

First Planetary Results with LOFAR

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First science with LOFAR - Dalfsen - 14/15 September 2011

Solar system planets

Jupiter & Saturn, observed for commissioning

Target	Date	Duration	Band	N _{stations}	Data type
Jupiter	27/11/09	56min	20-32 MHz	5	Raw outputs
	02/04/10	20min	20-39 MHz	4	Raw outputs
	03/06/10	30min	30-90 MHz	5	Raw outputs & Incoherent sum
	07/07/2011	82 min	10-40 MHz	15	1s visibilities
Saturn	08/04/10	3h	30-90 MHz	10	Incoherent sum
	17-18/12/10	2x8h	15-75 MHz	22	Incoherent sum
	07-08/07/11	2x6h	20-70 MHz	5	Coherent sum

Early scientific studies (see TKP/PWG science case)

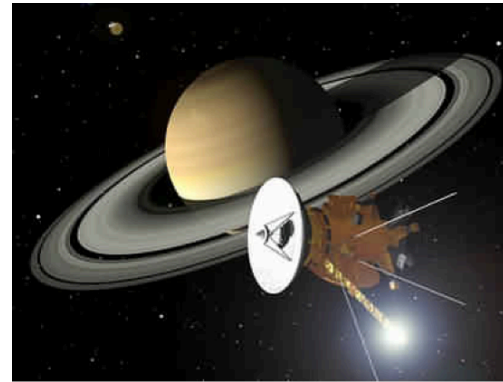
Saturn Electrostatic Discharges (SED)

First discovered by Voyager

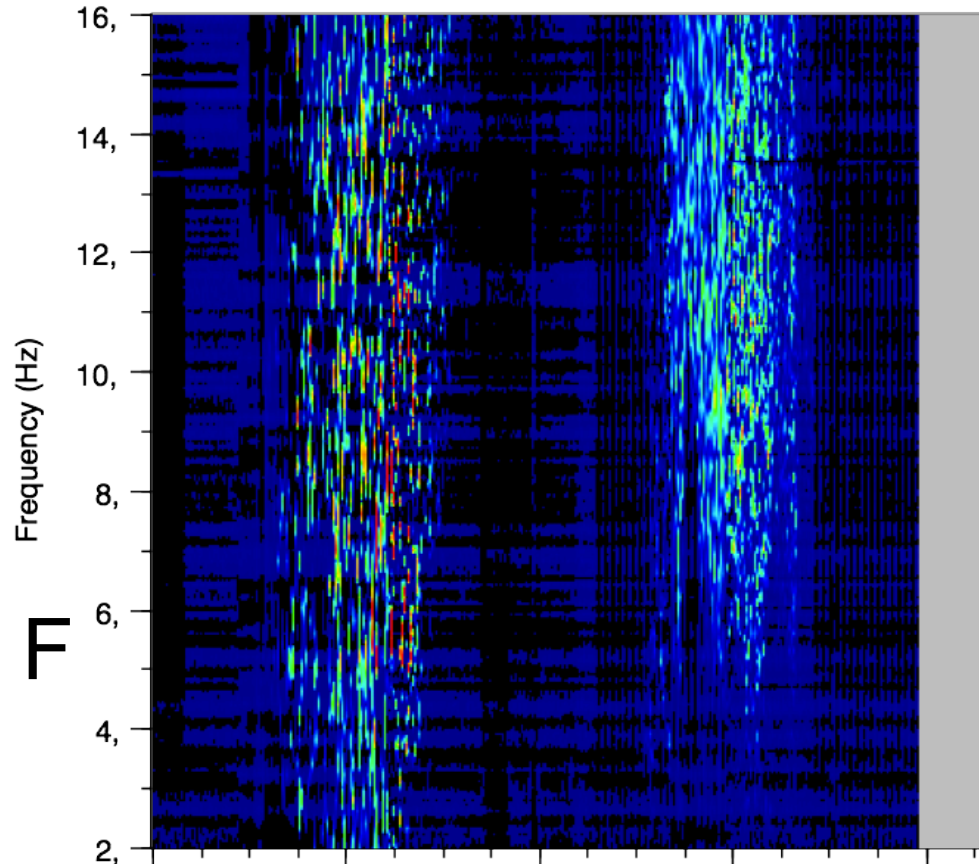
(Warwick et al., 1981)

Now observed by Cassini

$$P_{\text{storm}} = 10.7 \text{ h}$$



correlated with
optical observations



	00:00	08:00	T	16:00	00:00	08:00
R_S	8,85	4,93		4,19	8,00	11,67
Lon	136,77	6,76		160,48	17,09	268,68
Lat	0,16	-0,09		-0,27	0,03	0,15
LT	23,46	2,14		9,91	13,49	14,73
L	8,85	4,93		4,19	8,00	11,67

- Wideband unpolarized intense bursts
- Burst duration: few ms to 100s ms
- Spectrum: up to ≥ 40 MHz
- Flux @ Earth: ~ 1 -1000 Jy

Saturn 08/04/2010

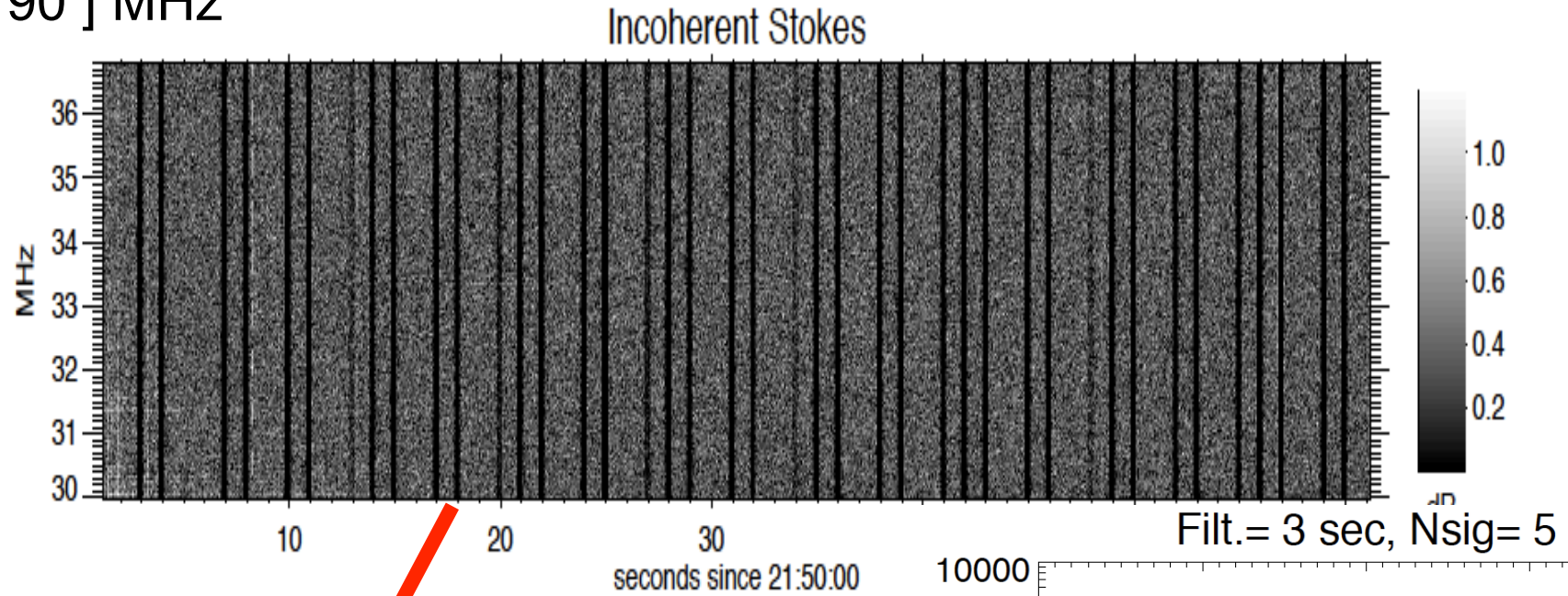
Incoherent sum of 10 stations

T= 3H during active storm

dT= 81 μ s

F= [30, 90] MHz

~clean data with data gaps

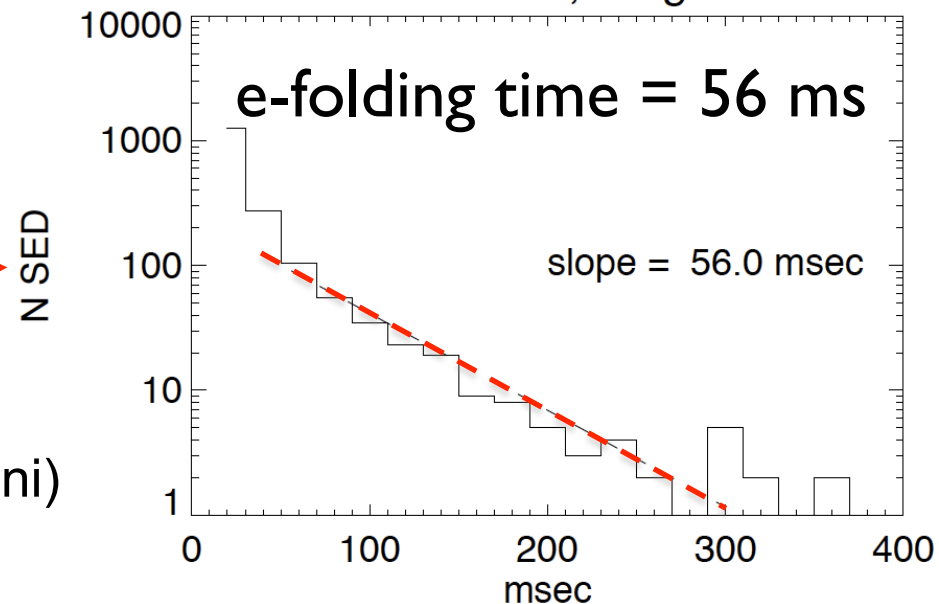


- RFI mitigation & spike detection
- Distribution of SED durations

$$N = N_0 e^{-\frac{D}{D_0}}$$

$D_0 \sim 50$ ms (as seen by Voyager I & II & Cassini)

- But no spatial/temporal «OFF» reference

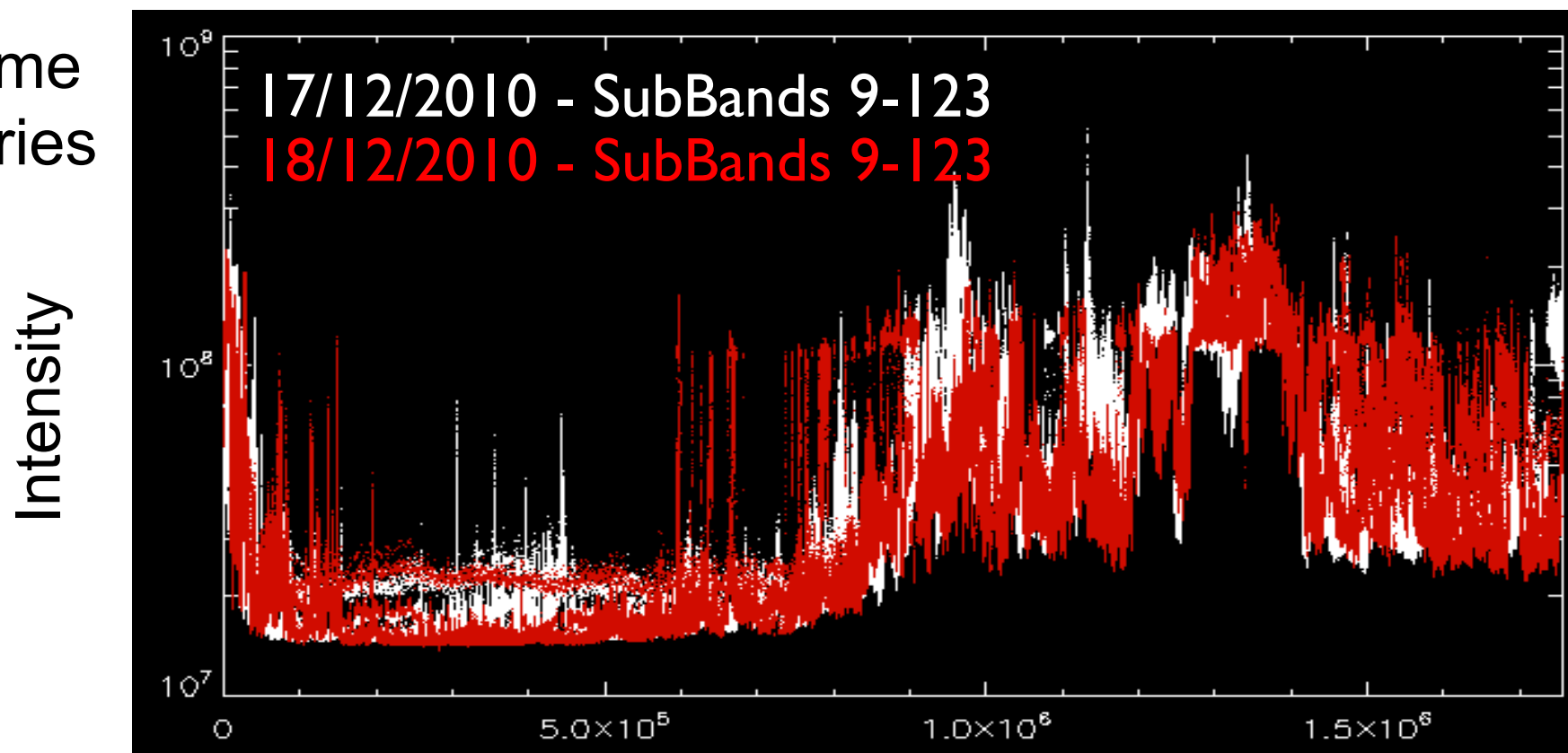


Saturn 17 & 18/12/2010 Incoherent sum of 22 stations

T= 8h dt = 81 μ s

Beam ON	17/12 Saturn	18/12 Saturn
Beam OFF	Arbitrary	PSR1133

Time series



3:00 am

Time steps

11:00 am

- Data heavily polluted
 - Heavy RFI mitigation
 - Marginal detection on the 18th & Pulsar detected in OFF beam
- lesson learned = no blind incoherent sum

Saturn 7 & 8/07/2011

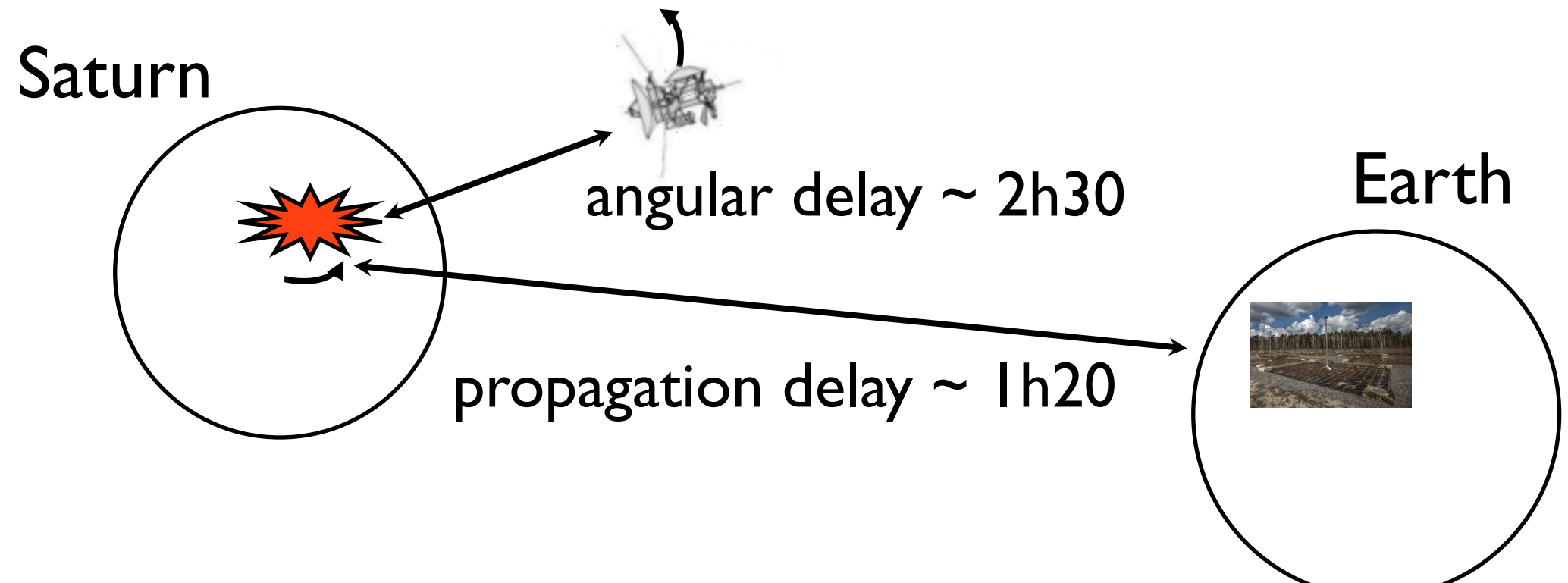
T= 6H
F= [20, 70] MHz

→ Coherent sum of 5 superterp stations
ON & OFF Beam

2011/07/07 :LOFAR observation 15:56 - 21:56 UT

2011/07/08 :LOFAR observation 13:00 - 19:00 UT

→ visibility from Earth ~1h15 before Cassini (at 17:00 LT)

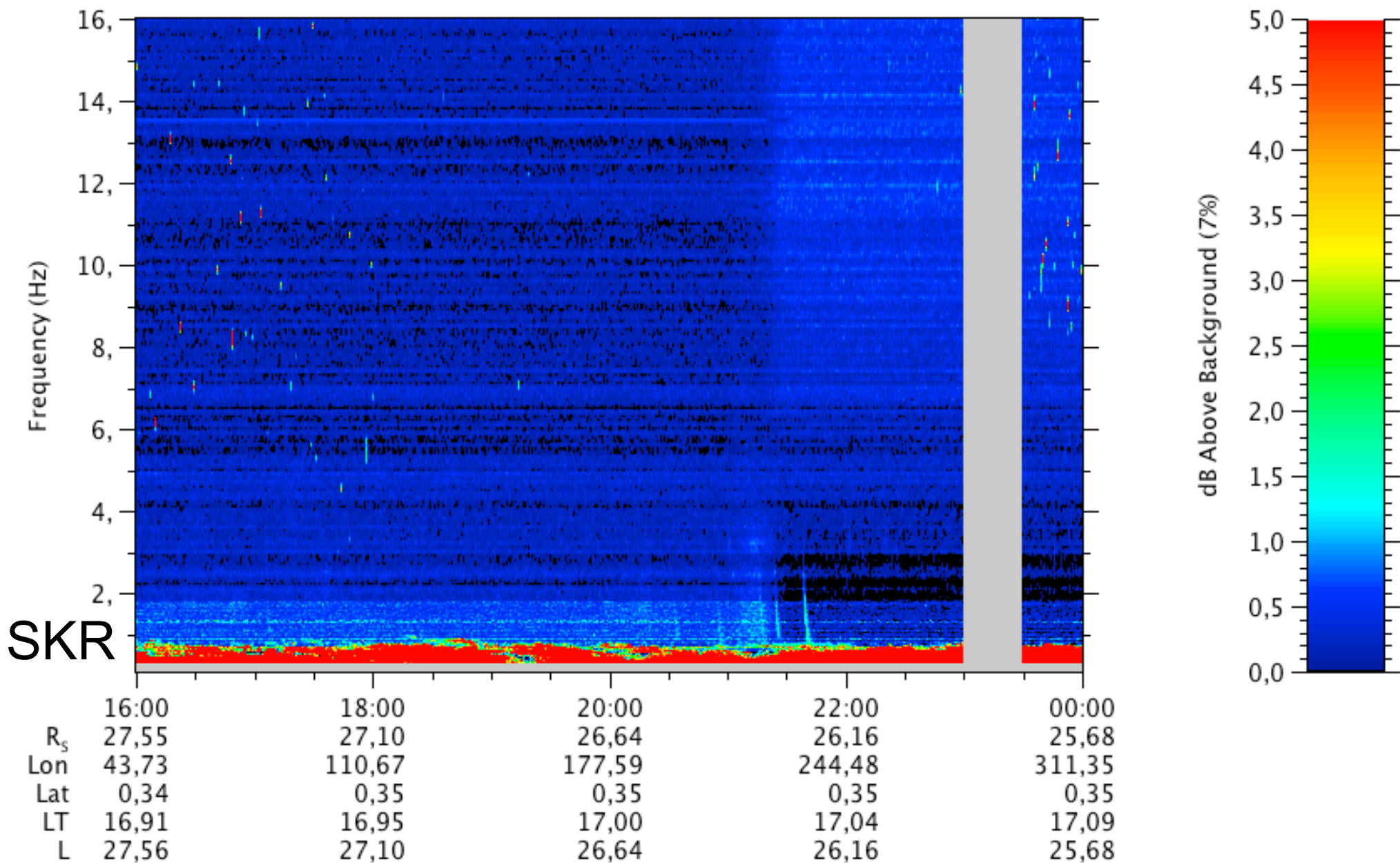


Cassini Data

2011-07-07 (188) 16:00

2011/07/07

2011-07-08 (189) 00:00

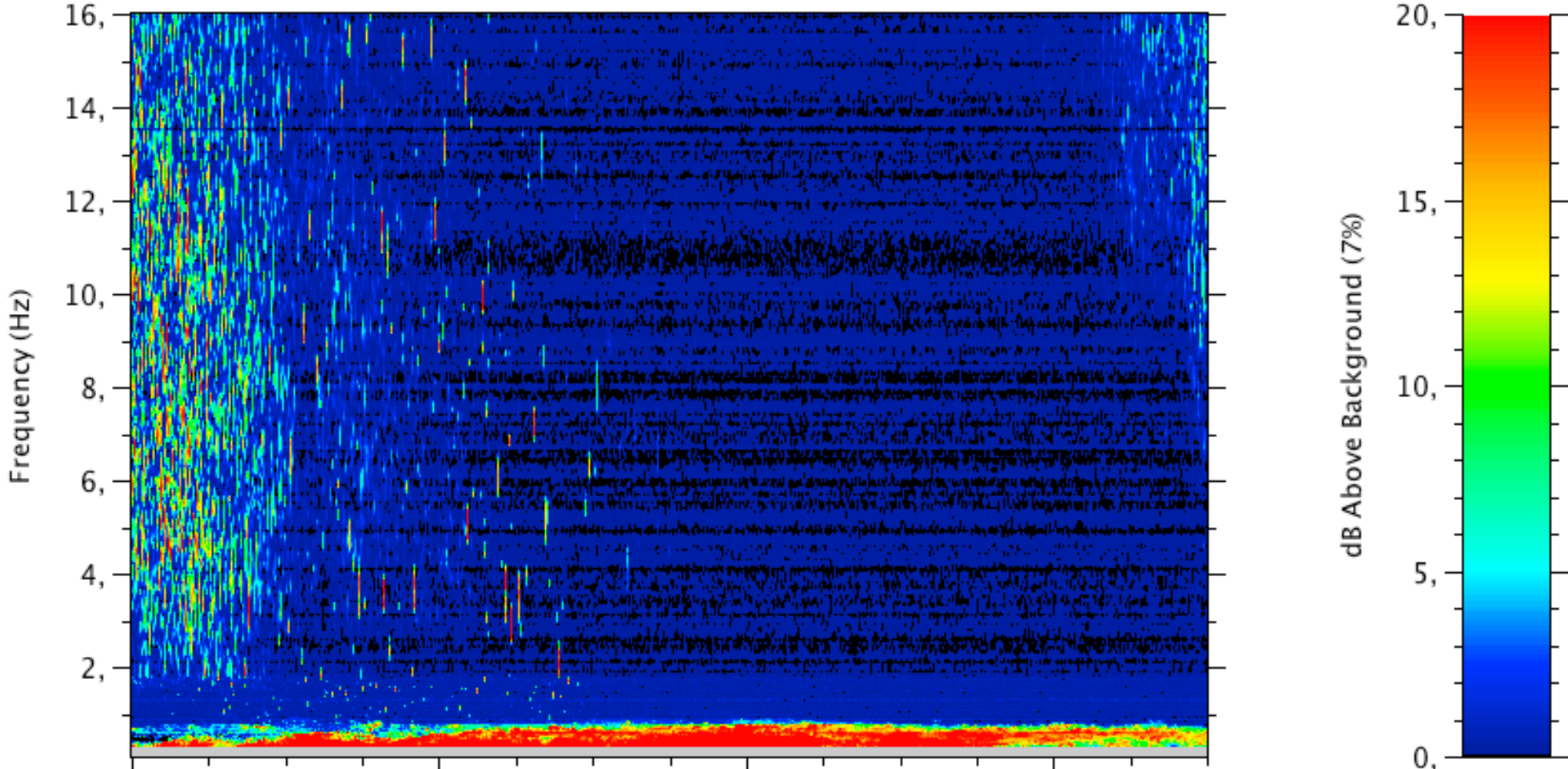


LOFAR observation

2011-07-08 (189) 14:00

2011/07/08

2011-07-08 (189) 21:00

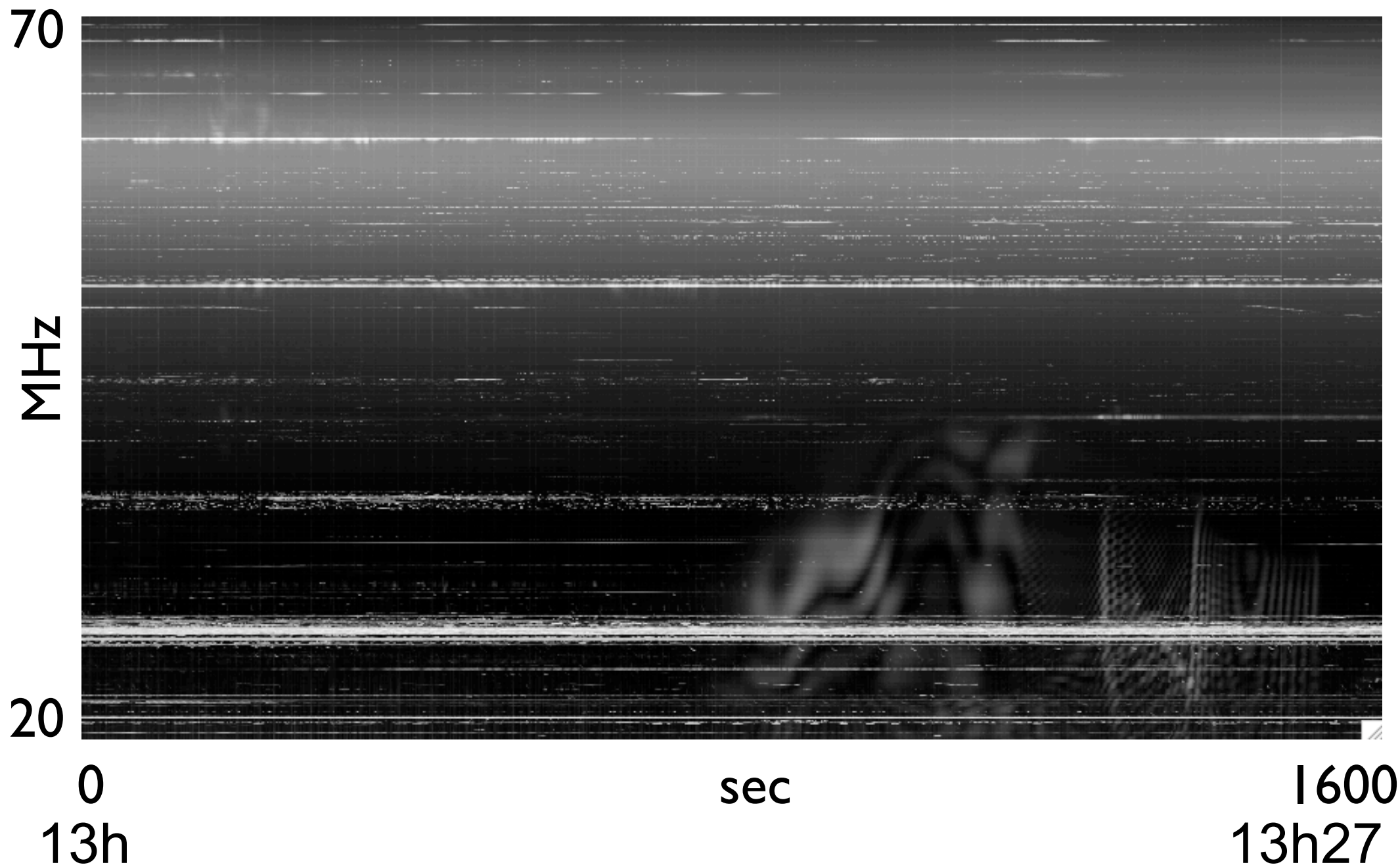


	14:00	16:00	18:00	20:00
R_s	22,02	21,45	20,86	20,27
Lon	58,55	125,12	191,65	258,11
Lat	0,36	0,36	0,36	0,36
LT	17,47	17,54	17,61	17,68
L	22,02	21,45	20,87	20,27

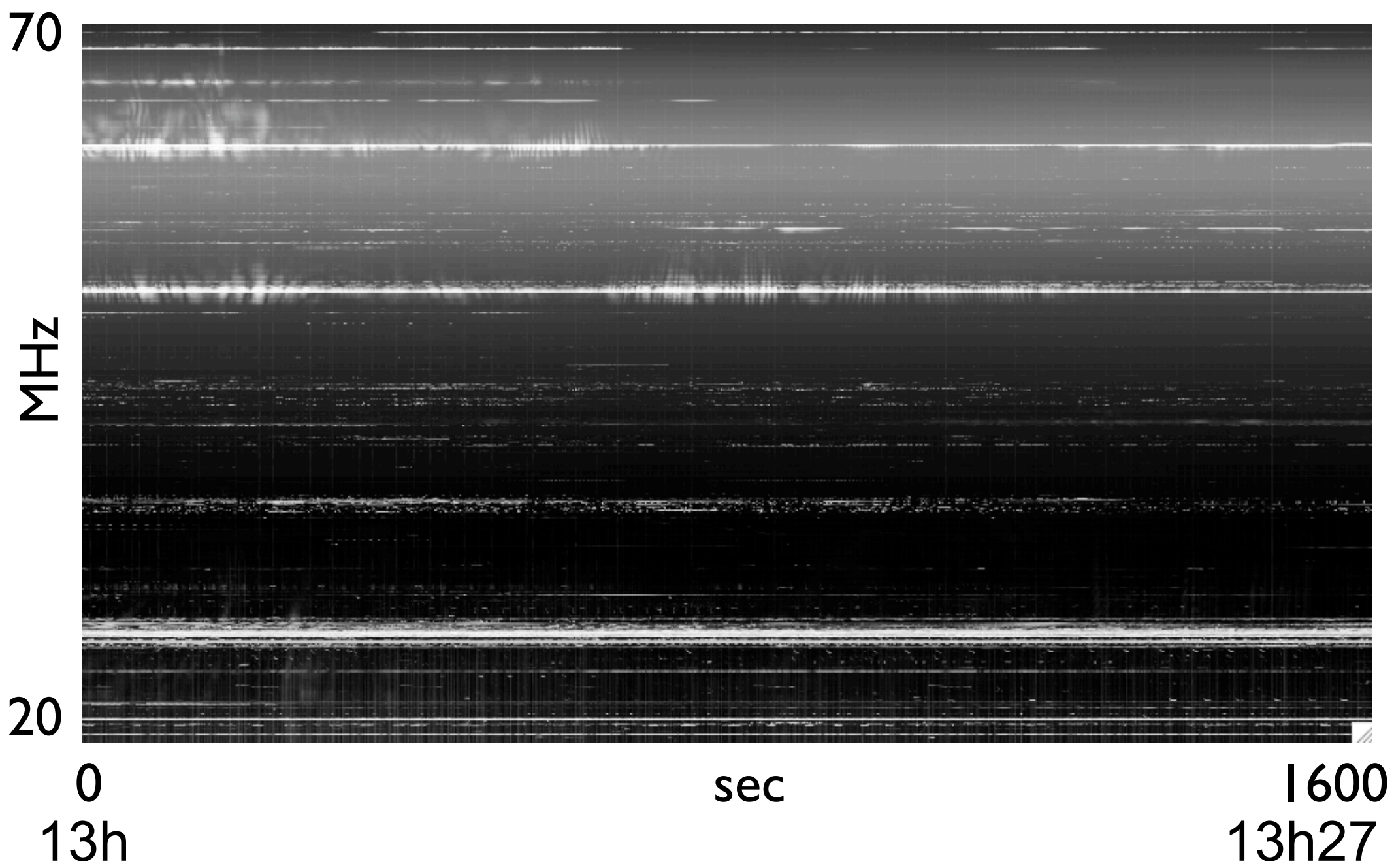


LOFAR observation

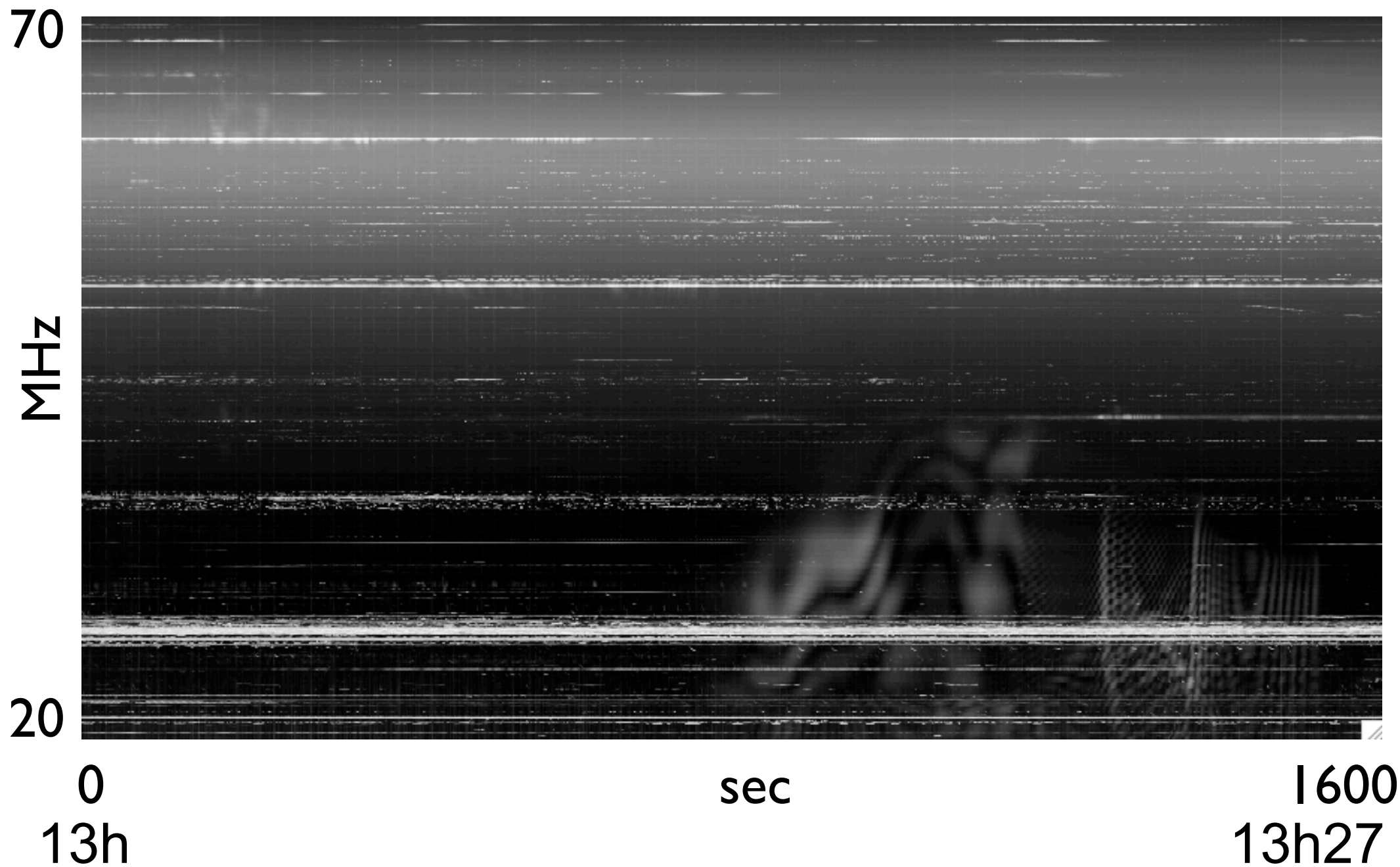
2011-07-08 : first 1600 sec, beam ON Saturn



2011-07-08 : first 1600 sec, beam OFF Saturn

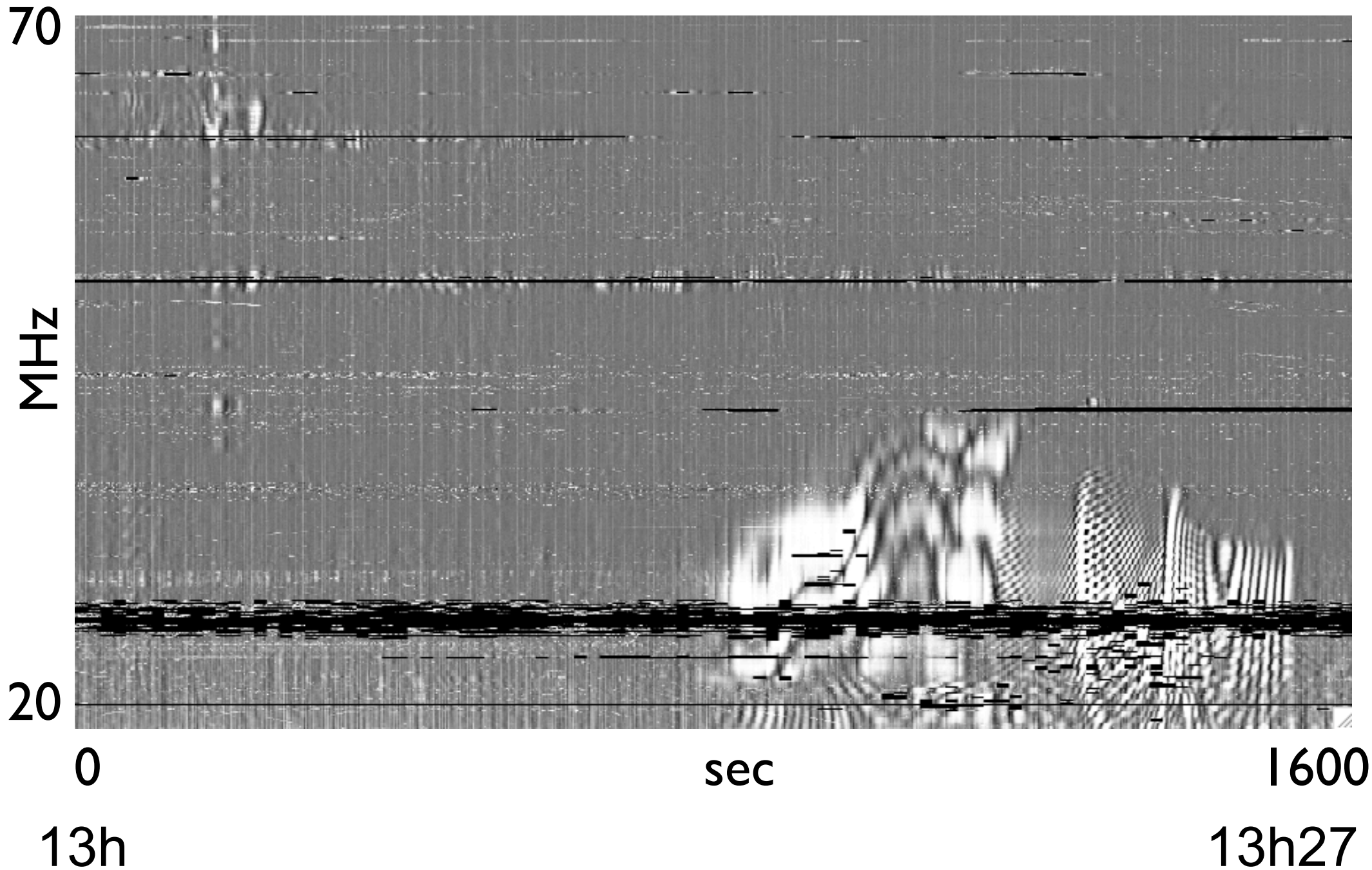


2011-07-08 : first 1600 sec, beam ON Saturn



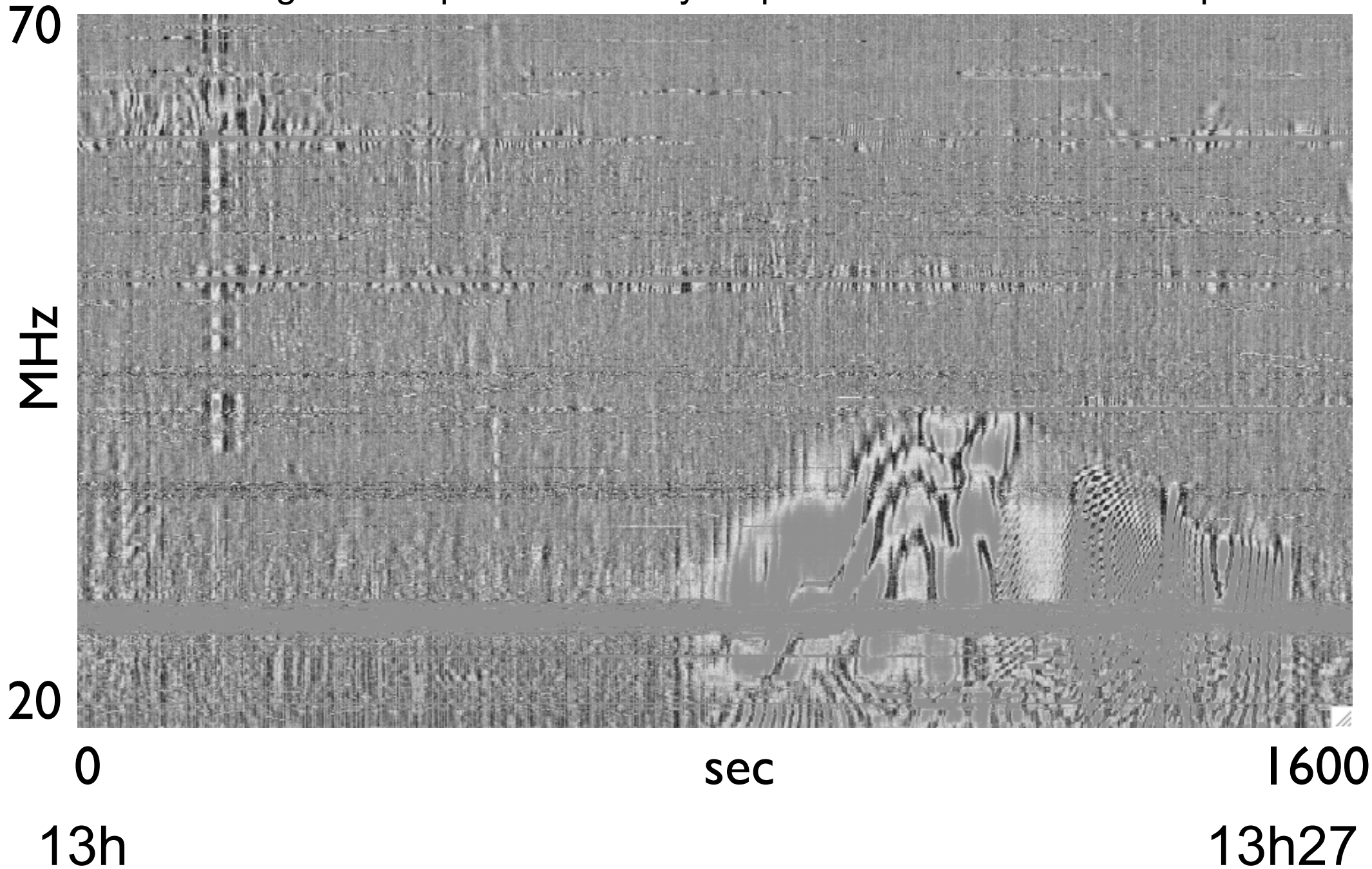
2011-07-08 : first 1600 sec, beam ON Saturn

1st RFI mitigation step: cut spikes $> 3\sigma$ above 10%-occurrence-spectrum

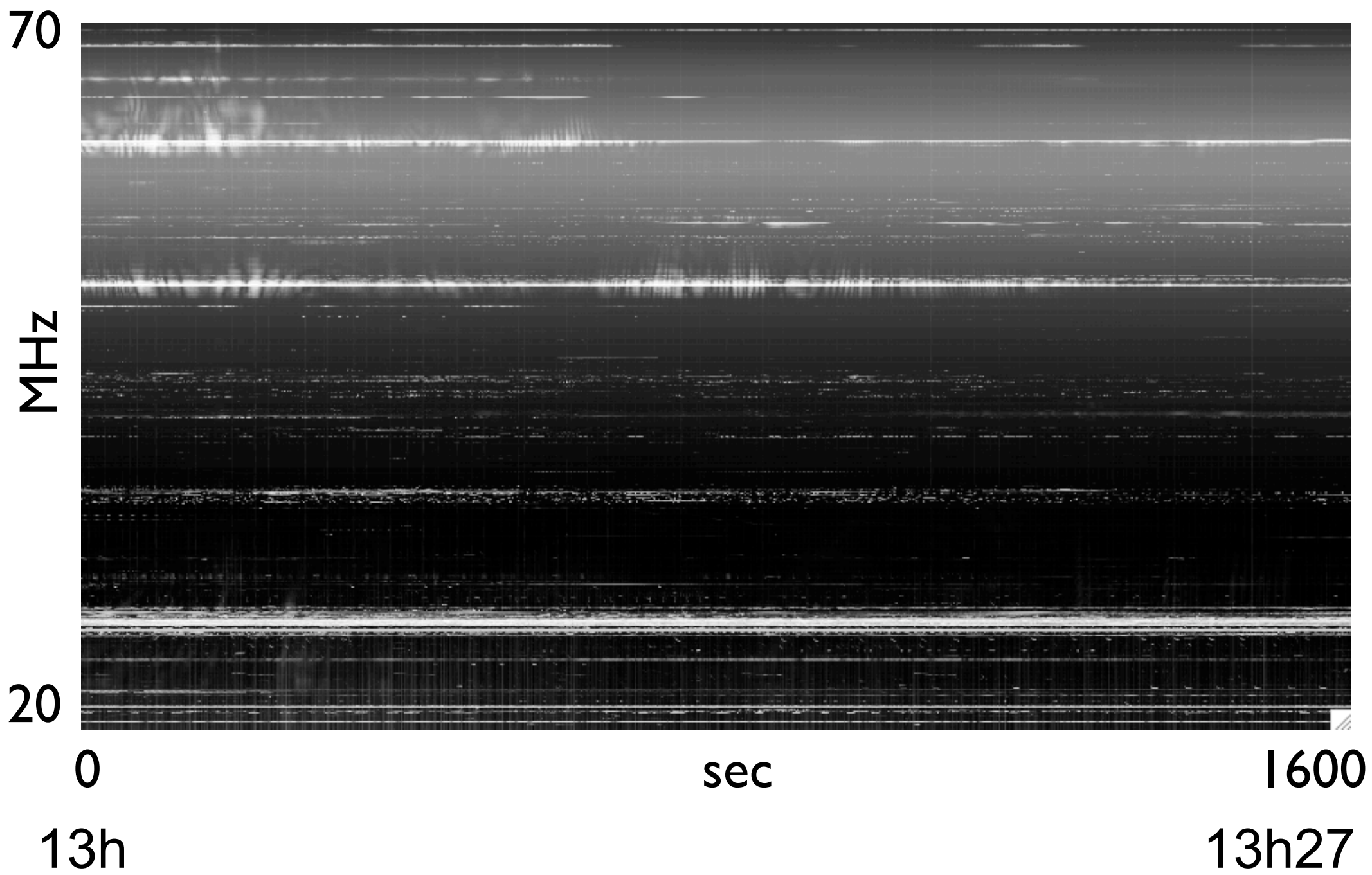


2011-07-08 : first 1600 sec, beam ON Saturn

2nd RFI mitigation step: cut ~ 1000 Jy amplitude around reference spectrum

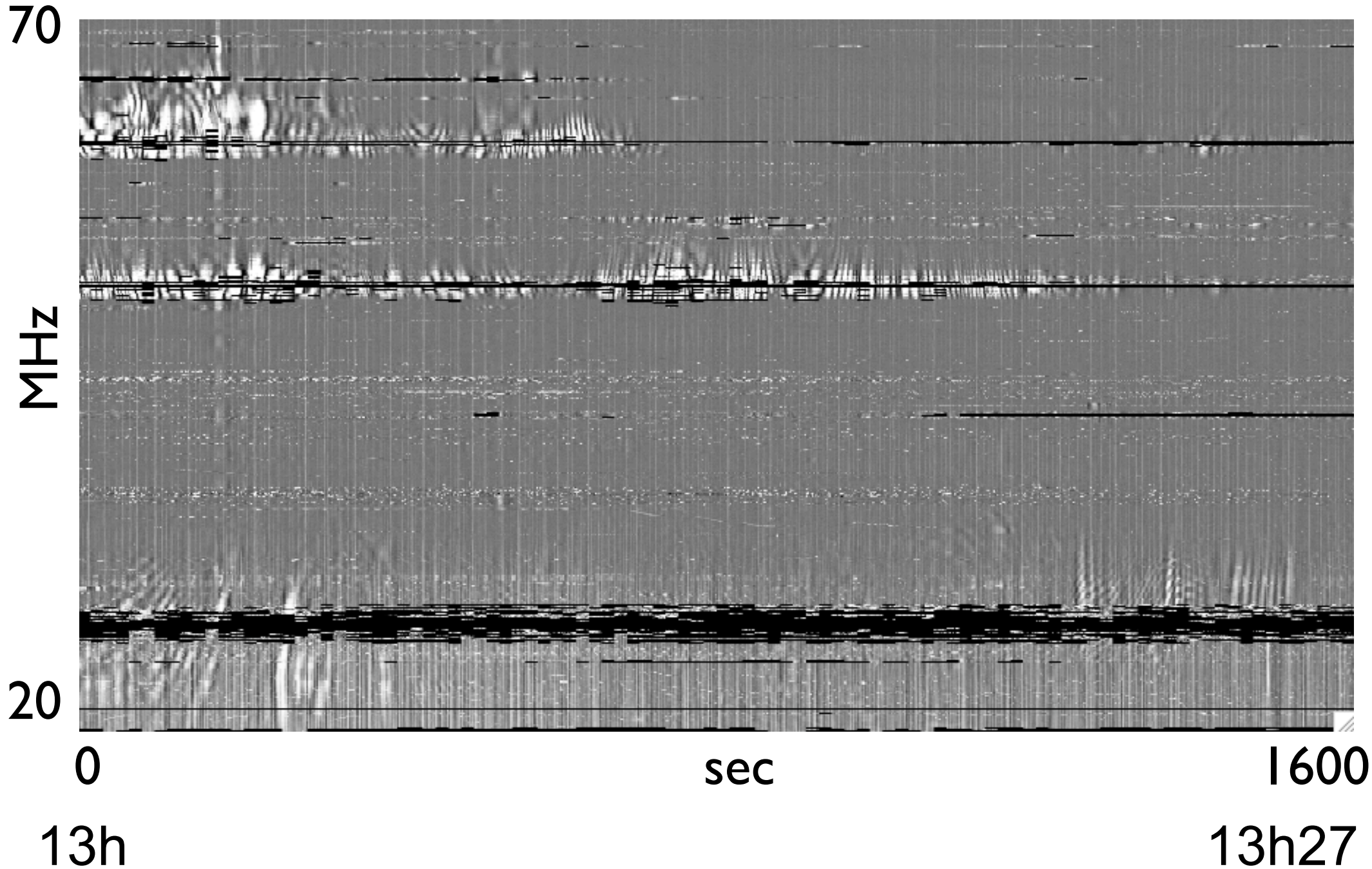


2011-07-08 : first 1600 sec, beam OFF Saturn



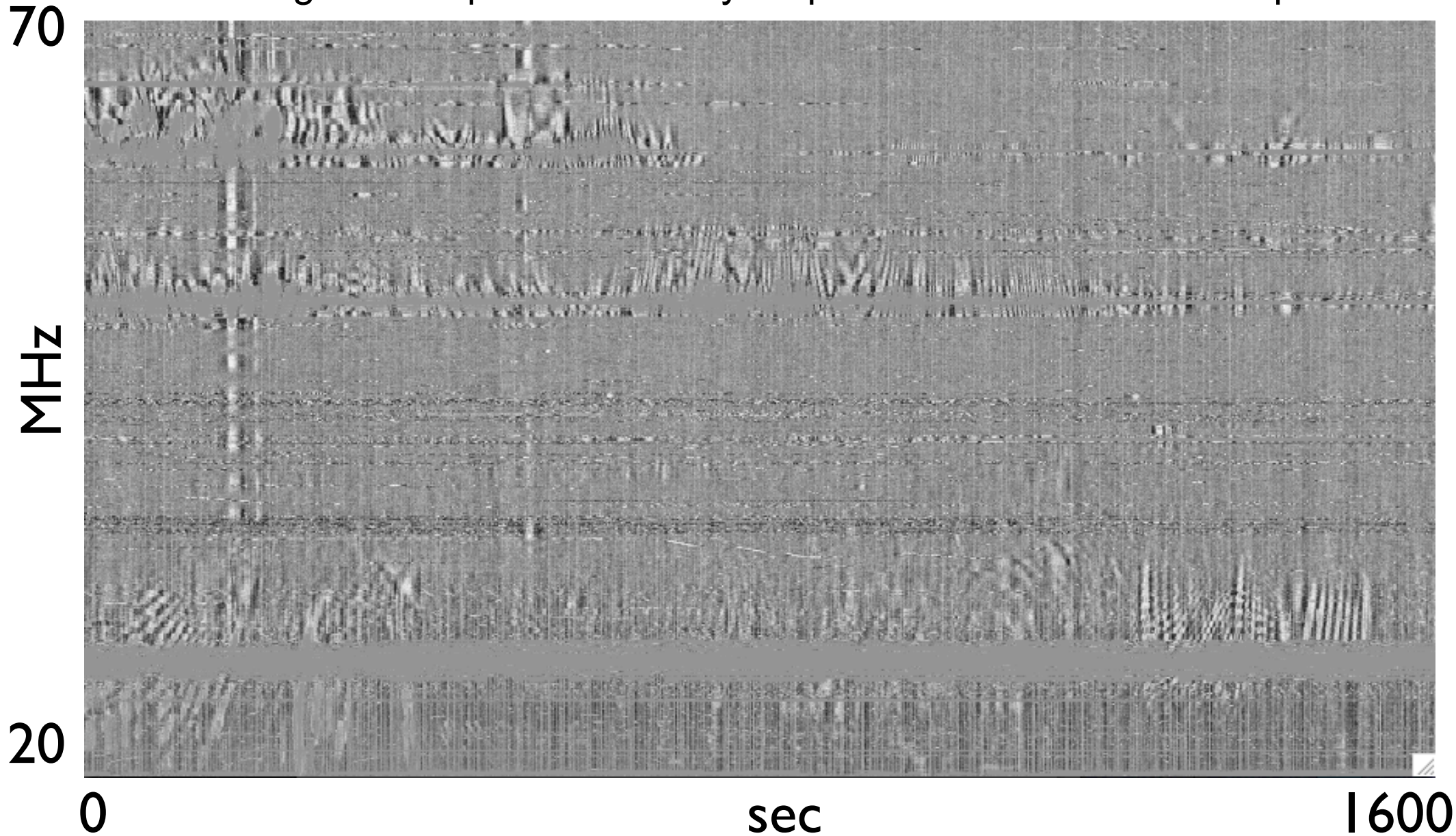
2011-07-08 : first 1600 sec, beam OFF Saturn

1st RFI mitigation step: cut spikes $> 3\sigma$ above 10%-occurrence-spectrum



2011-07-08 : first 1600 sec, beam OFF Saturn

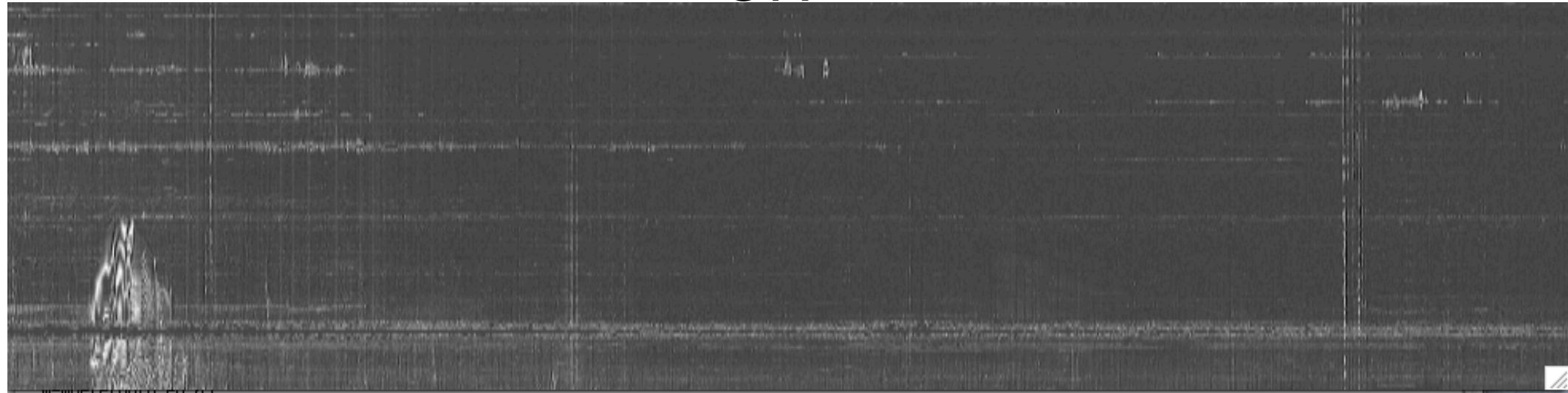
2nd RFI mitigation step: cut ~ 1000 Jy amplitude around reference spectrum



2011-07-08 : first 4 hours

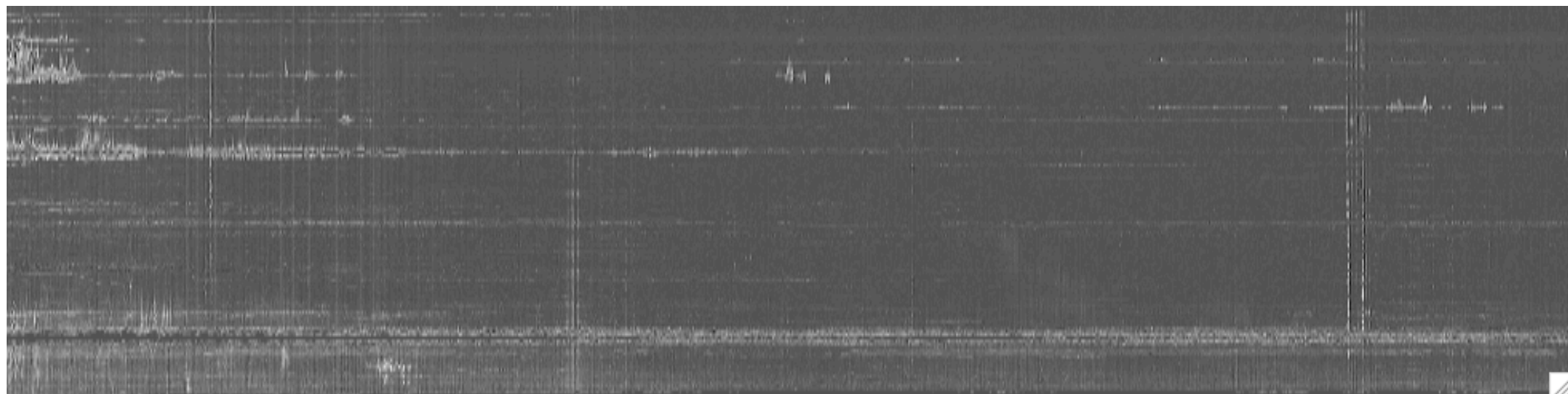
70 MHz

ON



20 MHz

OFF

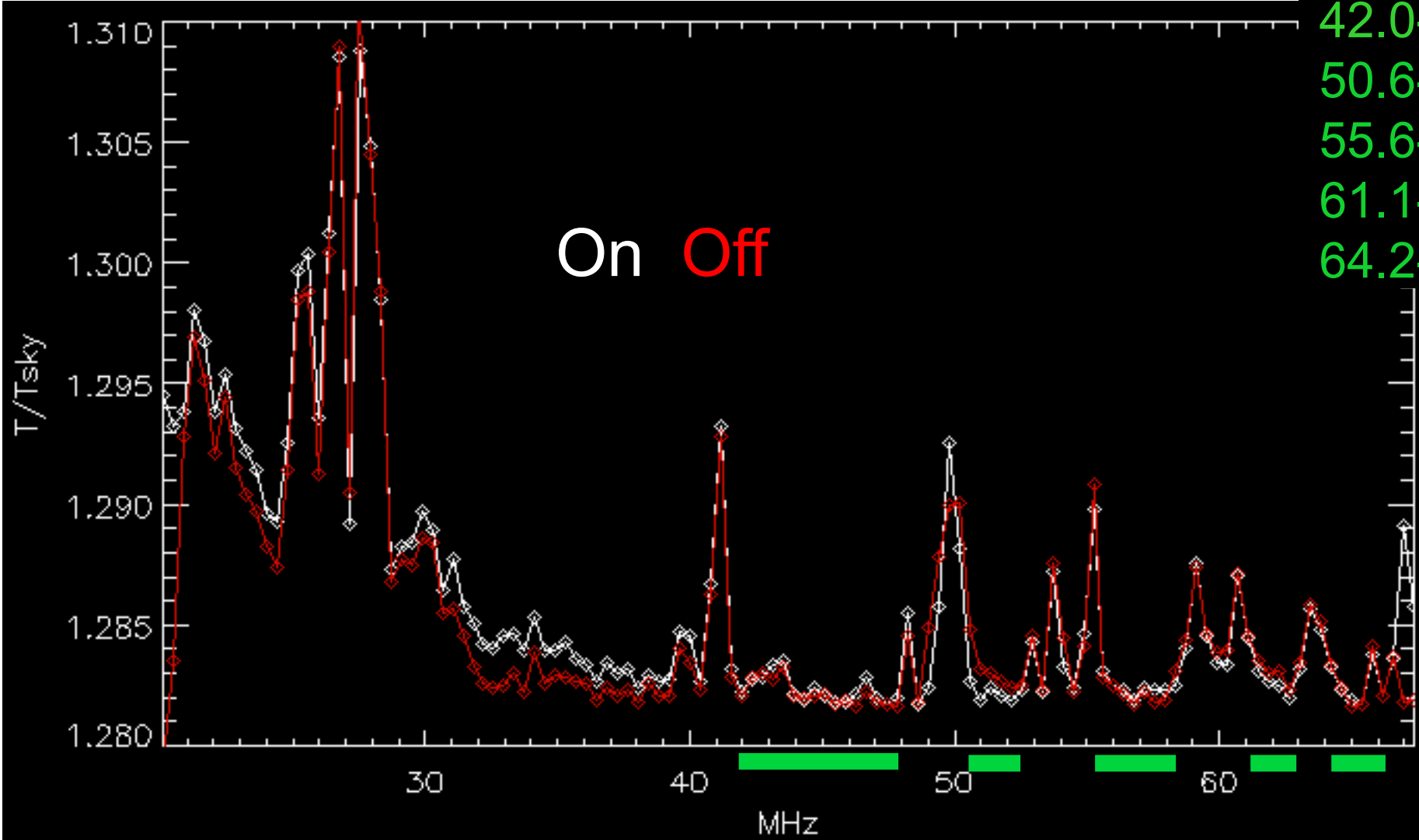


13:00

17:00

Average spectrum

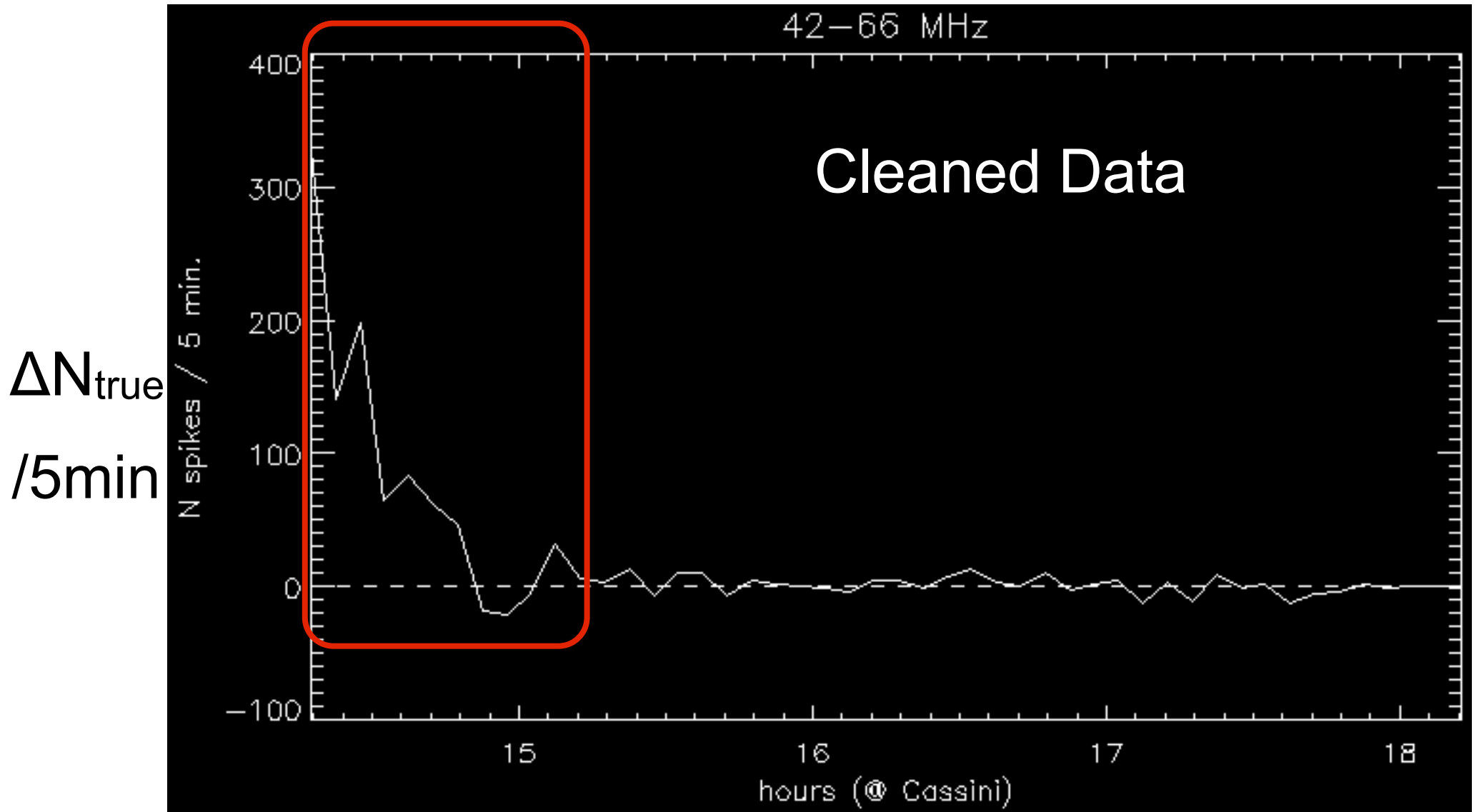
Selection of 5 clean bands



- (MHz)
- 42.0-47.8
- 50.6-52.5
- 55.6-58.4
- 61.1-63.1
- 64.2-66.2

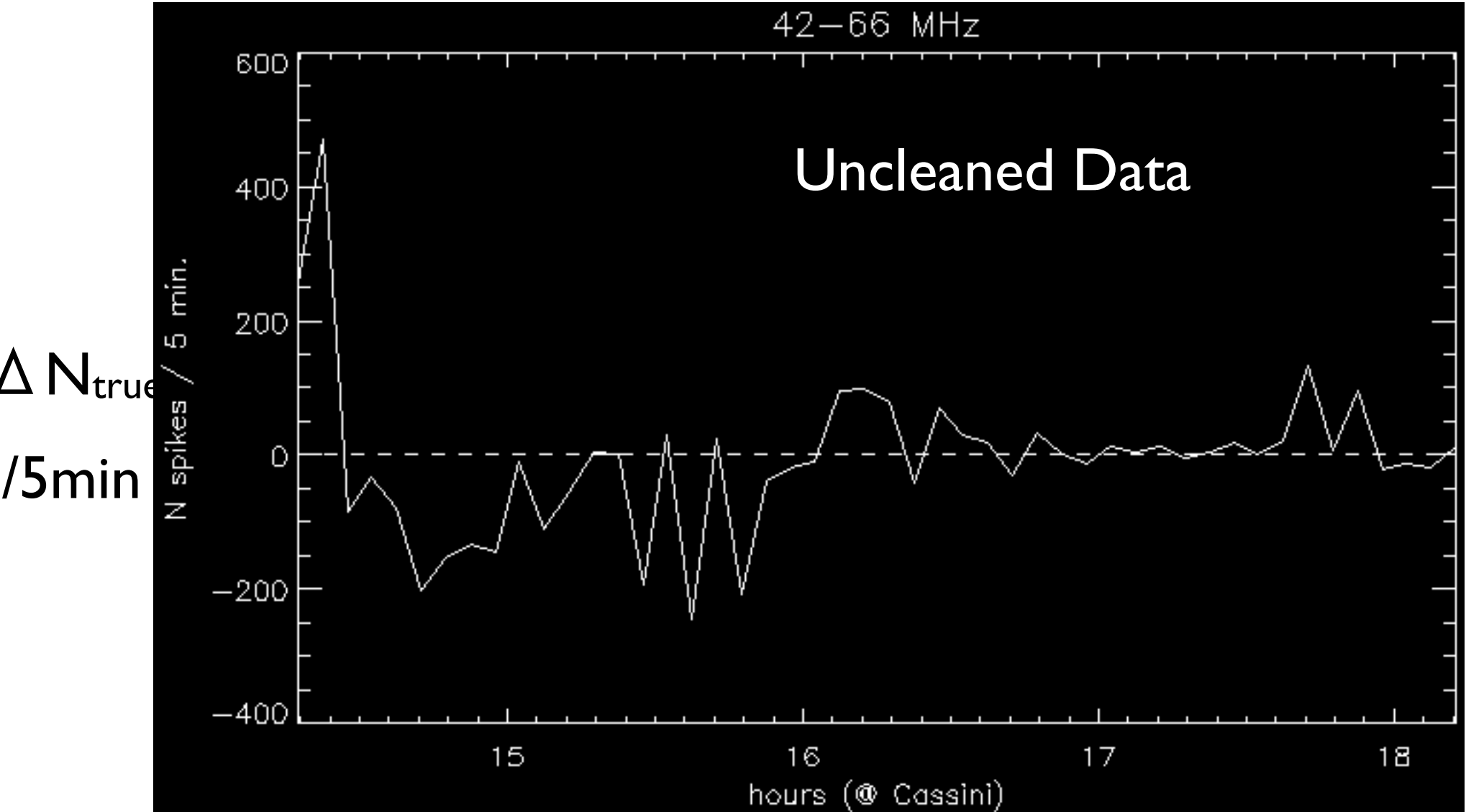
Spike detection

$$\Delta N_{\text{true}} = N_{\text{ON}} - N_{\text{OFF}}$$



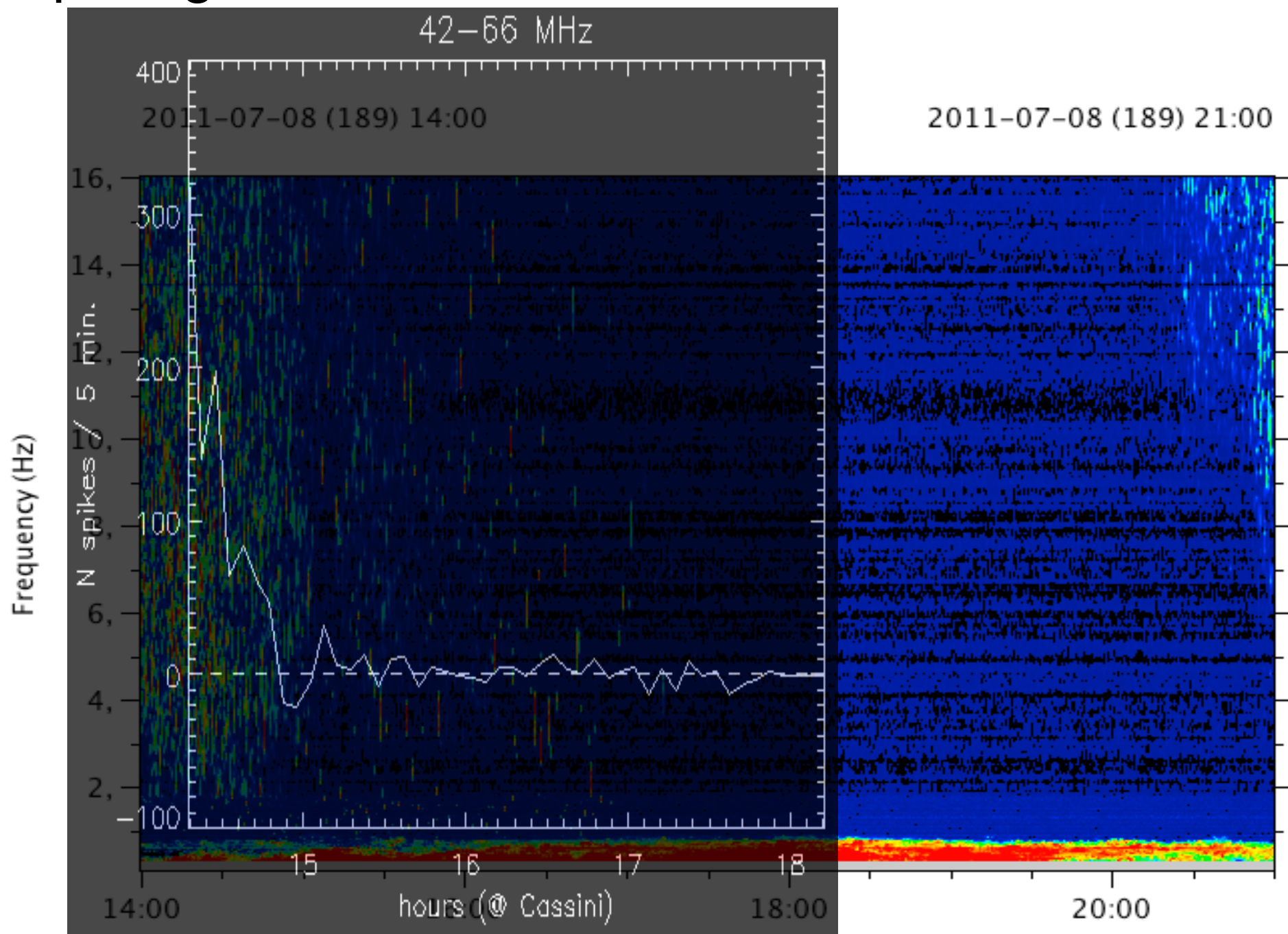
Excess in ON between 13h-14h (LOFAR Time)

Same procedure on uncleaned data



- Higher fluctuations
- No unambiguous detection

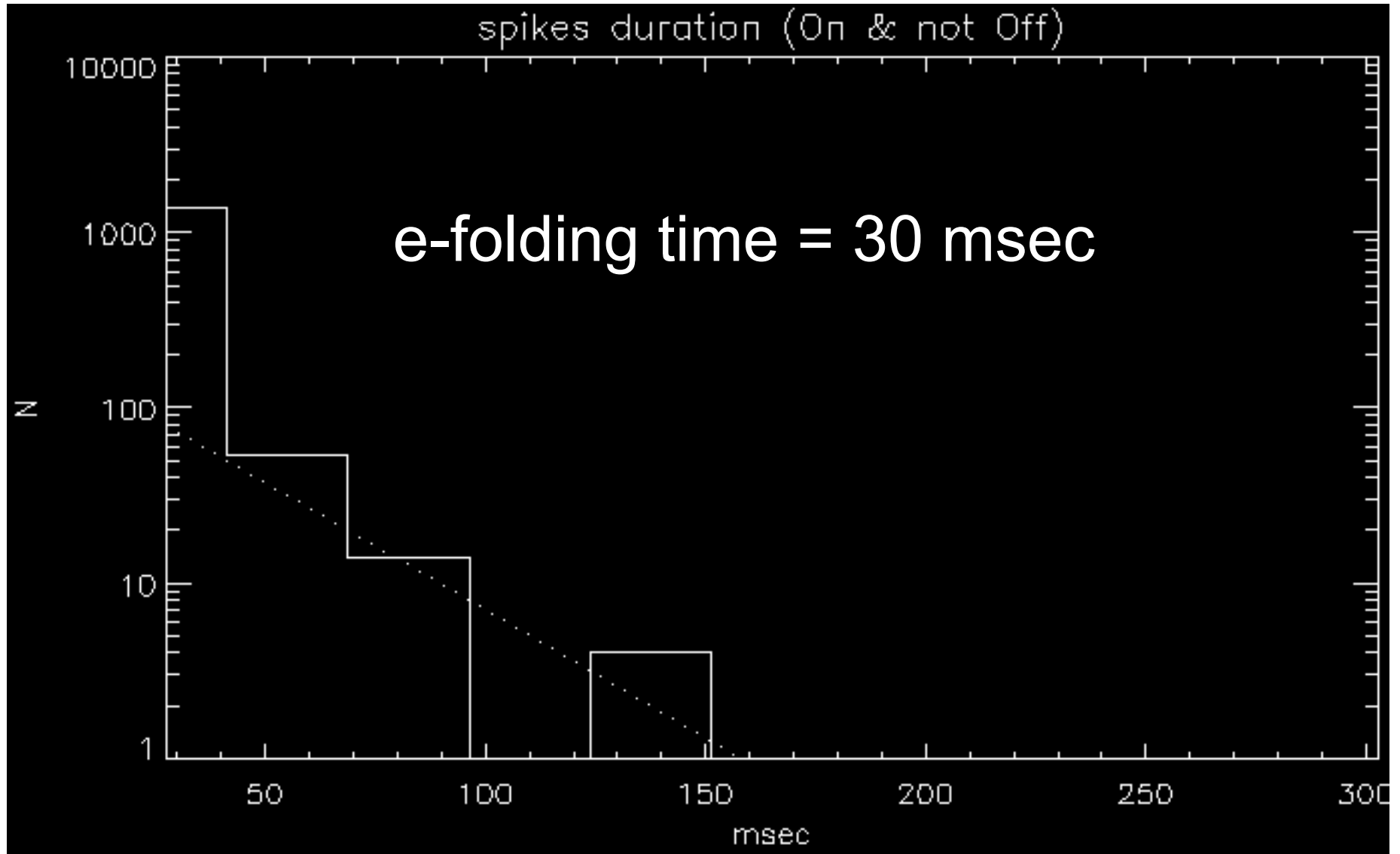
Comparing with Cassini data

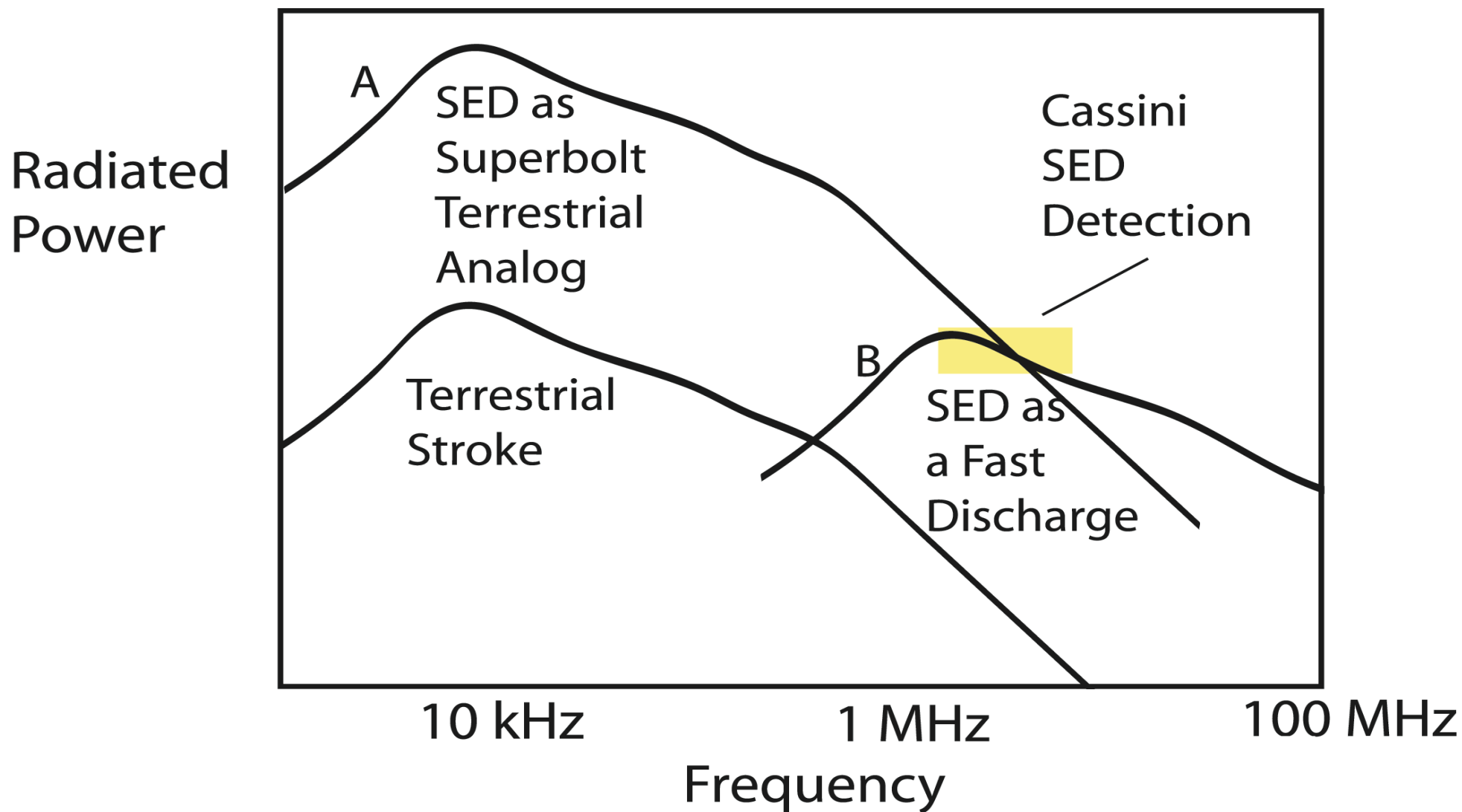


14:00

18:00

Spike duration (On & not Off)

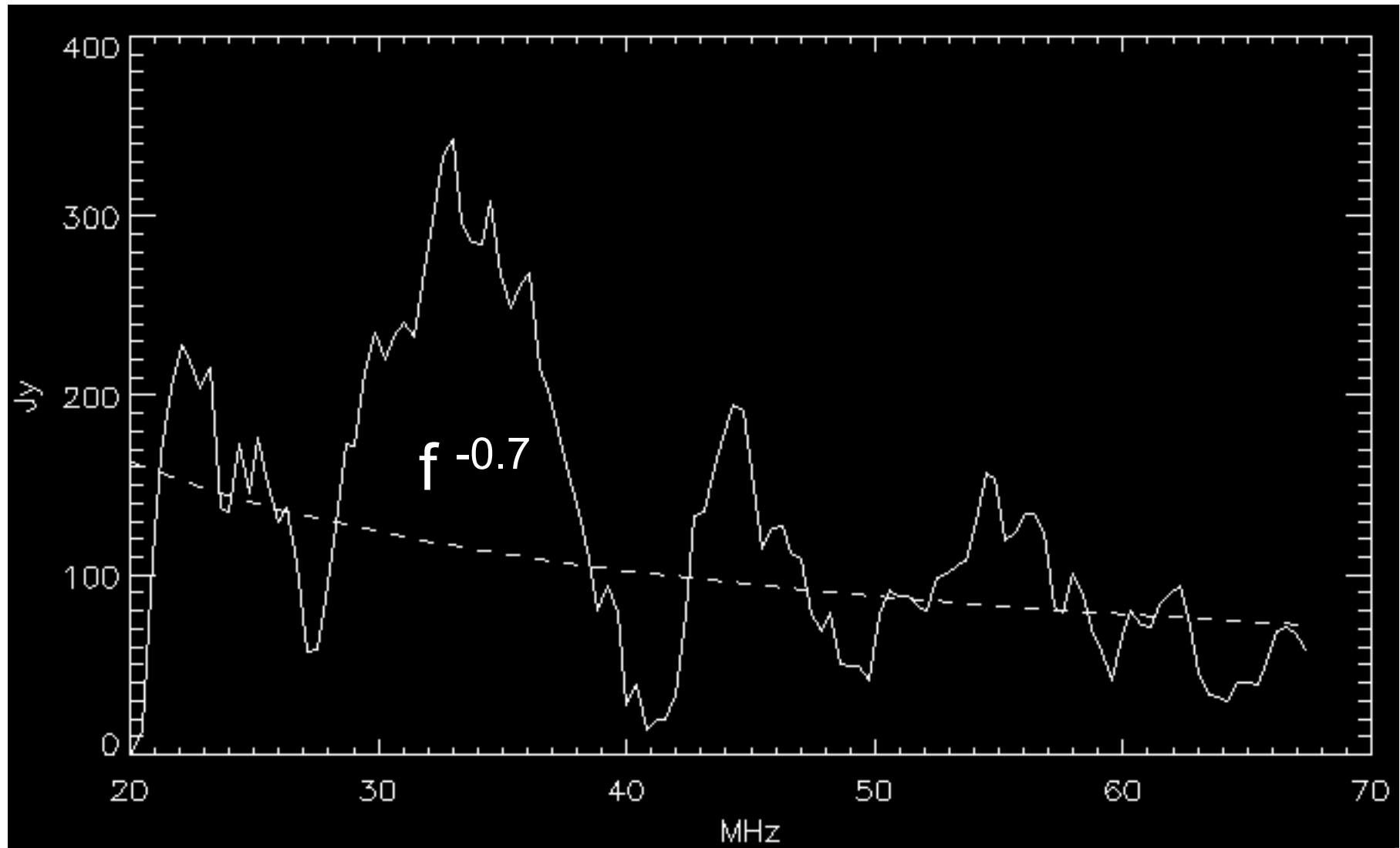




Flux observed about 10 MHz for Saturn's lightning (SED – in yellow) and the two possible interpretations (A) and (B).

(Farrell et al., 2007)

Power spectrum on 1 event



$$P \sim 1.8 \times 10^9 \text{ W}$$

$$E \sim 6 \times 10^7 \text{ J}$$

→ moderate, suggests fast strokes

→ check fine time structure of spikes (full-res TAB + TBB)

What's next?

Short term:

- New observations during strong emission at full time resolution (5 μ s)
- Correlation with Cassini: - Composite spectrum
- Event-to-event
- Reanalyse past data

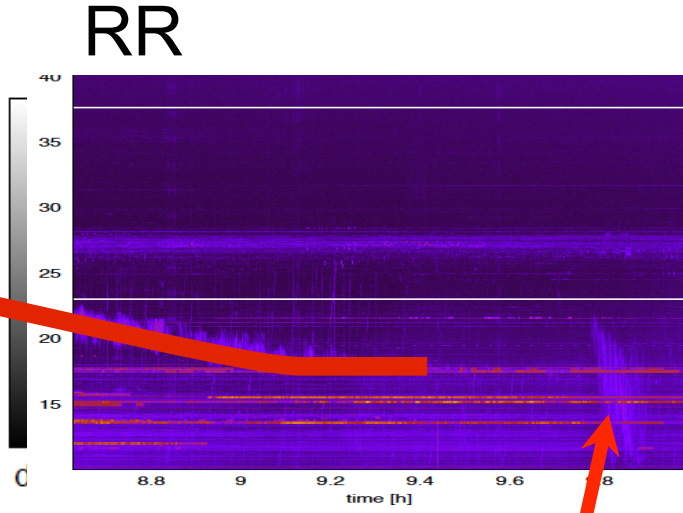
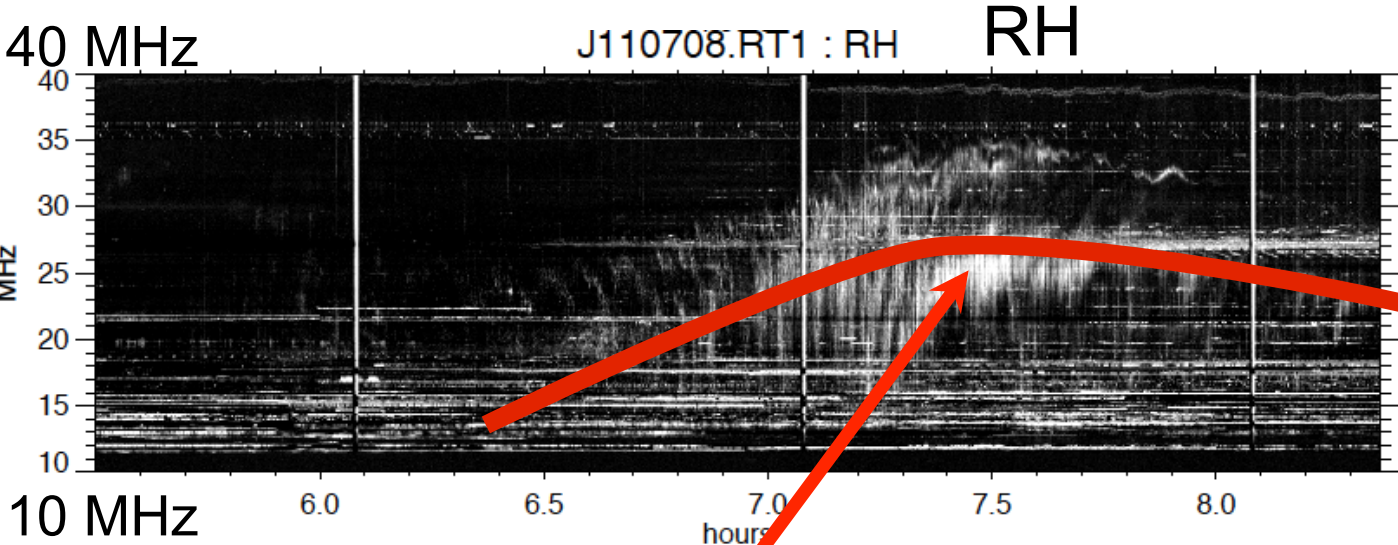
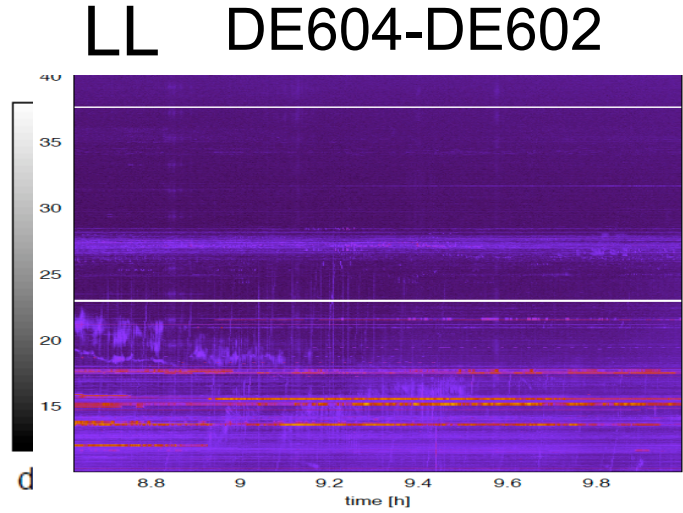
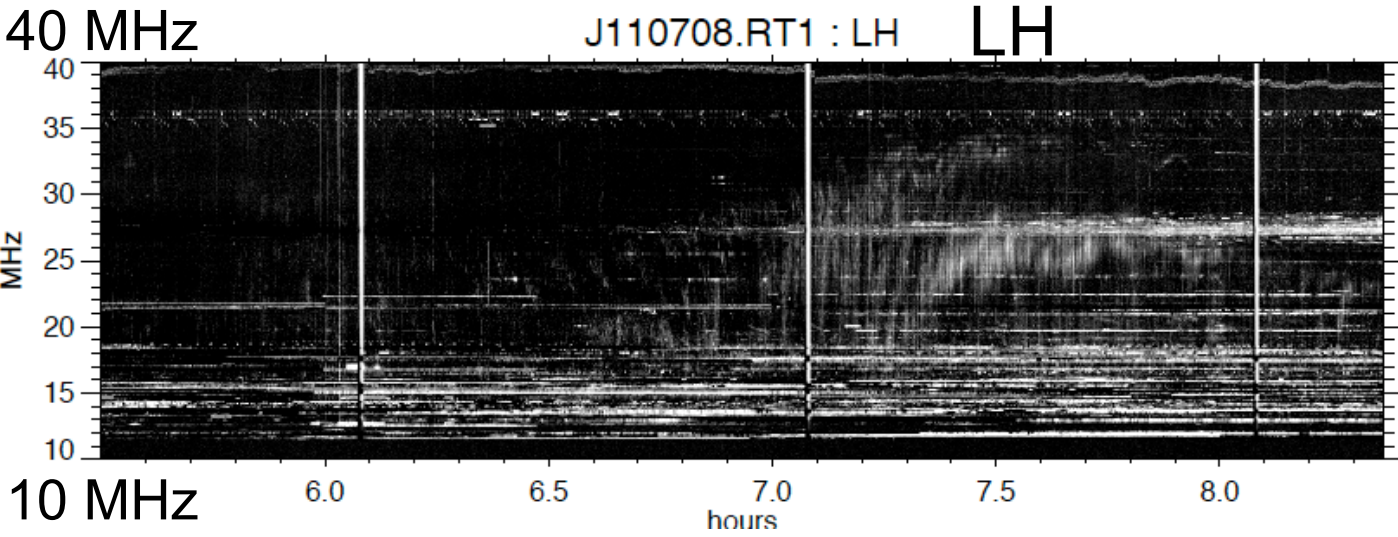
Mid term:

- Investigate lightning at other planets:
 - Uranus (UED seen by Voyager)
 - Venus (Controversial)
 - Mars (Dust devils discharges ?)

(Zarka, 2004)

Jupiter 8/7/2011 N_{stations} = 5
Nançay Decameter array (TAB mode)

LOFAR
(Correlation mode)



Io-Jupiter emission
RH elliptically polarized

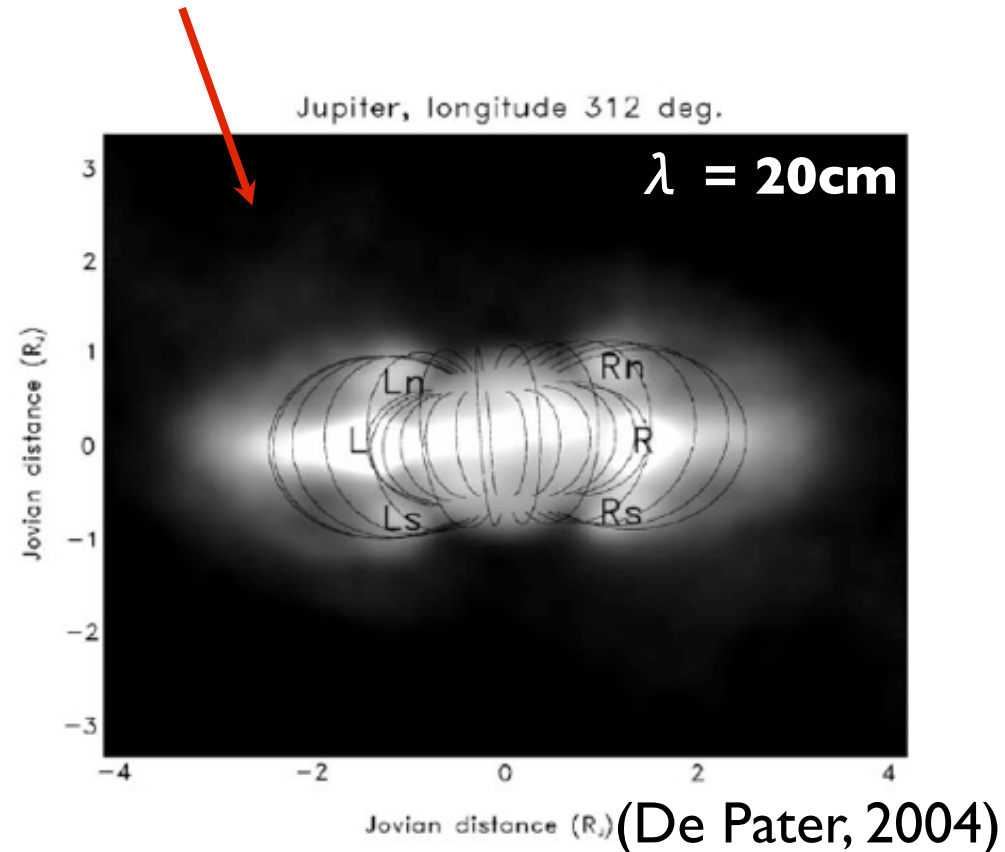
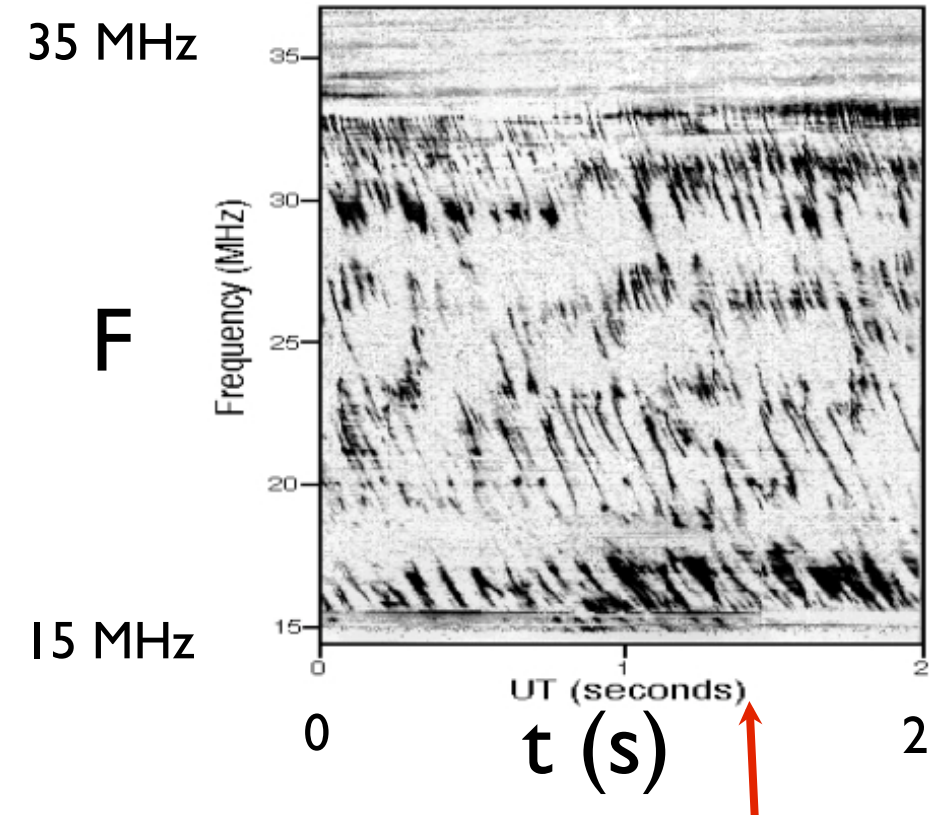
Jupiter's auroral emission
RH circular/elliptical

Credits: Olaf Wucknitz

Future plans for Jupiter

Using LOFAR in correlation mode

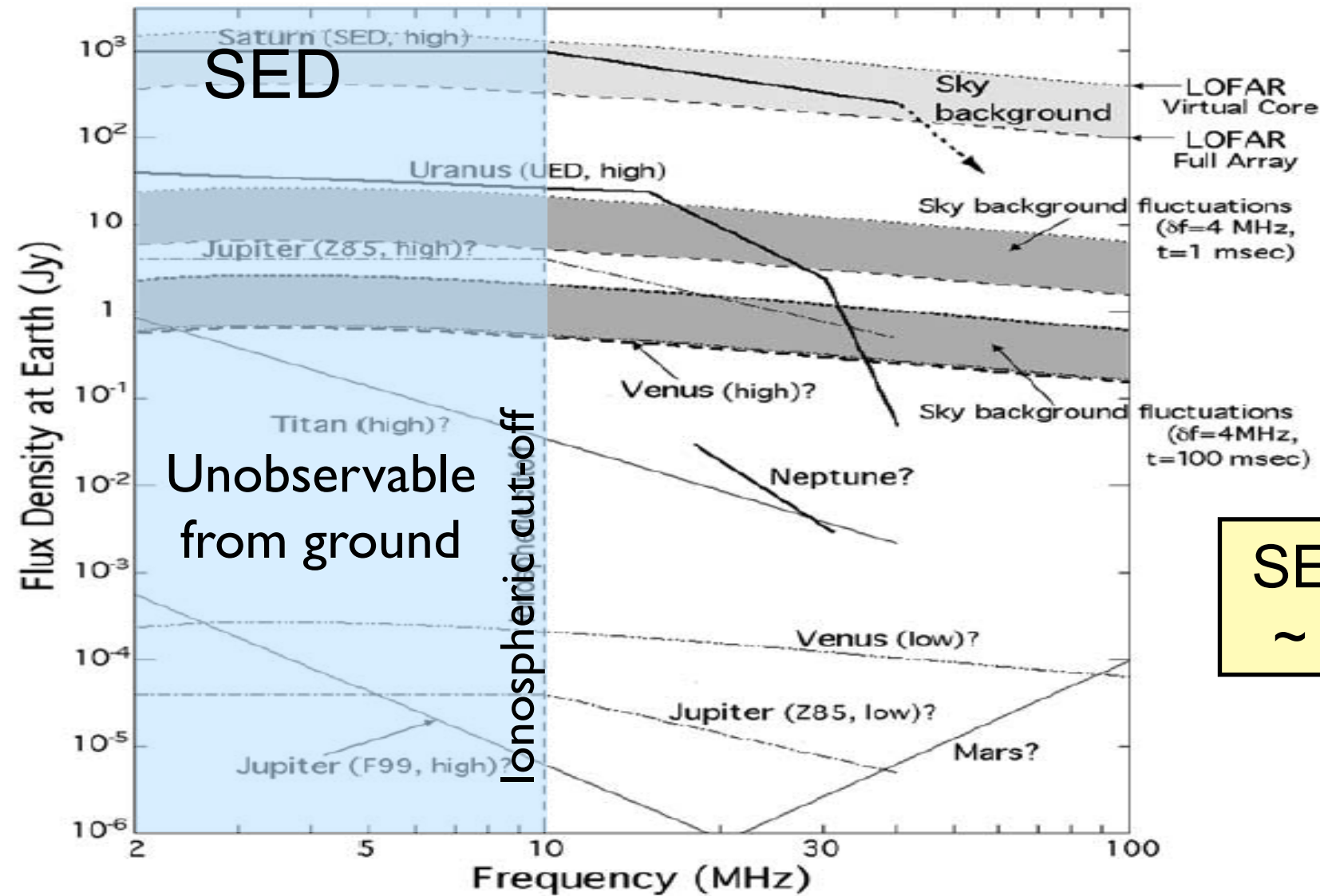
- Map synchrotron emission from Jupiter radiation belts in the HBA range.
→ *Define a correct calibration procedure*



- (Fast) Decameter radio sources astrometry in the LBA range

→ Tracing the quick flows of e^- along B field line

SED Detectability with LOFAR



SEDs @ Earth
~ 10-1000 Jy

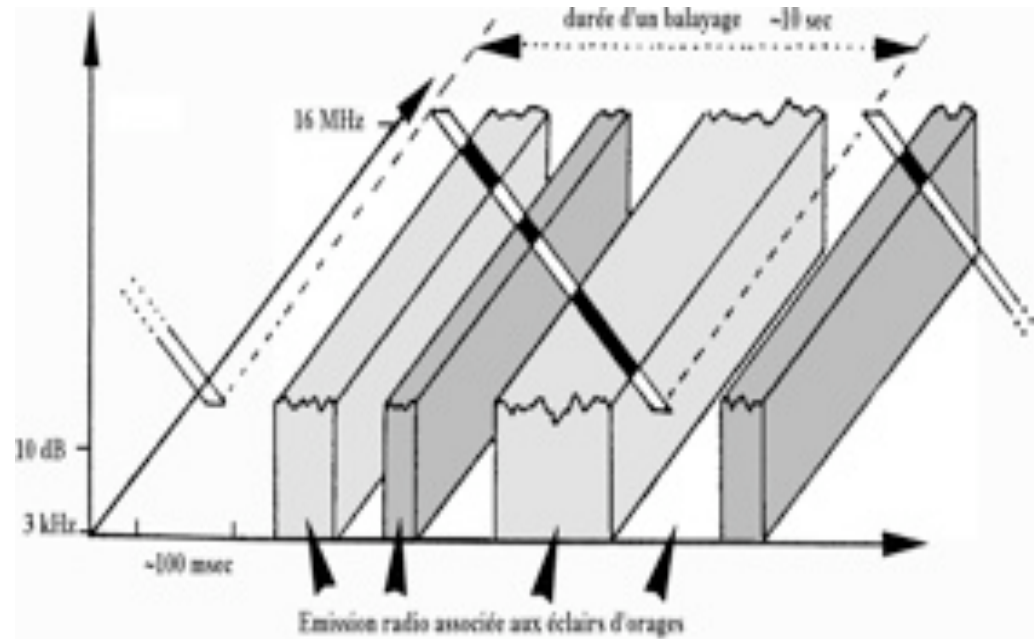
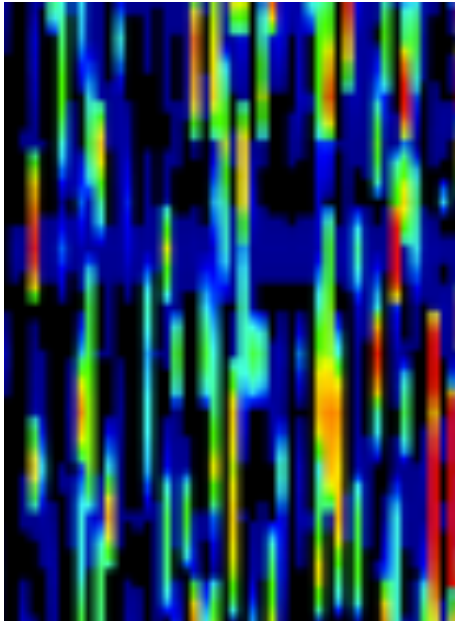
$$y = \frac{2k_b T_{sky}}{A\sqrt{b\tau}}$$

$$T_{sky} \approx \frac{1,15 \cdot 10^8}{f^{2.5}}$$

$$A_{1 \text{ Station}} \sim 48\lambda^2/3$$

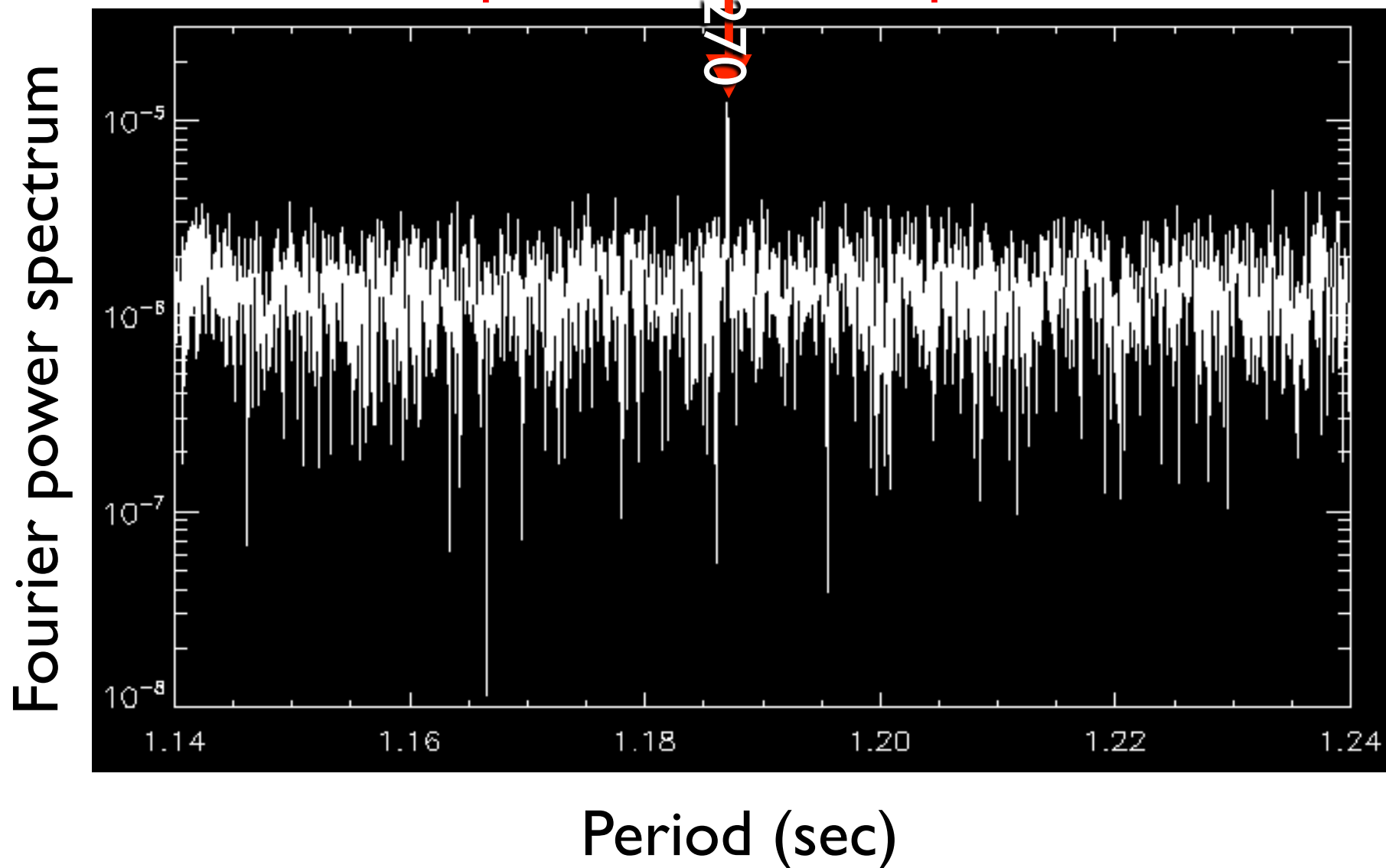
N _{stations}	f	b	τ	σ_{sky}
1 station	30 MHz	195 kHz	82 μ s	10^4 Jy
10 stations	30 MHz	6 MHz	20ms	37 Jy

- seen as narrow-band bursts by Cassini swept-frequency analyser



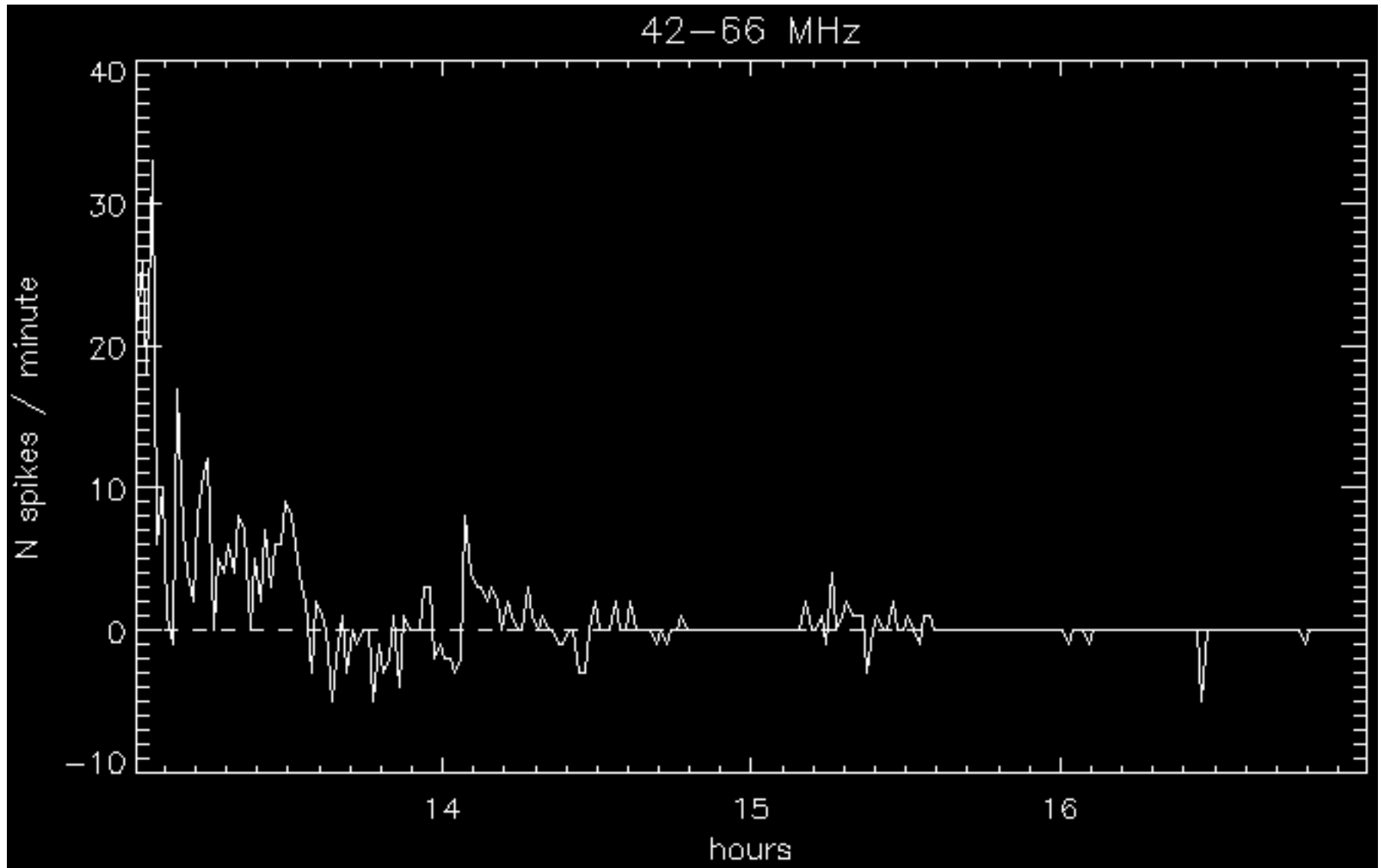
PSR I 133 in Off beam on 2010/12/18 (on unprocessed data)

expected PSR I 133 period

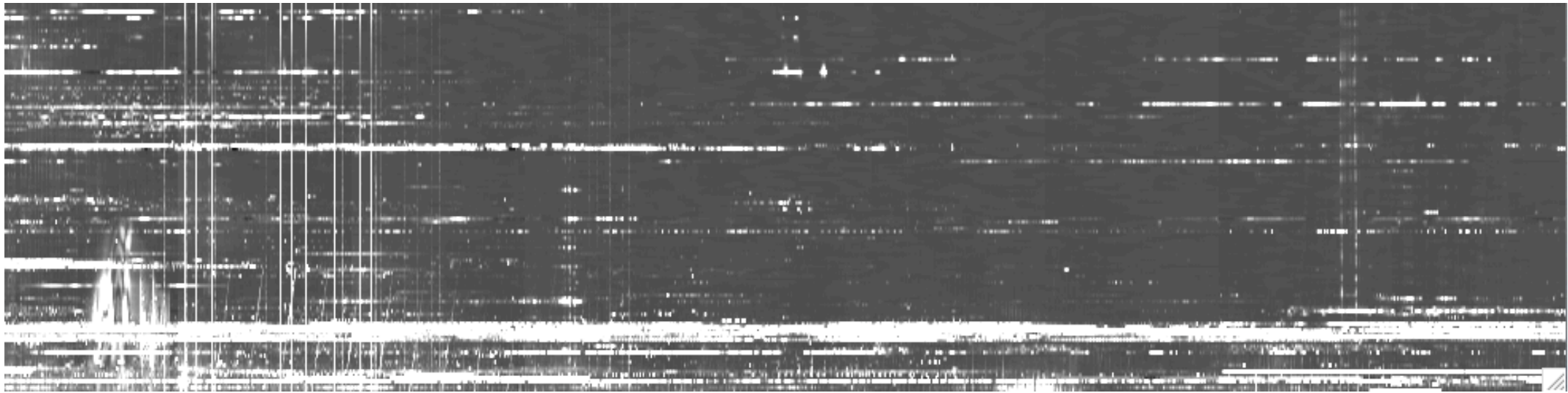


- PSR I 133 pulses recovered after manually folding off-beam data

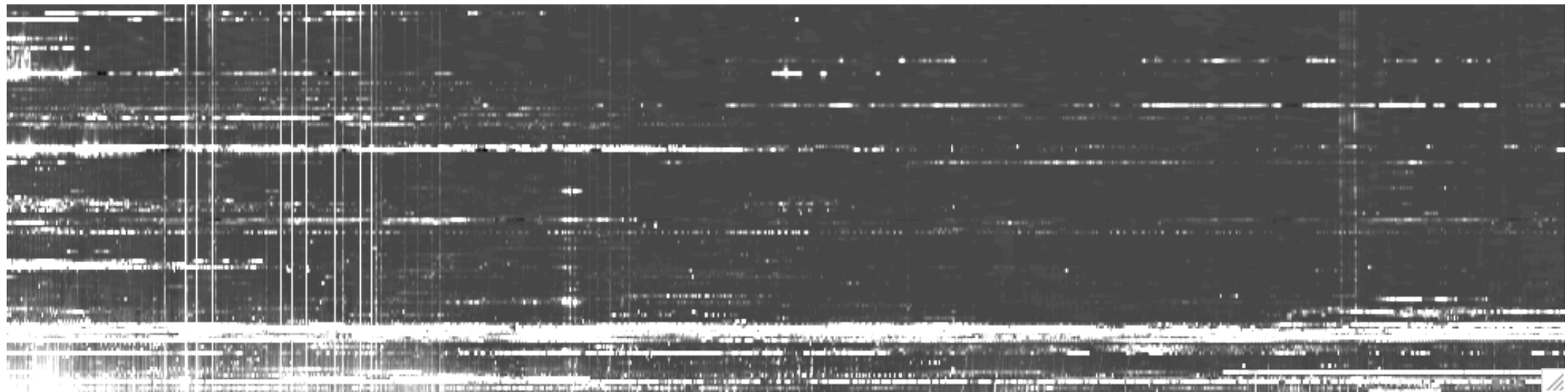
Excess number of On spikes appearing in ≥ 3 of the 5 upper bands



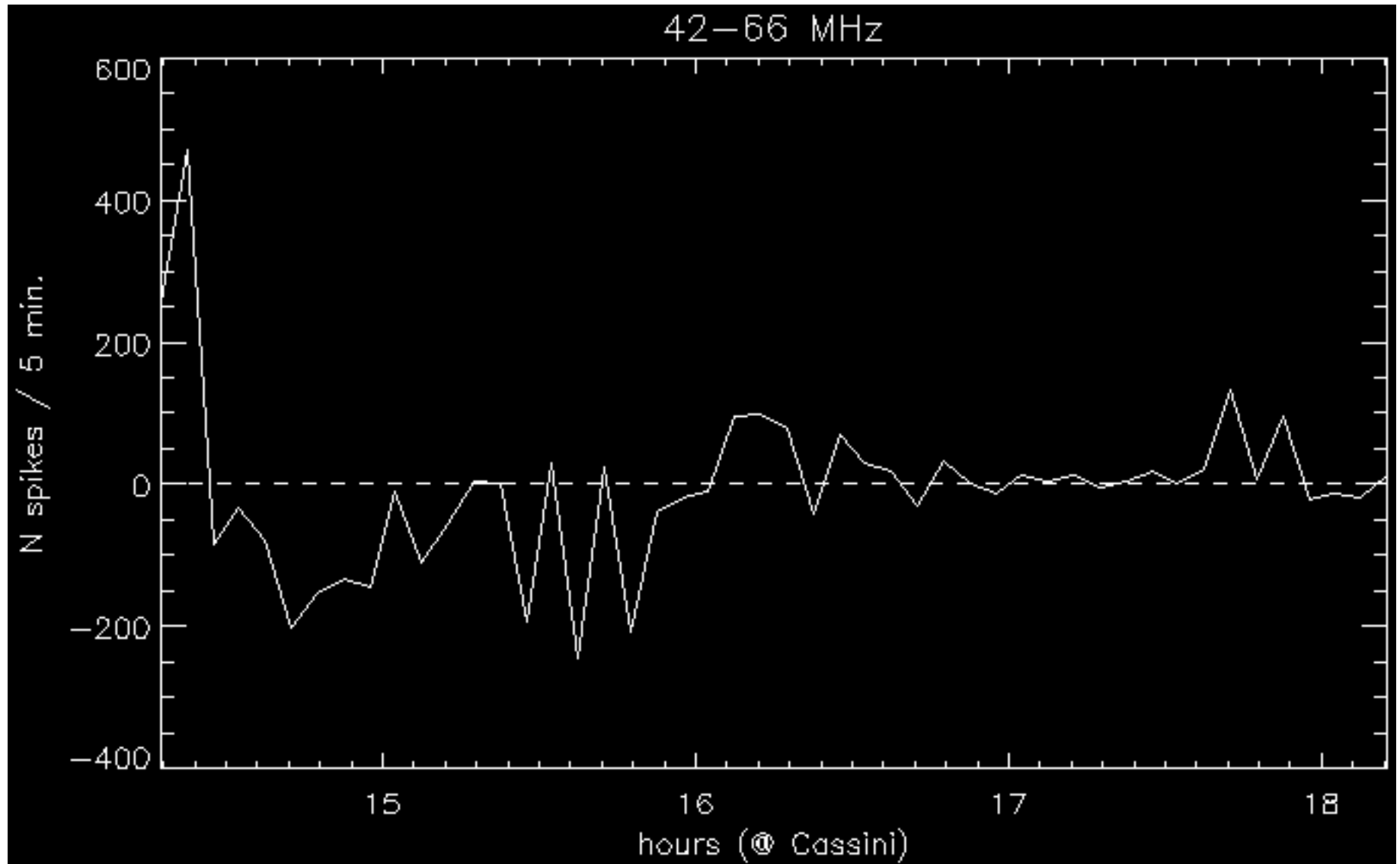
On



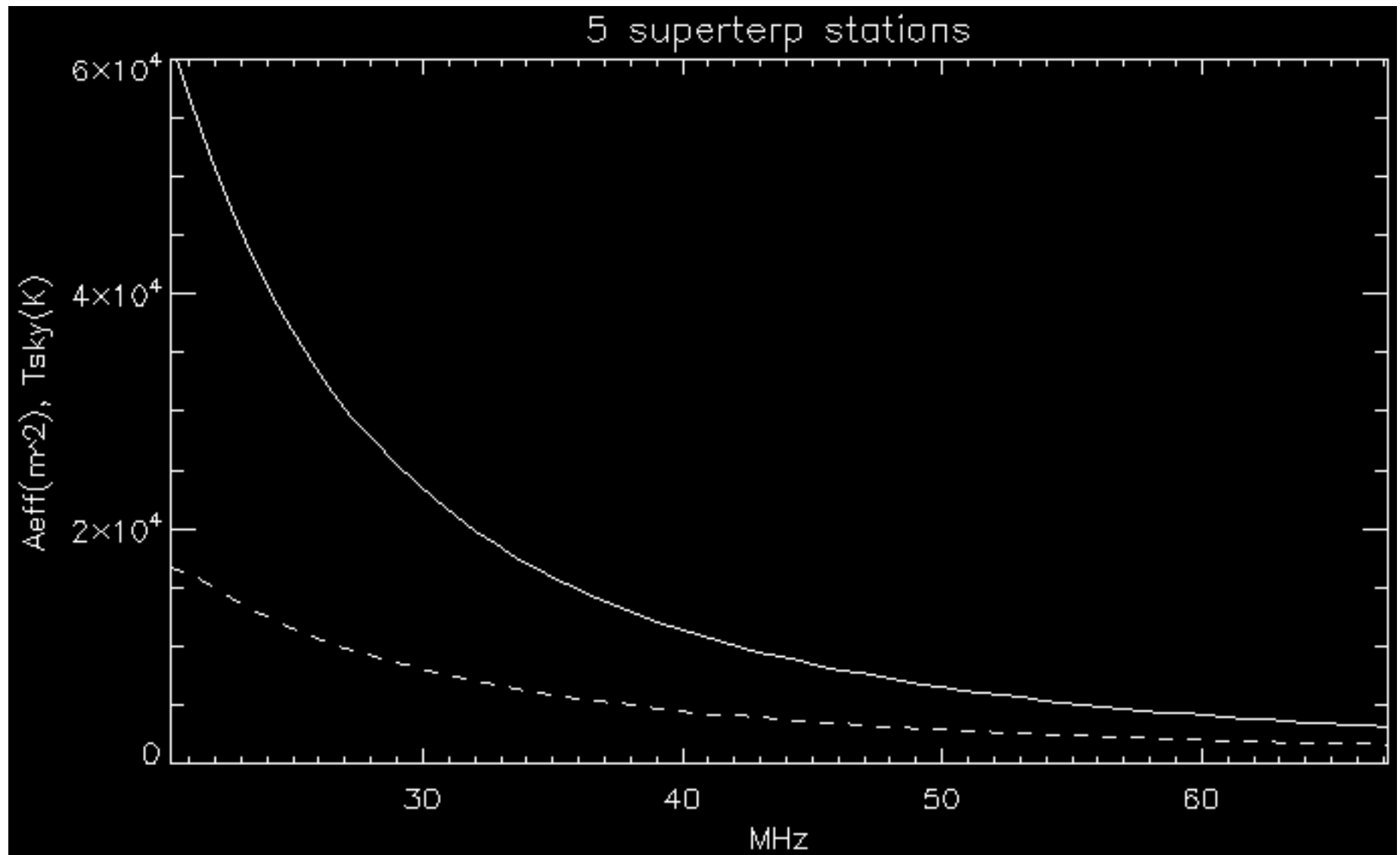
Off



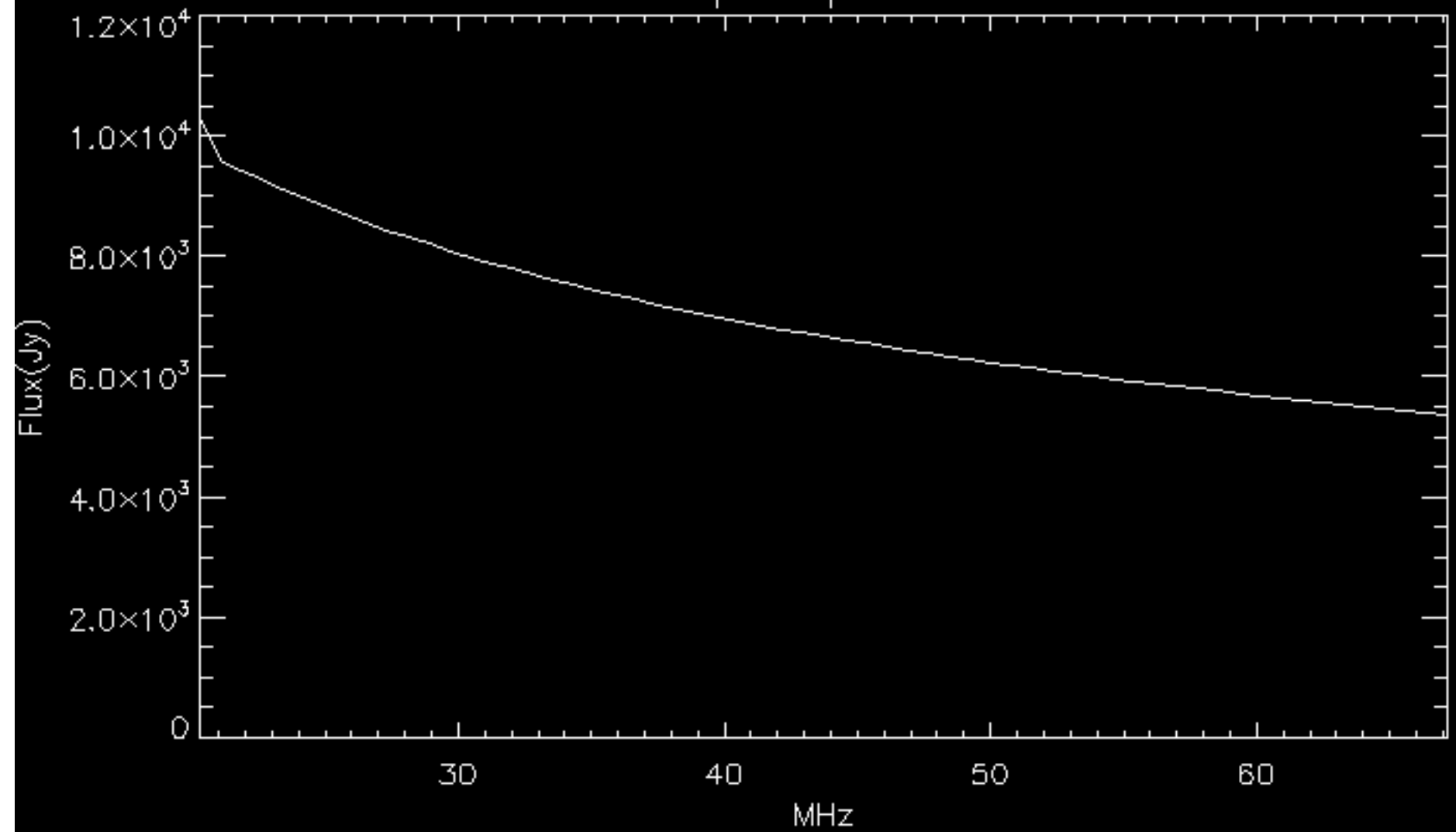
Uncleaned data



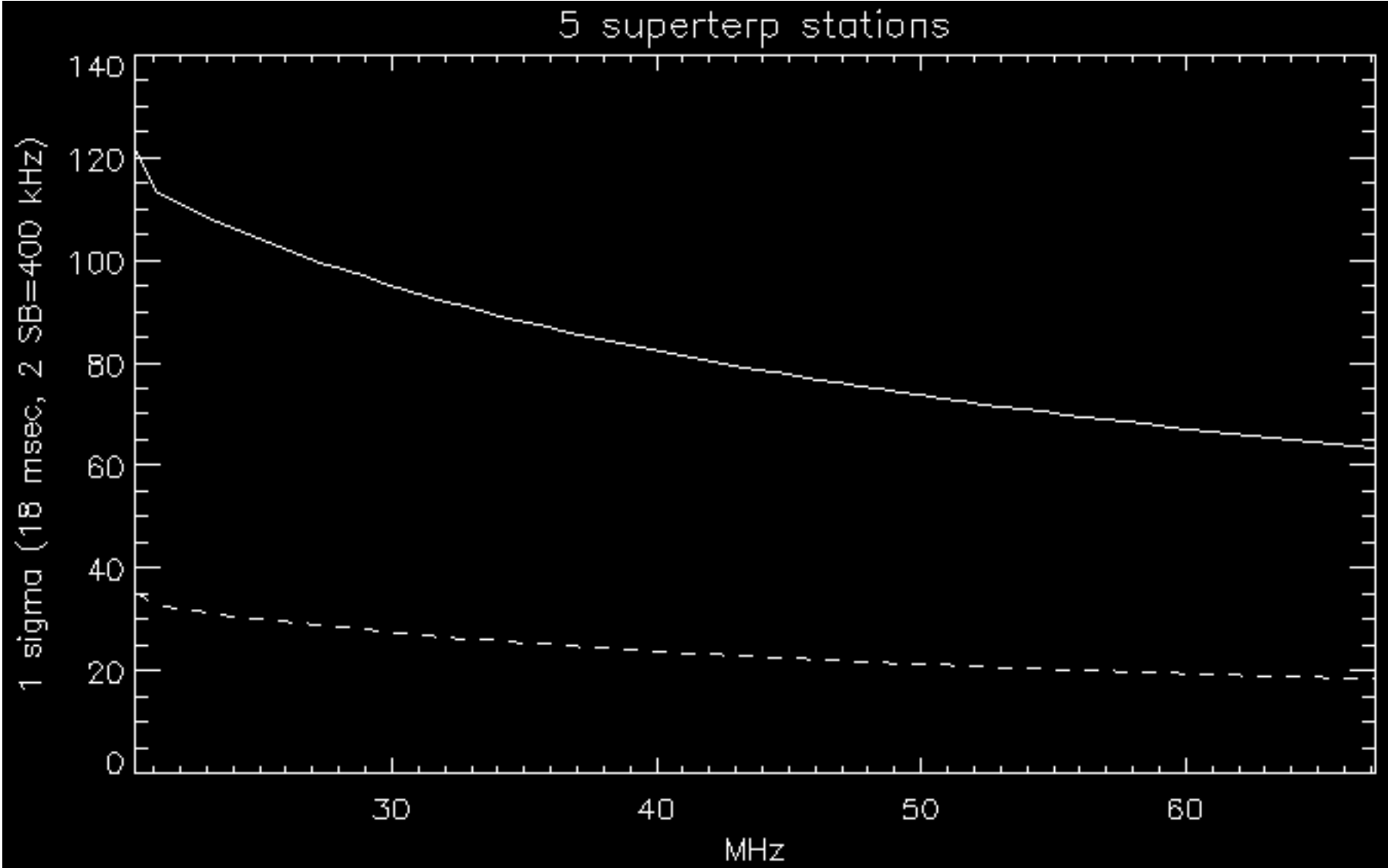
max(A_{eff}) & A_{eff} with overlaps



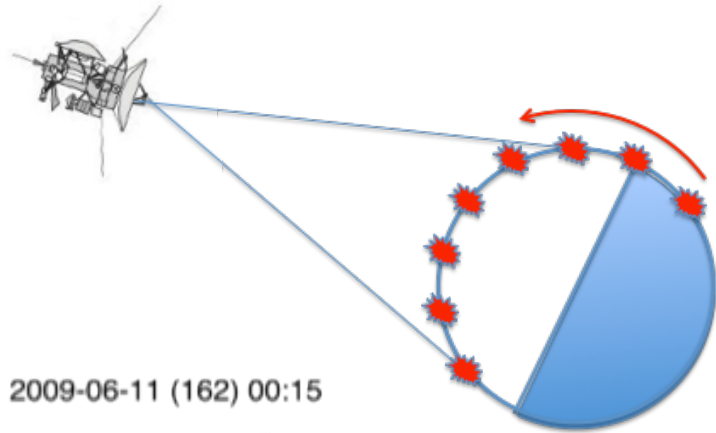
5 superterp stations



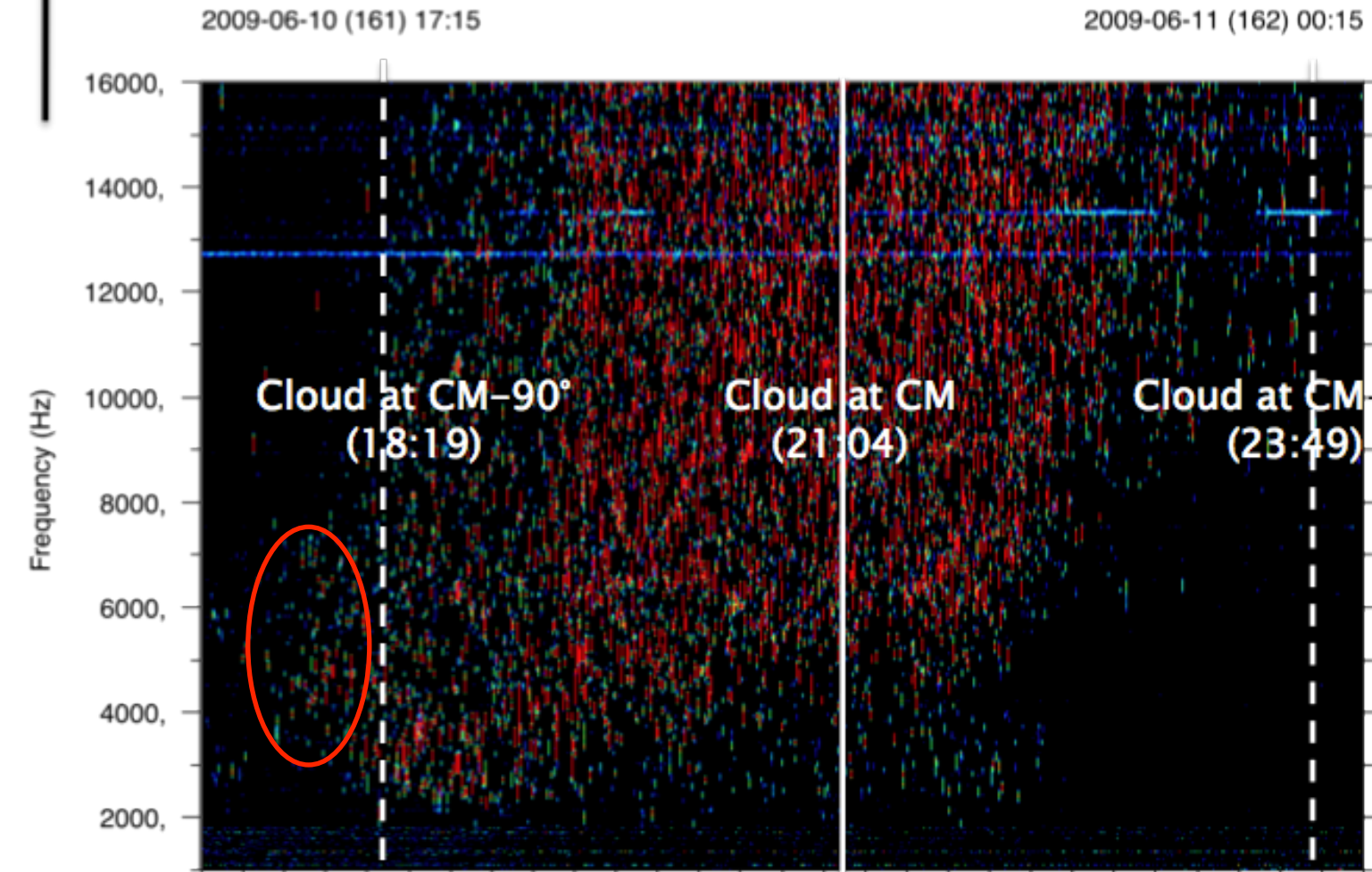
$$2kT/A * I / (\text{sqrt}(b * \text{tau}))$$



Over-the-horizon effect



f ↑

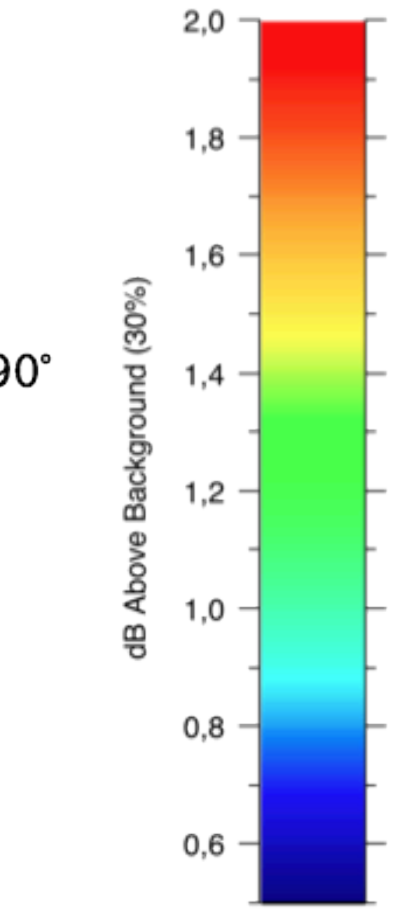


Cloud at CM-90°
(18:19)

Cloud at CM
(21:04)

Cloud at CM+90°
(23:49)

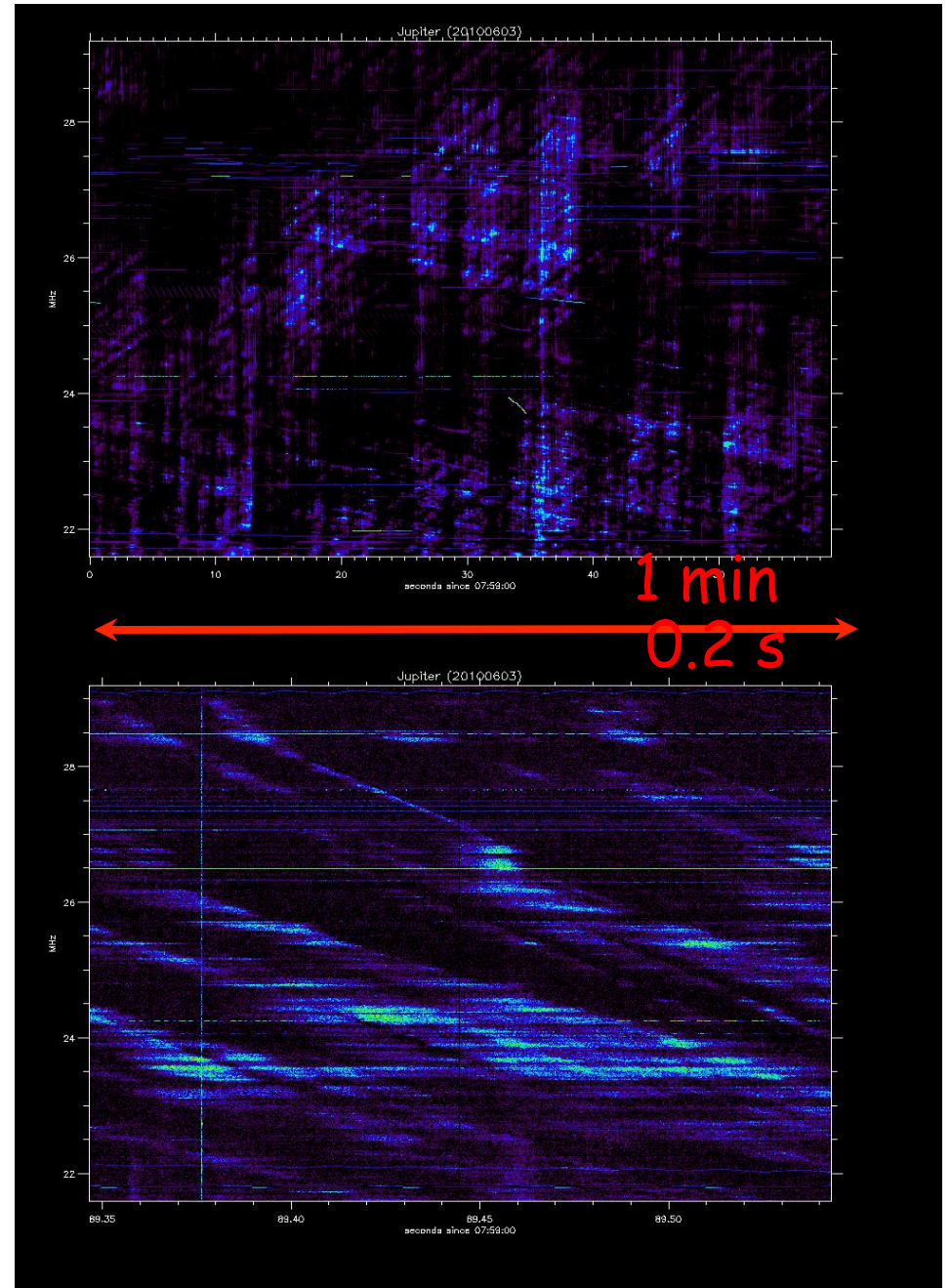
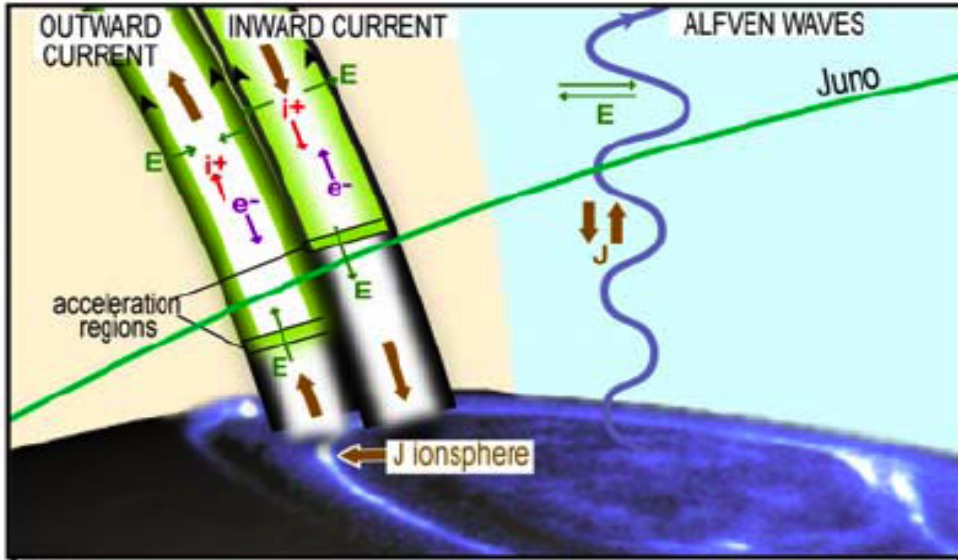
	18:00	19:00	20:00	21:00	22:00	23:00	00:00
R_s	13,12	13,32	13,53	13,73	13,94	14,15	14,35
Lon	255,33	287,94	320,55	353,18	25,82	58,48	91,14
Lat	18,18	19,69	21,15	22,55	23,91	25,21	26,48
LT	10,77	10,85	10,93	11,00	11,08	11,15	11,23

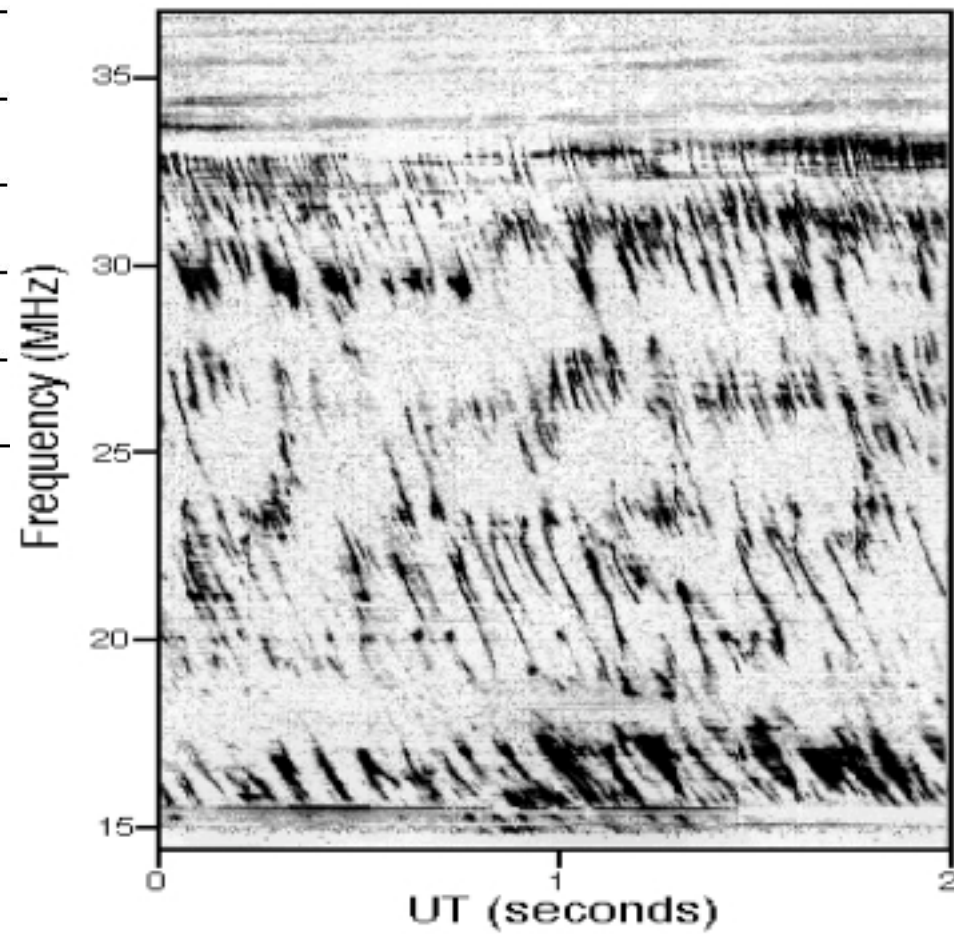
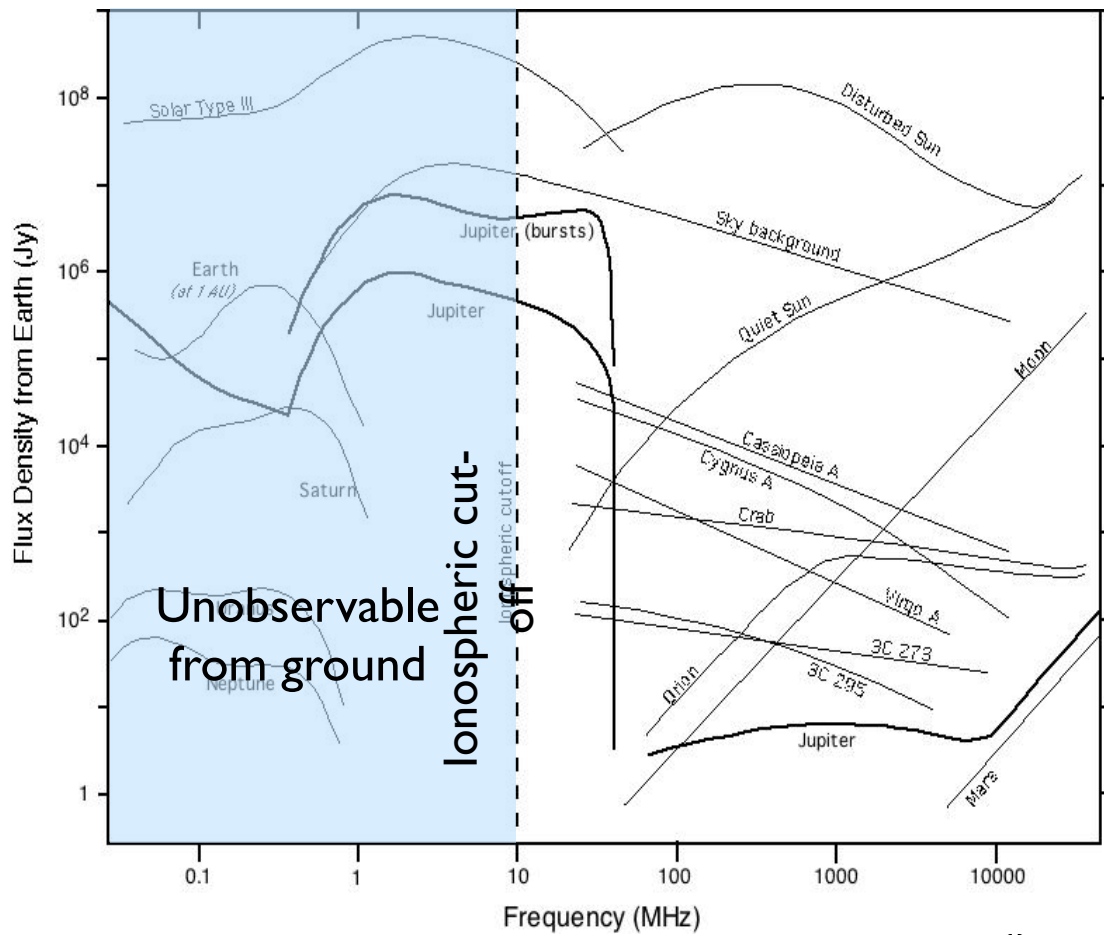


t →

Credits: A.-L. Gautier

Jupiter





S-Bursts