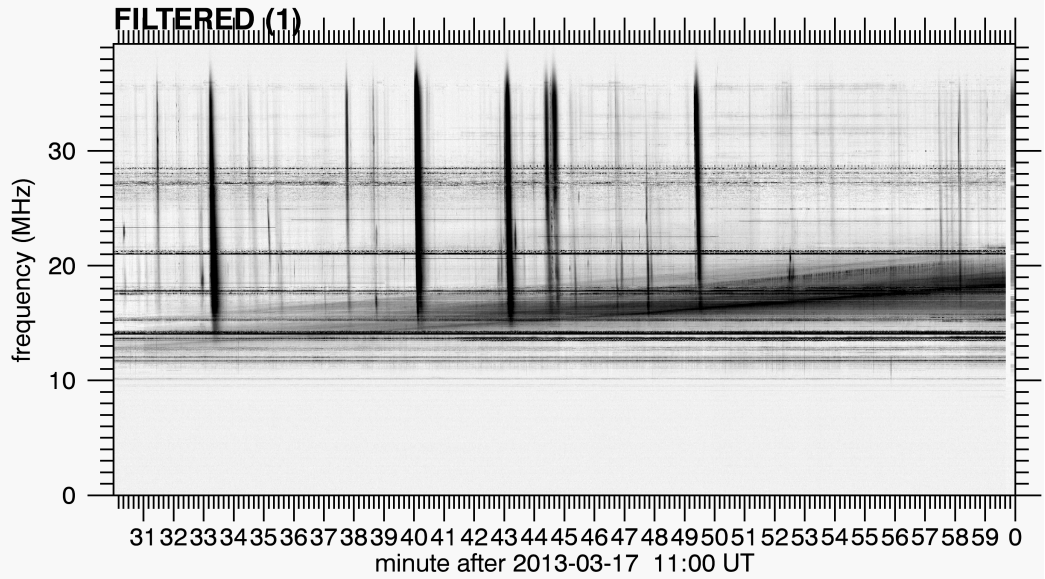

UNFILTERED (0)
frequency (MHz)
0
10
20
30
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
0.0 0.5 1.0 1.5 2.0 2.5 3.0
dB above background

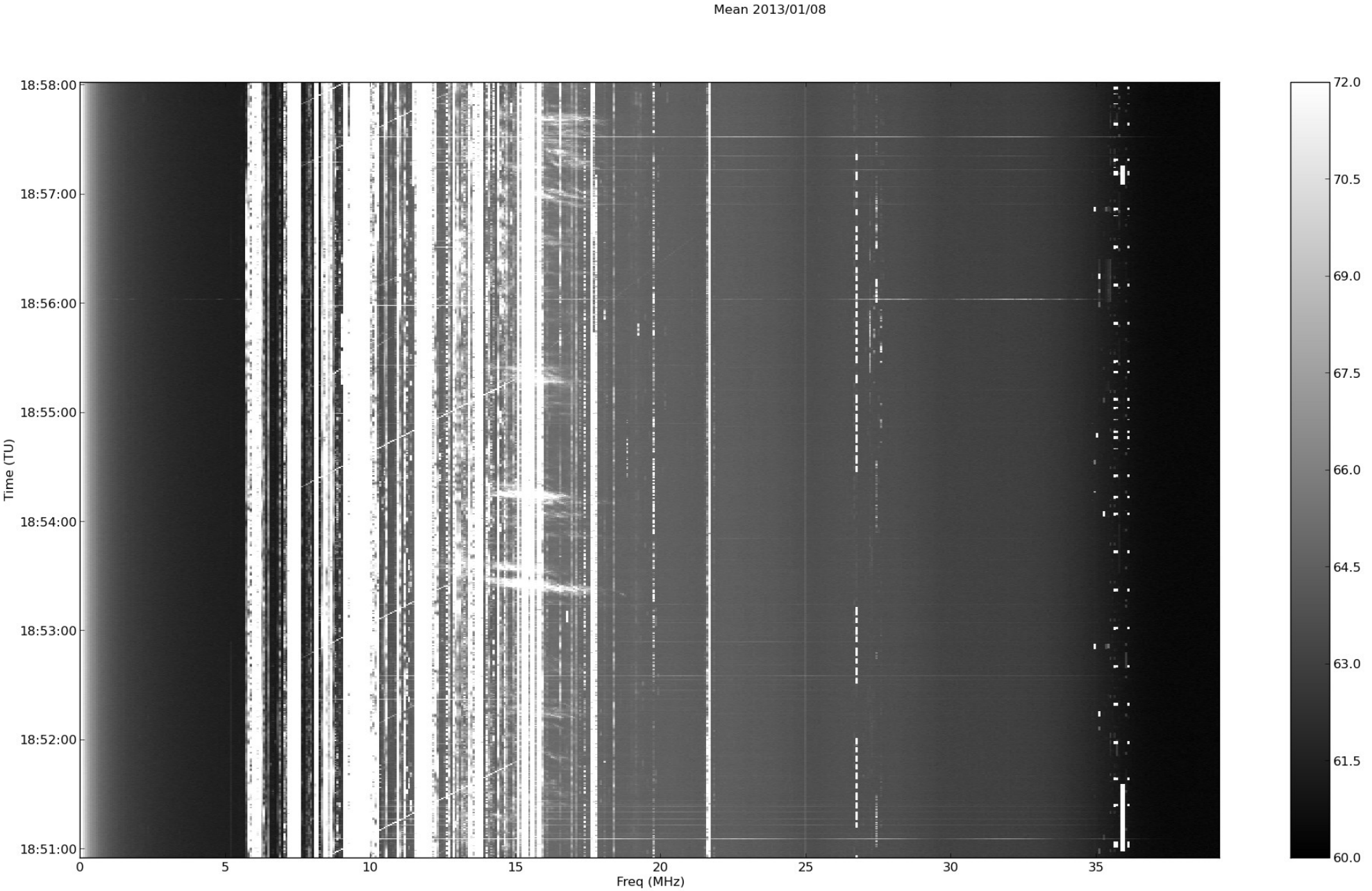

dB above background
FILTERED (1)
frequency (MHz)
0
10
20
30
36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
minute after 2013-03-18 09:00 UT

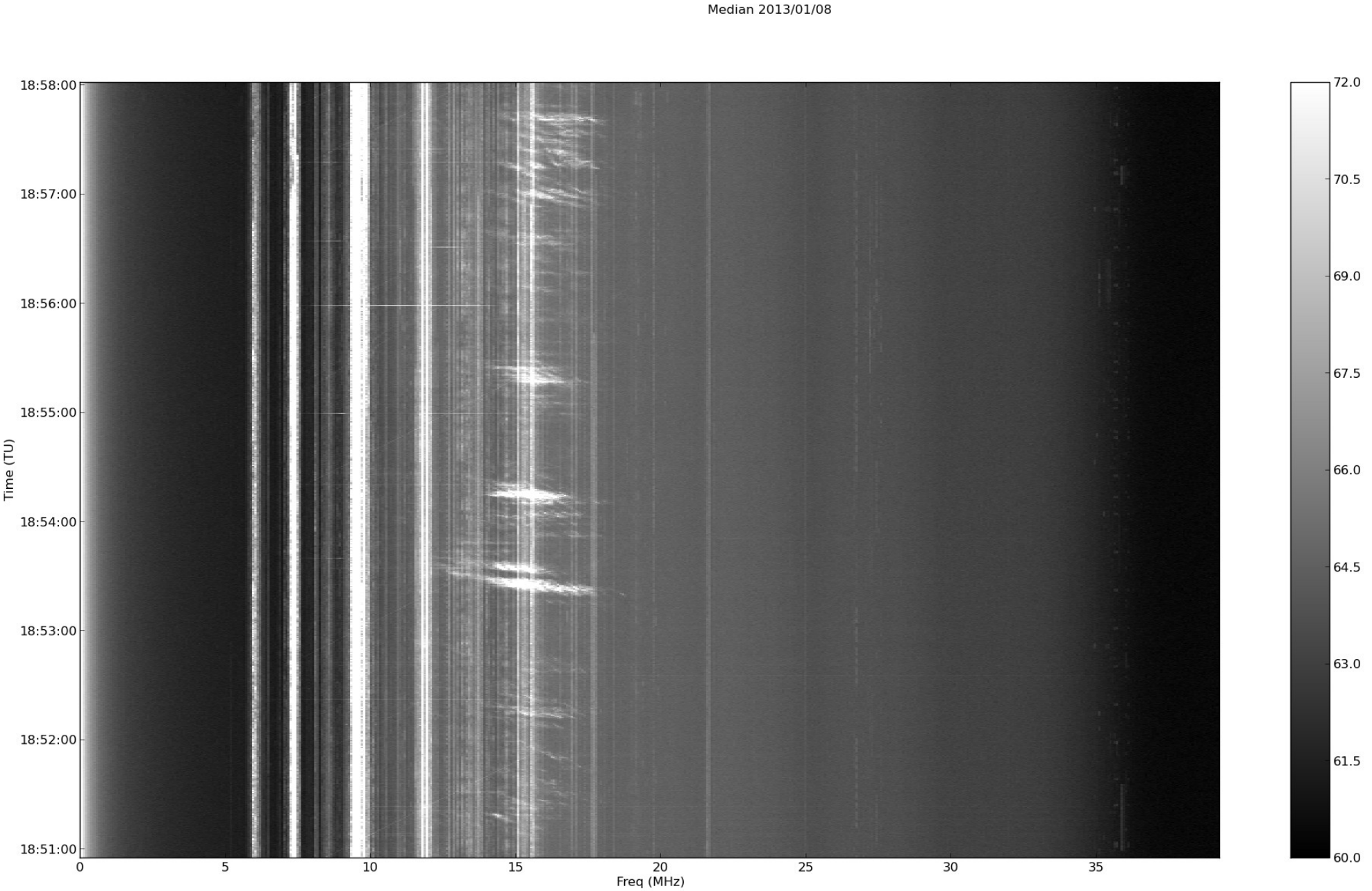

UNFILTERED (0)
frequency (MHz)
0
10
20
30
30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 0
0 2 4 6 8 10 12 14
dB above background

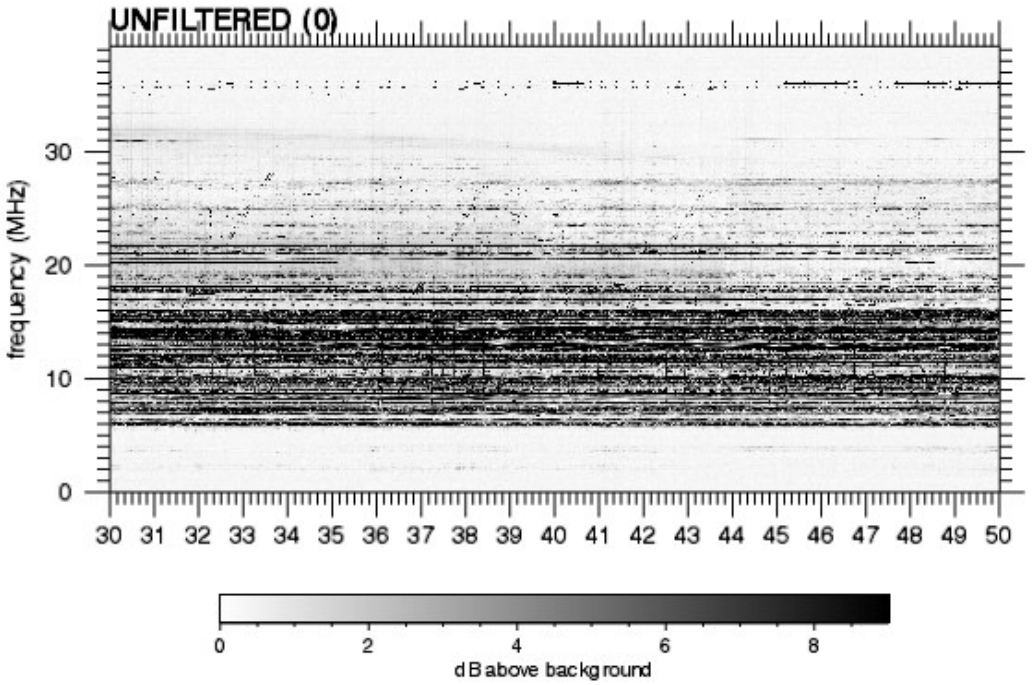

UNFILTERED (0)
frequency (MHz)
0
10
20
30
31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 0
0 2 4 6 8 10
dB above background

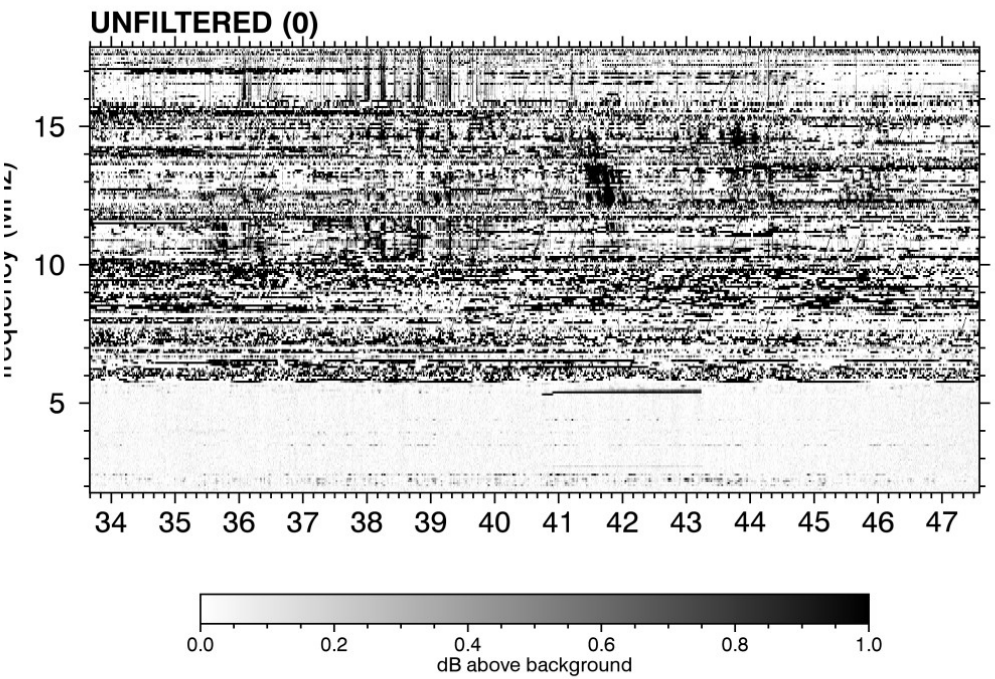

FILTERED (1)
frequency (MHz)
0
10
20
30
30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 0
minute after 2013-03-17 12:00 UT

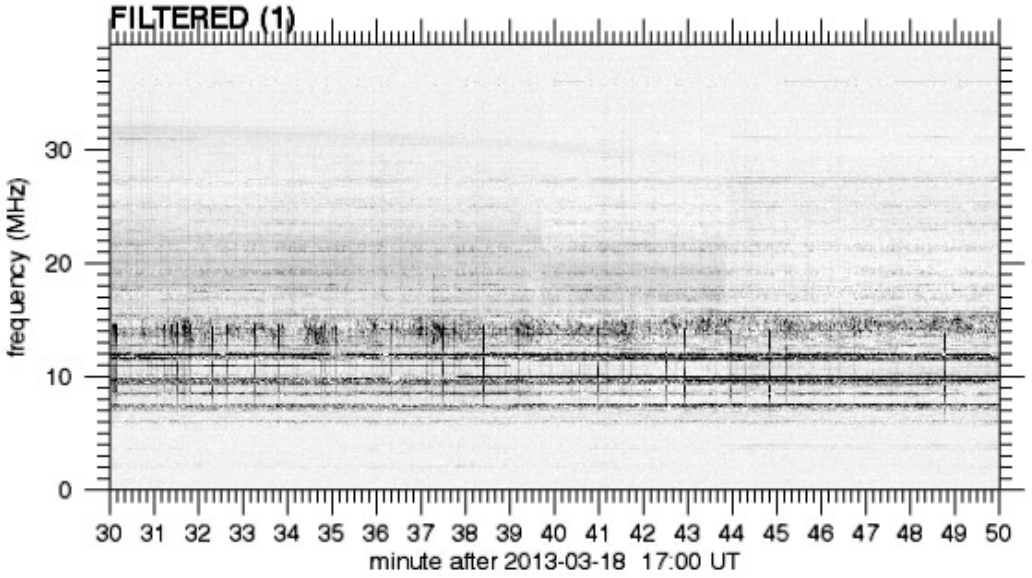

FILTERED (1)
frequency (MHz)
0
10
20
30
31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 0
minute after 2013-03-17 11:00 UT

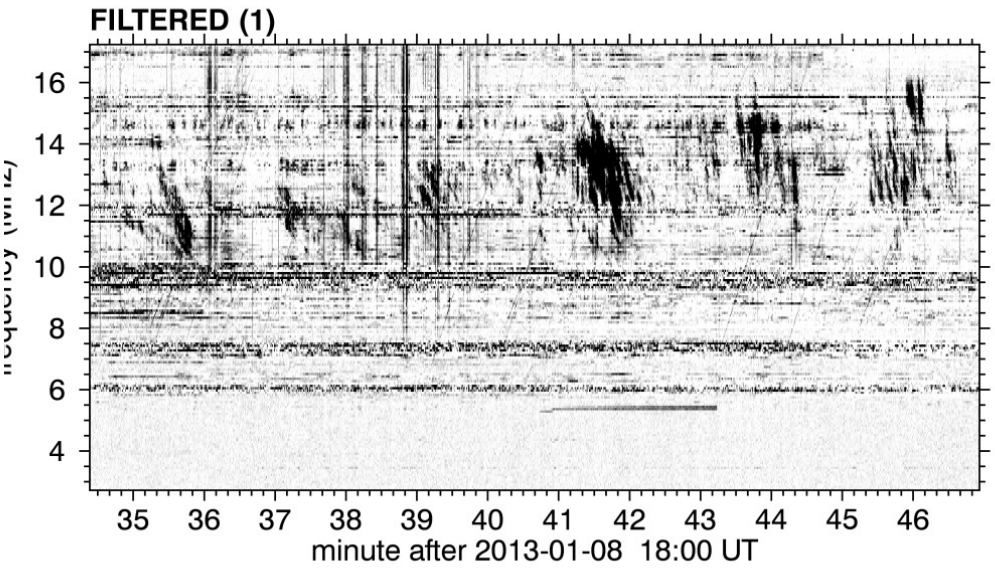

Mean 2013/01/08
Time (TU)
18:58:00
18:57:00
18:56:00
18:55:00
18:54:00
18:53:00
18:52:00
18:51:00
0
5
10
15
20
25
30
35
Freq (MHz)
72.0
70.5
69.0
67.5
66.0
64.5
63.0
61.5
60.0


Median 2013/01/08
18:58:00
18:57:00
18:56:00
18:55:00
18:54:00
18:53:00
18:52:00
18:51:00
Time (TU)
0
5
10
15
20
25
30
35
Freq (MHz)
72.0
70.5
69.0
67.5
66.0
64.5
63.0
61.5
60.0


UNFILTERED (0)
frequency (MHz)
0
10
20
30
30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50
0 2 4 6 8
dB above background


UNFILTERED (0)
5
10
15
34 35 36 37 38 39 40 41 42 43 44 45 46 47
0.0 0.2 0.4 0.6 0.8 1.0
dB above background


FILTERED (1)
frequency (MHz)
0
10
20
30
30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50
minute after 2013-03-18 17:00 UT


FILTERED (1)
4
6
8
10
12
14
16
35 36 37 38 39 40 41 42 43 44 45 46
minute after 2013-01-08 18:00 UT

Conclusion

- The new spectrometer embedding real-time filtering provides enhanced observations, with single dish antenna, in presence of strong RFI.

- It makes use of *a priori* knowledge on the spurious signals and on the SOI.
- The filtering procedure is applied on every single elements of the TF- plane.

- This processing is possible thanks to the sparse nature of RFI. Wide band continuous RFI (DVB, DAB, …) are not well handled by such method.