UTR-2 : Capabilities and Prior Observations

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Decameter wave observations :

- Bright sky background
- Ionospheric perturbations
- RF Interference (man-made)

® Required large area, high resolution, broadband, « flexible » instrument

→ **Ukrainian T-shape Radiotelescope, mark 2**

- S_{min} ~10 Jy
- Δf = 10-25 MHz (7-35)
- multi-beam
- resolution (beam size) ≤ 1°

→ Survey of discrete radiosources $-10° \leq \delta \leq +80°$

DECAMETRIC SURVEY OF DISCRETE SOURCES IN THE NORTHERN SKY

I. *The UTR-2 Radio Telescope.*
Experimental Techniques and Data Processing

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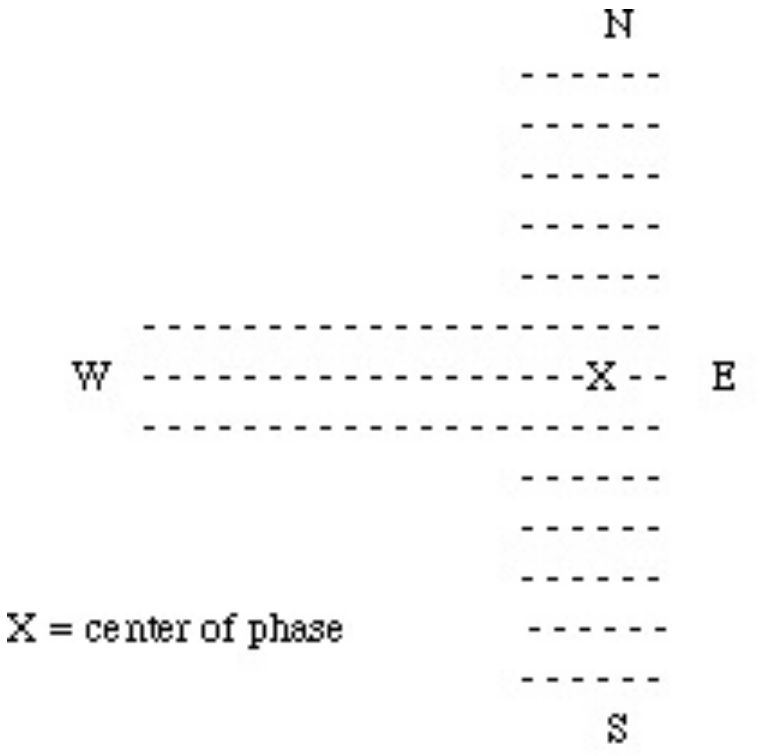
Astrophysics and Space Science **54** (1978) 3–36

- T-shape
- NS branch : 1440 dipoles in 1860 x 50 m^2 (6 rows)
- EW branch : 900 dipoles in 900 x 50 m^2 (6 rows)
- Field : |cos(el)sin(az)) ≤ 0.84, all elevations



- Broadband dipoles 8 x 1.8 m, at 3.5 m height
- EW linear polarization
- steel, zinc-coated wires, 8mm diameter

- multi-step 2D phasing (time delays)
- 2048 beam positions NS, 1024 EW
- time stepping ~2 min for source tracking
- electrical pointing (quasi-instantaneous)

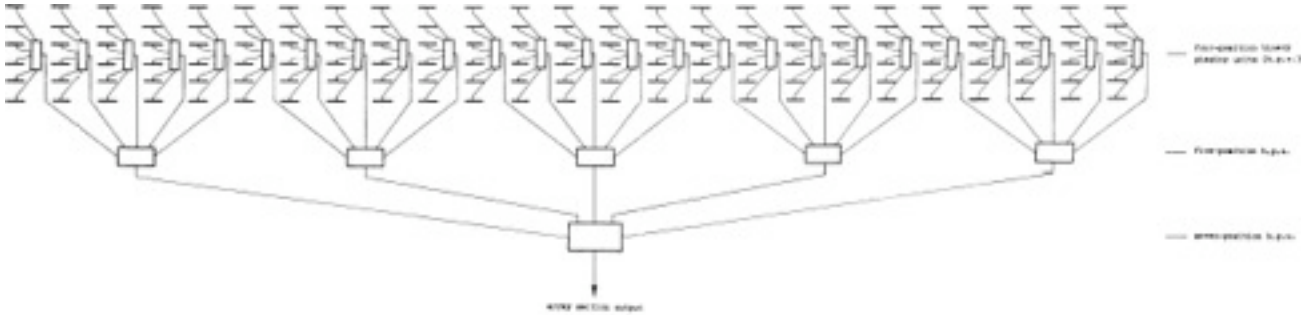


Fig. 3. A diagram of the east–west array section.

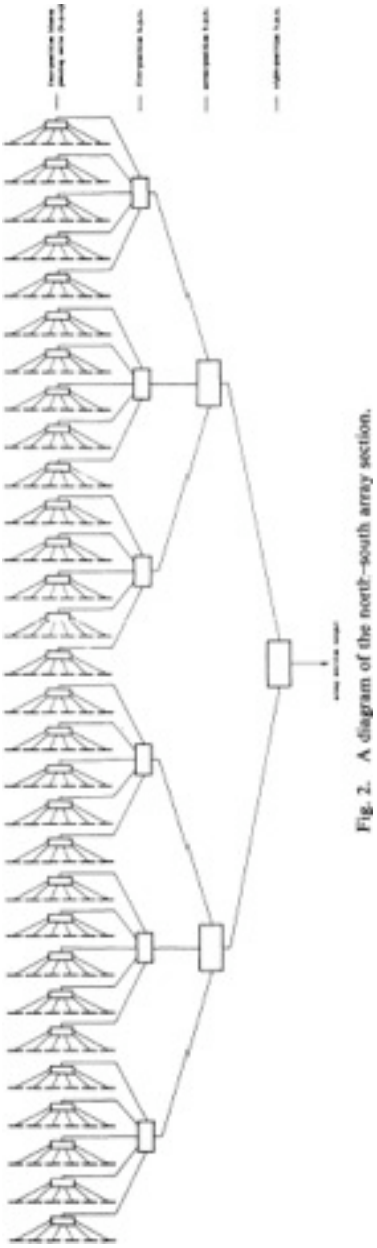


Fig. 2. A diagram of the north–south array section.

- EW beam :
  ~1° (EW) x ~10° (NS)

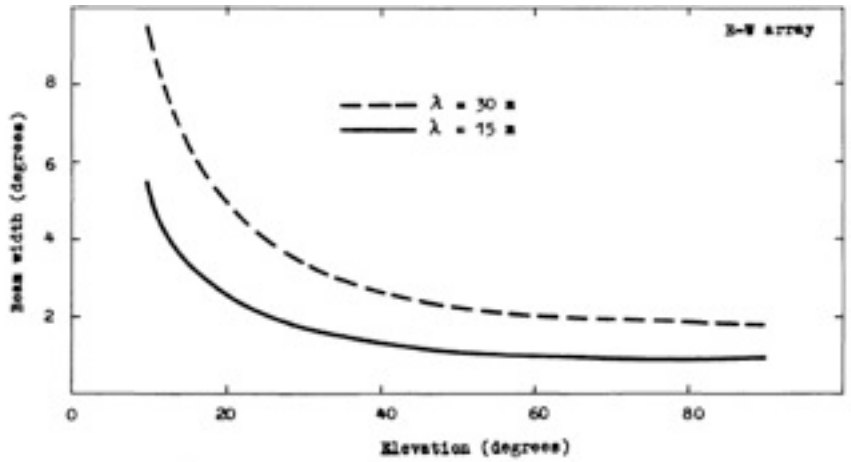


Fig. 10. The parallel-plane beam width of the east–west antenna in dependence of the elevation.

- NS beam :
  ~30′ (NS) x ~10° (EW)

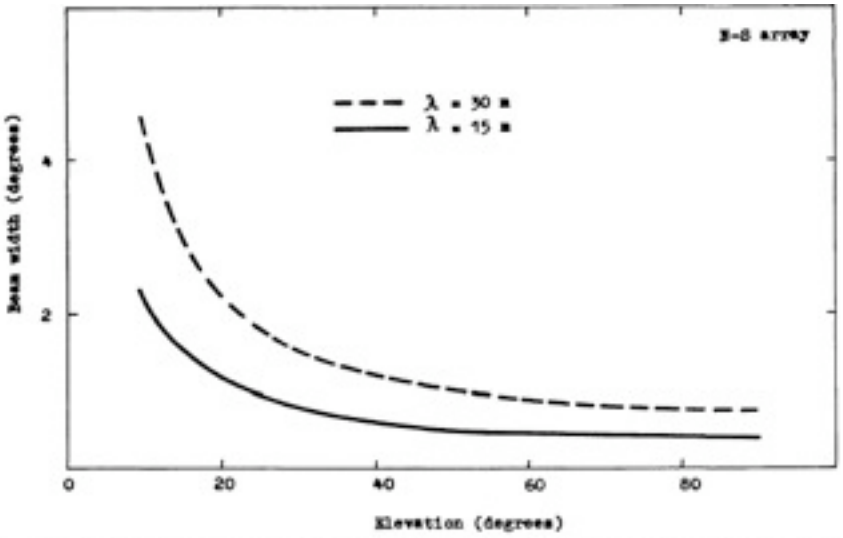


Fig. 9. The meridional-plane beam width of the north–south antenna in dependence of the elevation.

- 5 phasing schemes in parallel

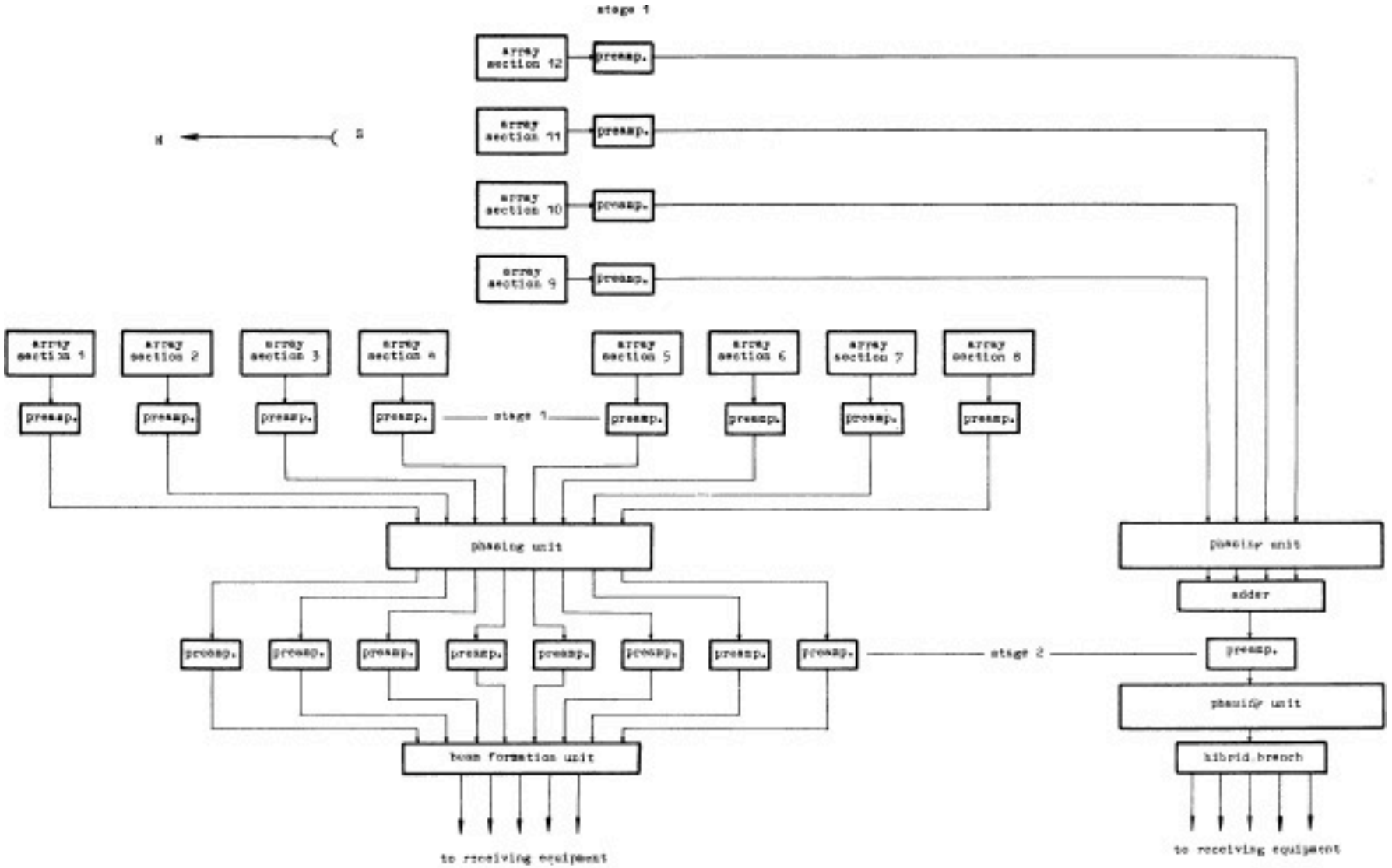


Fig. 4. Phasing and amplification of the section signals.

→ 5 beams in the sky (NS & EW)
(possibility for 25 pencil beams)

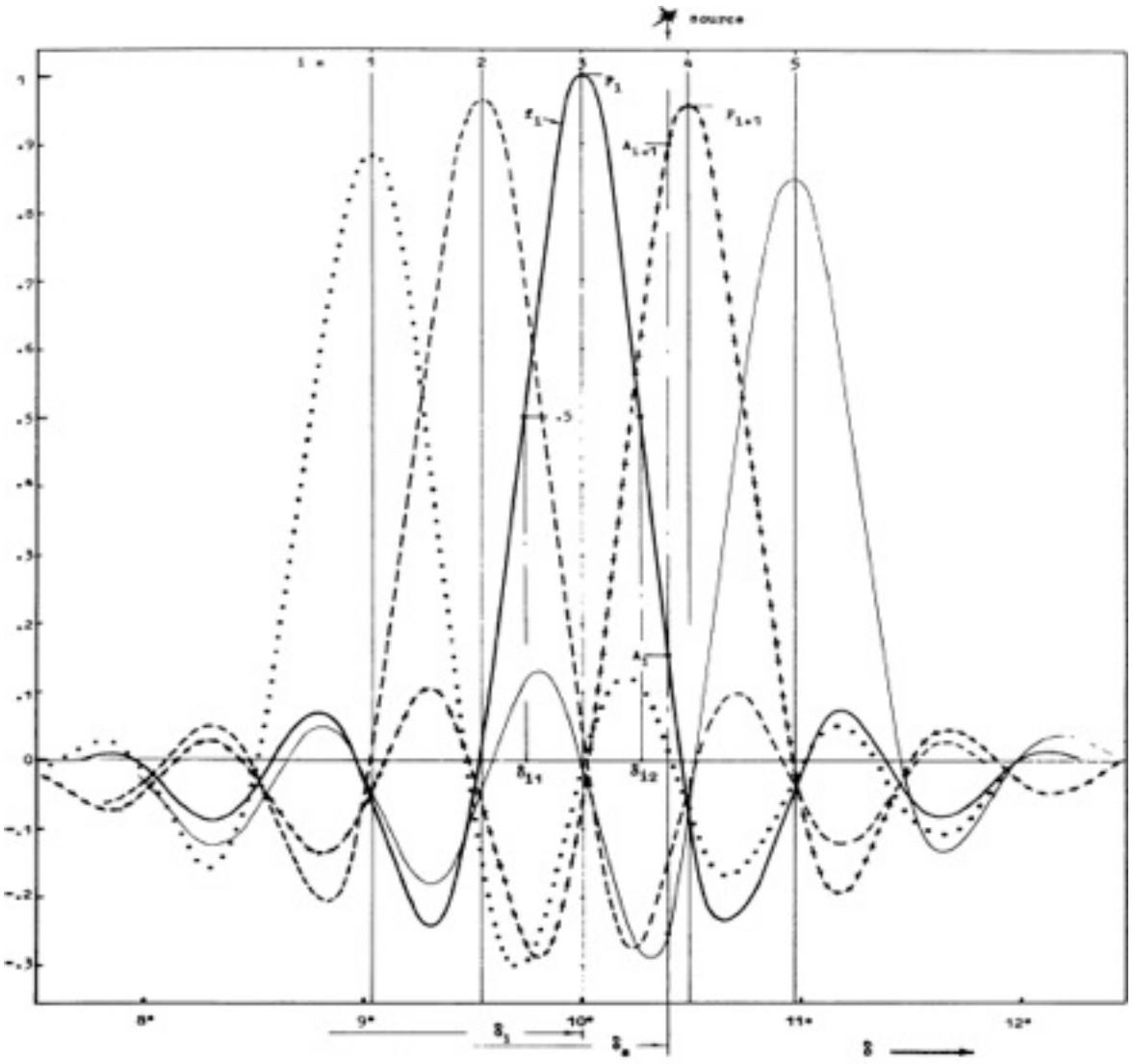


Fig. 5. Five-beam pattern of the north–south array.

UTR-2 array :

- A = 93000 m^2 (NS) , 45000 m^2 (EW)
- efficiency η ~ 0.1
- $A_e = A\,\eta$ = 7000 m^2 (25 MHz) - 15000 m^2 (10 MHz)
- Directive gain D ~ $10^4 = 4\pi/\lambda^2\,(A_e/\eta)$

® as galactic background limitates sensitivity (receiver noise negligible), area to take into account is $A=A_e/\eta$

(we have measured A~60000 m^2 at 25 MHz with Cyg.A)

Receivers (originally)

- >30 dB linearity (amplification/reception)
- 6 narrowband tunable receivers (δf = 3-15 kHz) per beam
  + pen-plotters / analog recorders / digitization → tape

- sensitivity limited by sky background noise / confusion

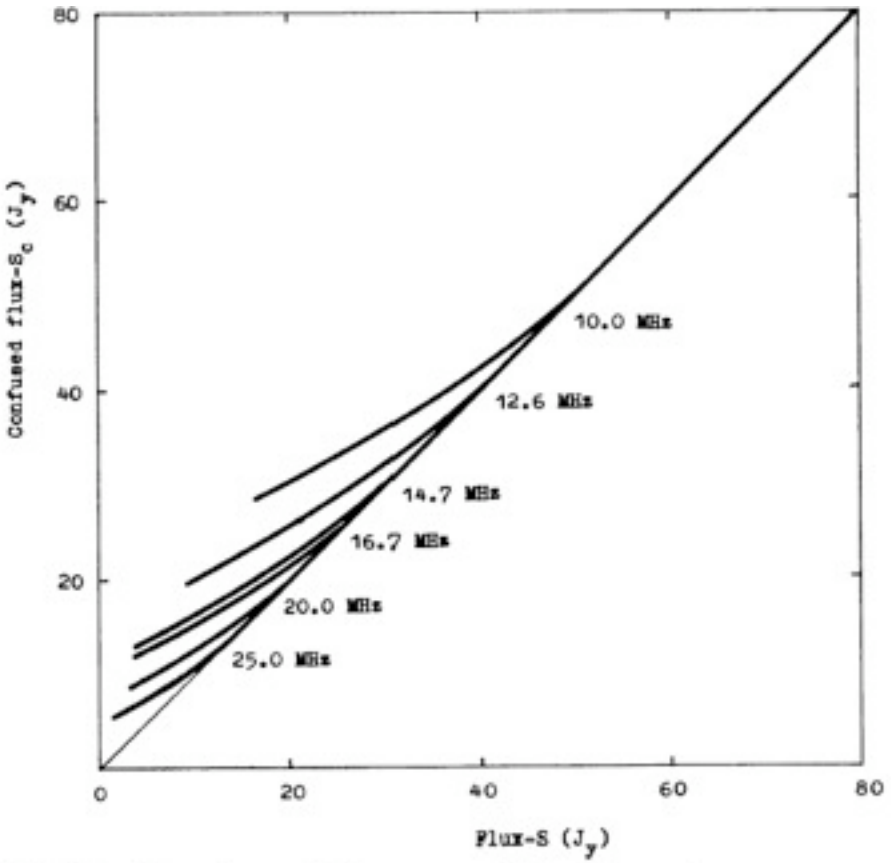
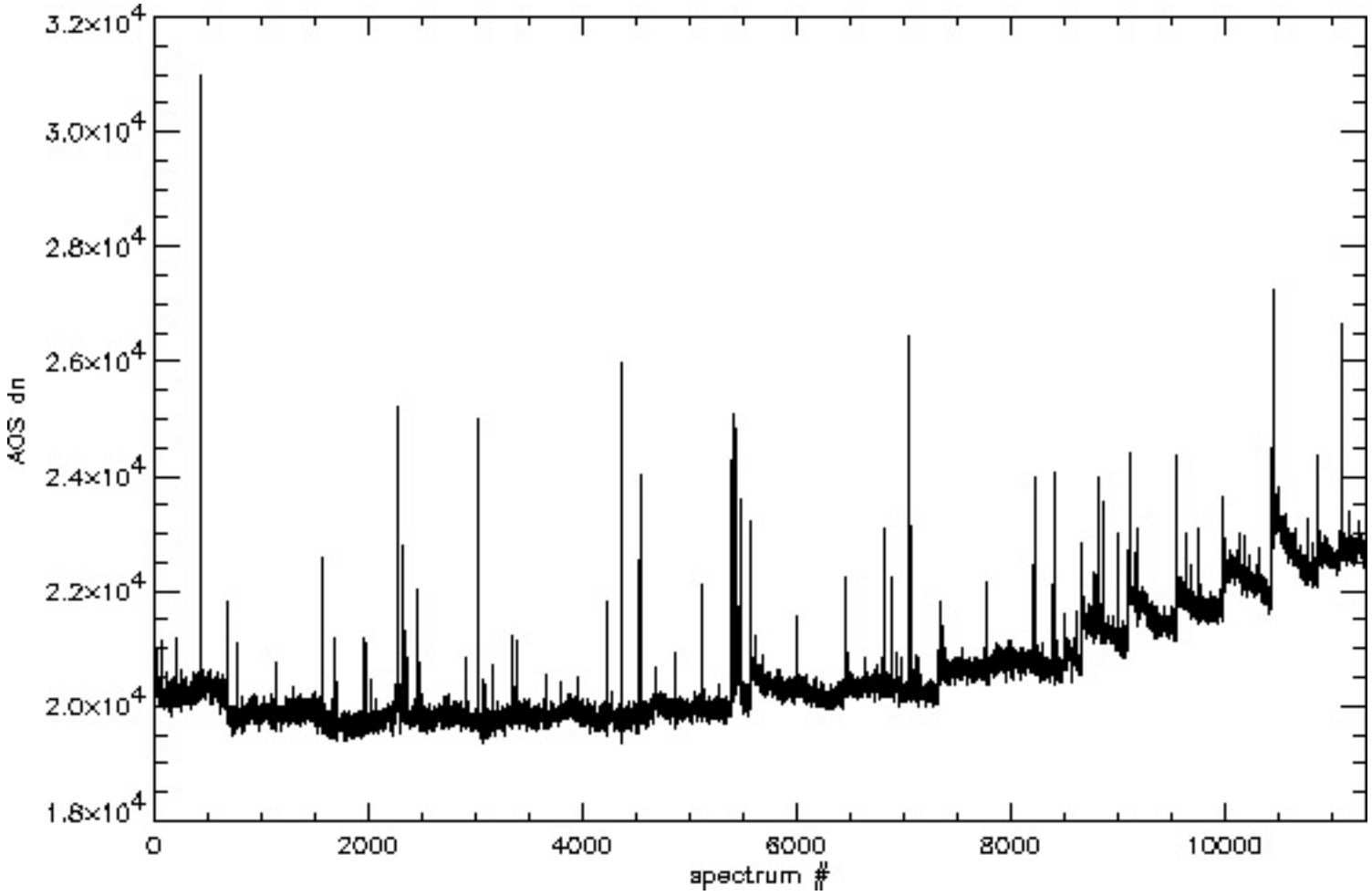


Fig. 16. The dependences of the mean confusion flux on the source group vs true flux.

Frequency	σ_c (Jy)
10	22
12.6	17
14.7	13
16.7	12
20	8
25	5

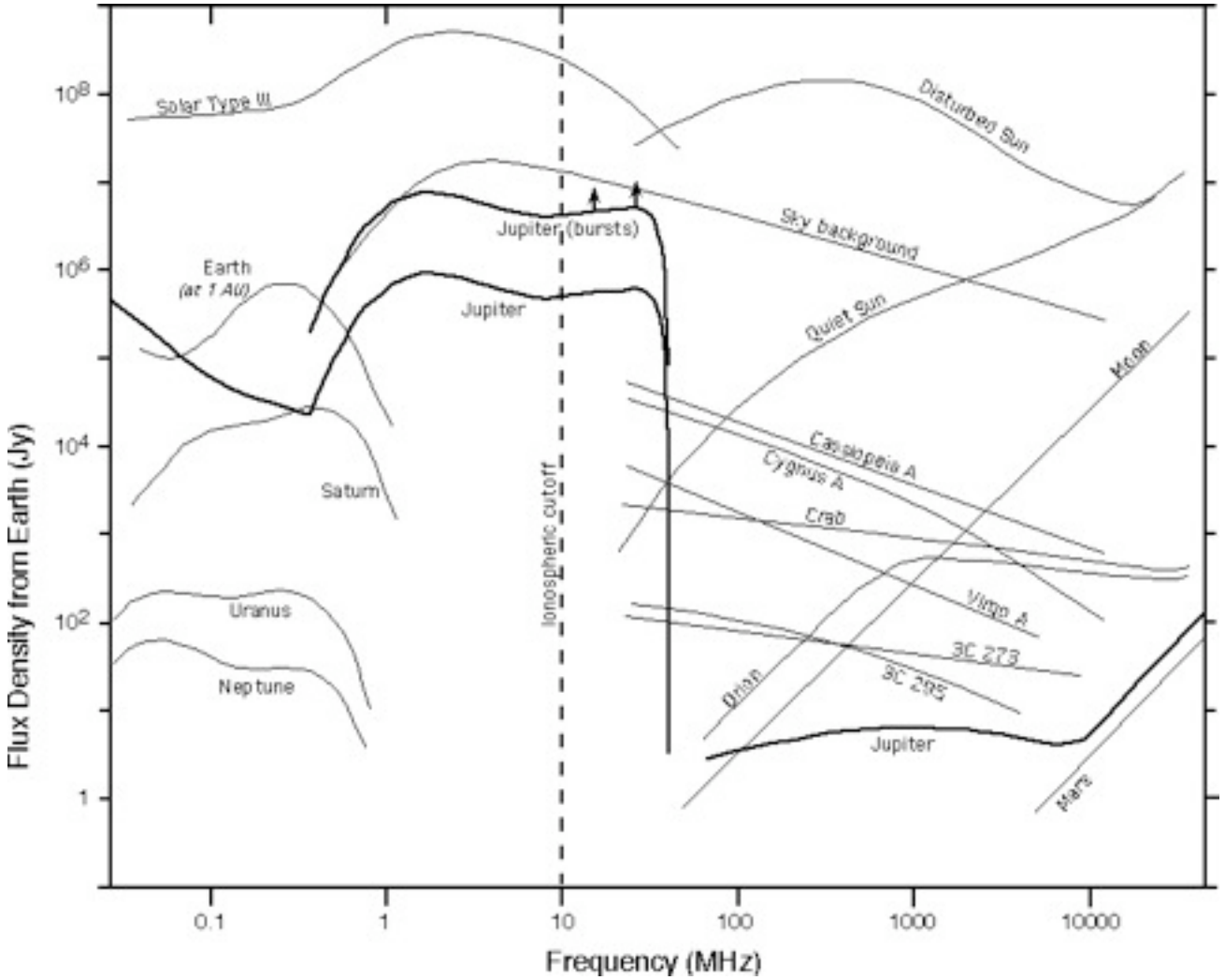
$(b\tau)^{1/2}$~300
(10 kHz x 10 s)

- noise source for calibration + *AGC*



Prior observations :

- Spectra of typical radio sources
- Sky background T ~ $1.15 \times 10^8 / f^{2.5}$
- Solar and planetary emissions very intense

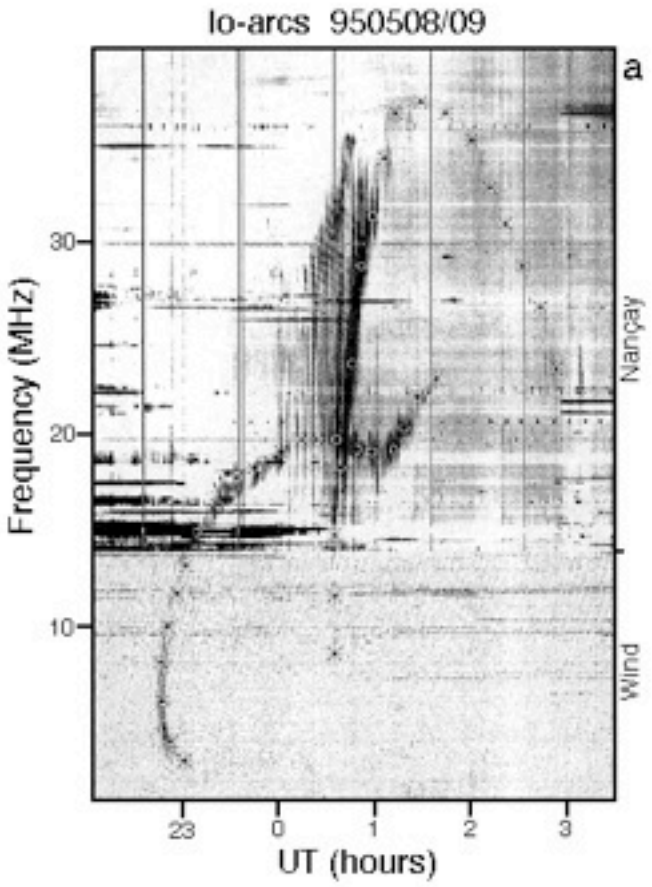


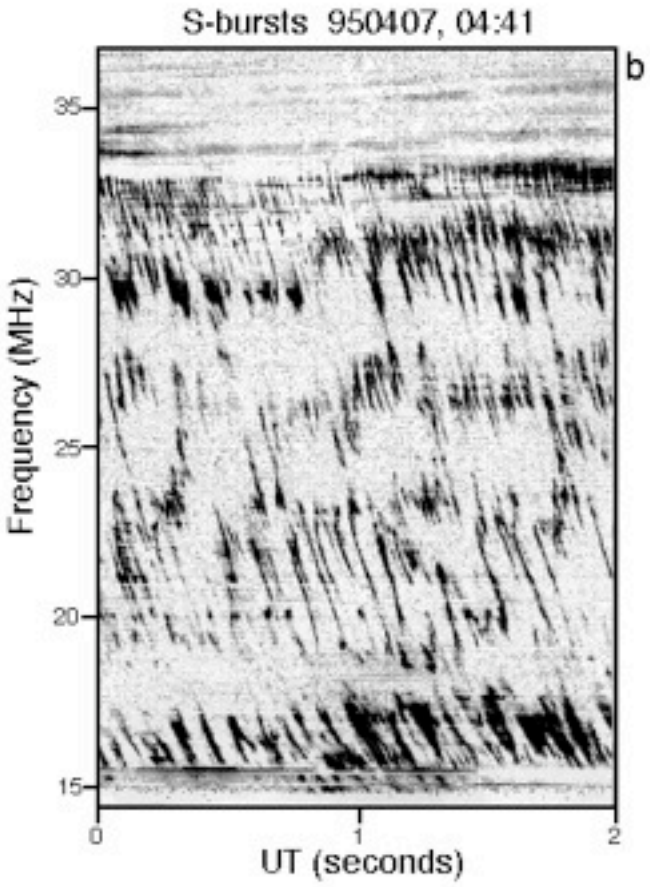
• 1 AU at 1 pc = 1 " ⇒ source imagery not adapted

® (1) detect a signal, (2) star or planet ?

® distinction via emission polarization + periodicity

• search for Jupiter-like bursts ?





Since 1994 (INTAS contracts) :

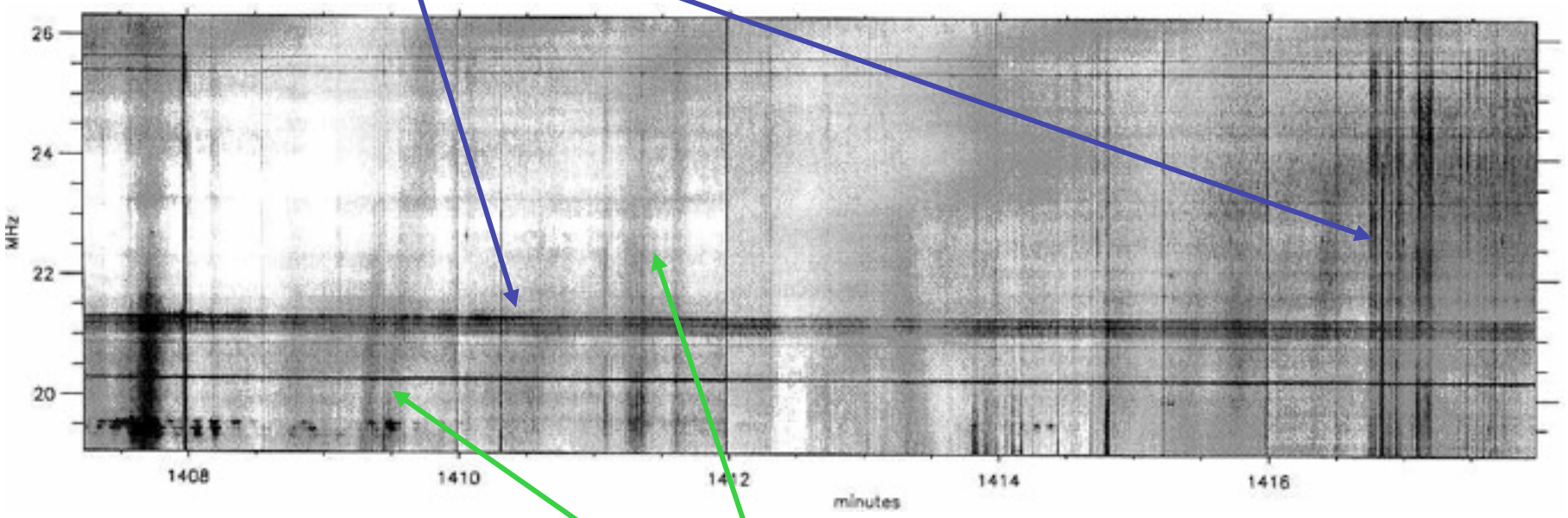
- Swept-Frequency Analyzer (HP)
- Acousto-Optical Spectrograph (Meudon-Nançay)
- Bank of lowpass/hipass high performance ceramic filters

- Channel switching interface (Meudon-Nançay)

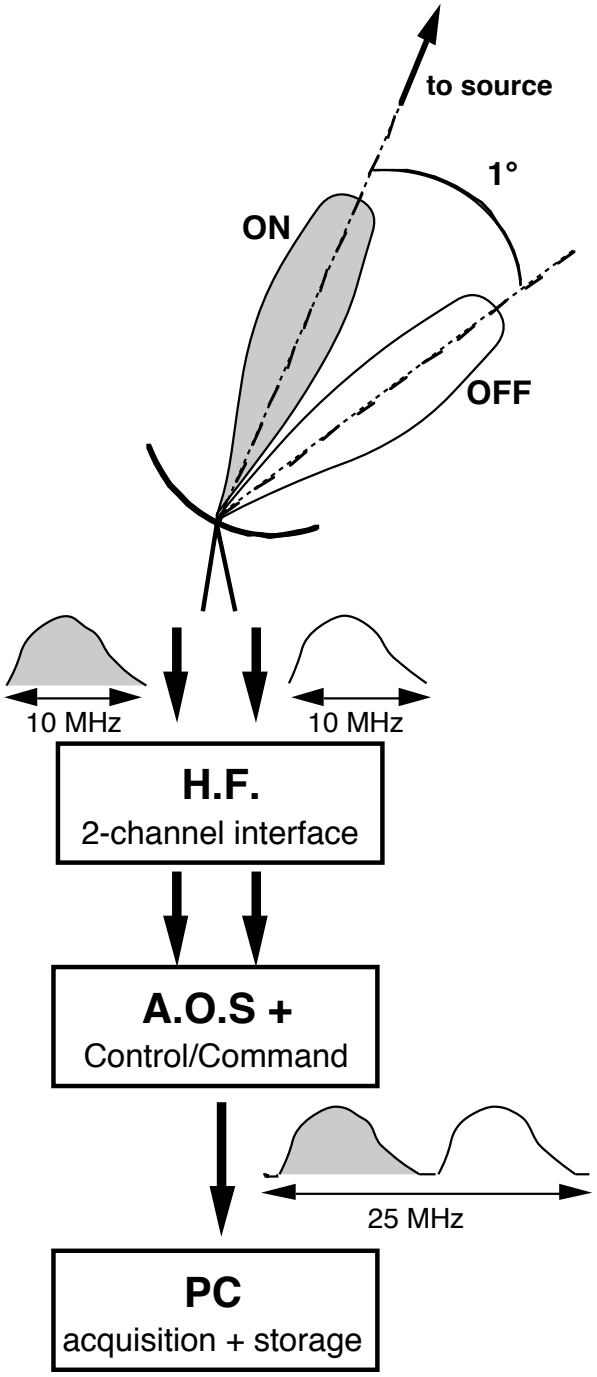
AOS (+IF interface) :

- Δf = 10 to 25 MHz band (tunable center frequency)
- Multichannel (33 channels / MHz), δf=90 kHz, step=30 kHz
- PC controlled
- Elementary spectra on 12 bits (0-4095)
- Integration time : 5 - 34 msec + Numerical integration (over 16 or 32 bits)
- acquisition sequence limited by RAM size
  (up to ~ 17000 spectra with 16-bit integration = 2-60 min./file)
- 25 dB dynamic range
- 1% gain fluctuations over minutes

RFI (interference)



ionospheric scintillations



DATA:
ON and OFF
dynamic spectra
333(f)×17000(t)

↓

Interference detection

↓

High-pass filtering

↓

(Parametric dedispersion) and frequency integration

↓

Statistical analysis: peaks detection algorithm

« Exoplanet » mode :

- Simultaneous ON/OFF observations

δt=20-300 msec

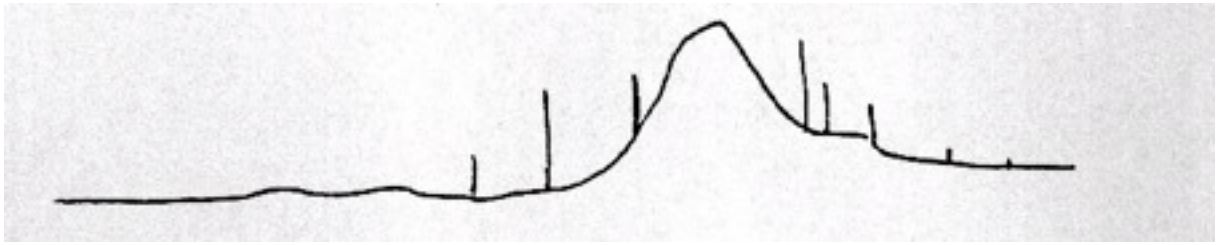
- Post-processing :

→ RFI recognition / elimination

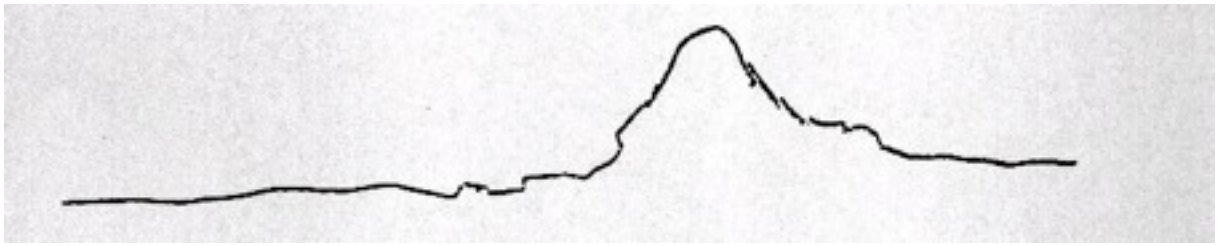
→ Correction of ionospheric scintillations

→ Spectral integration

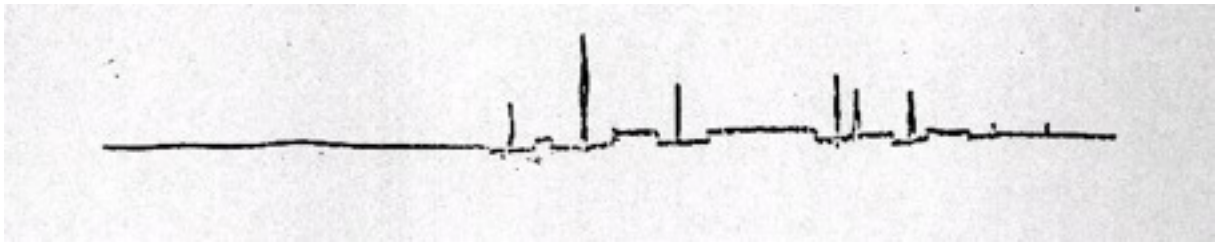
→ Peak detection



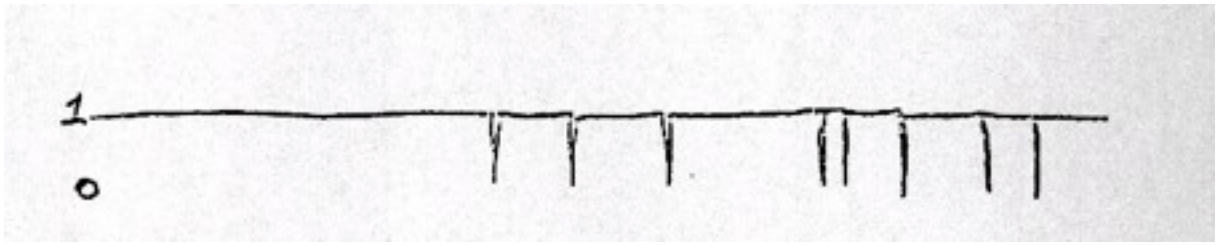
(1) raw data



(2) boxcar smoothed



(1)/(2) or (1)-(2)



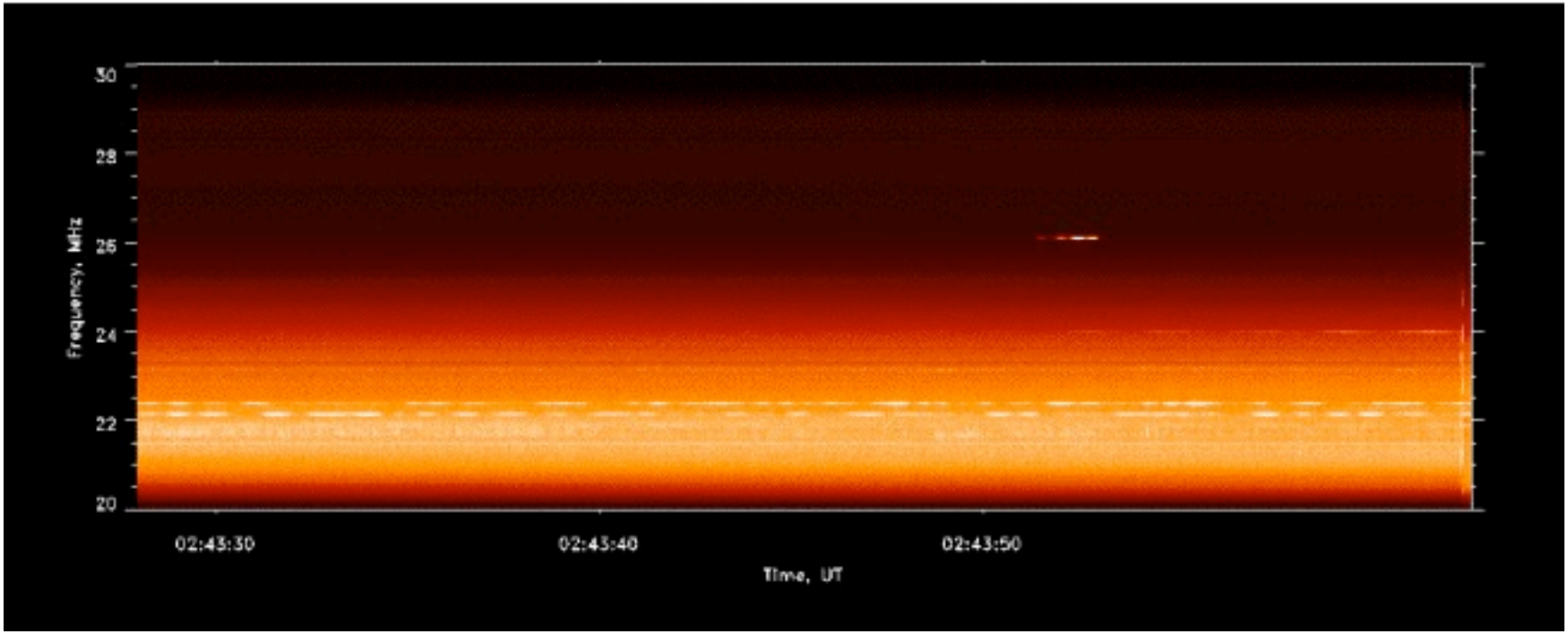
Thresholding → weighting function

®Interpolation over

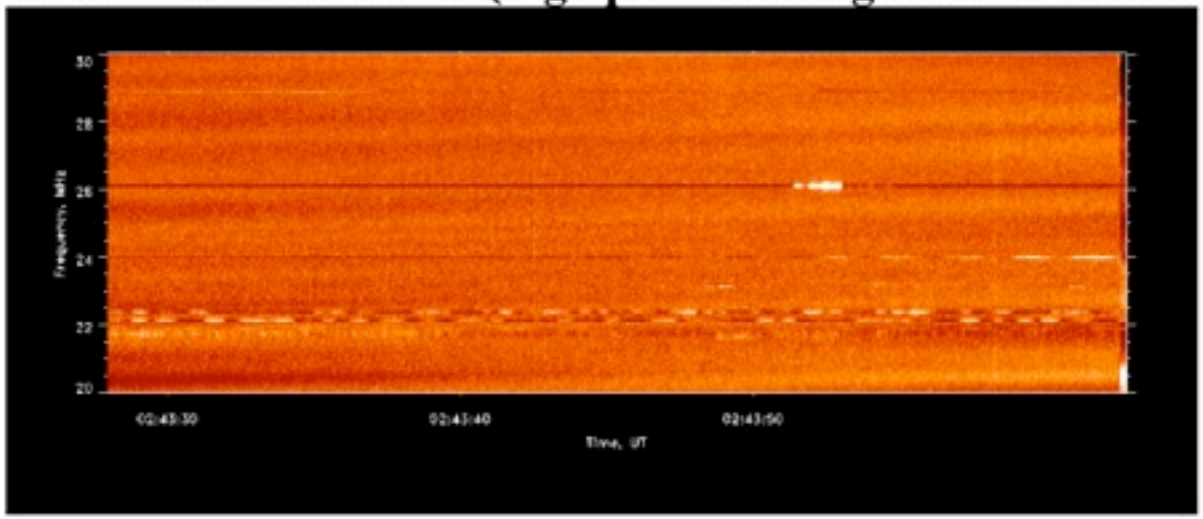
Hanisch, Proceedings of the NRAO workshop "Interference identification and excision", Green Bank, 1982

Source HD187123, March 16th , 2000

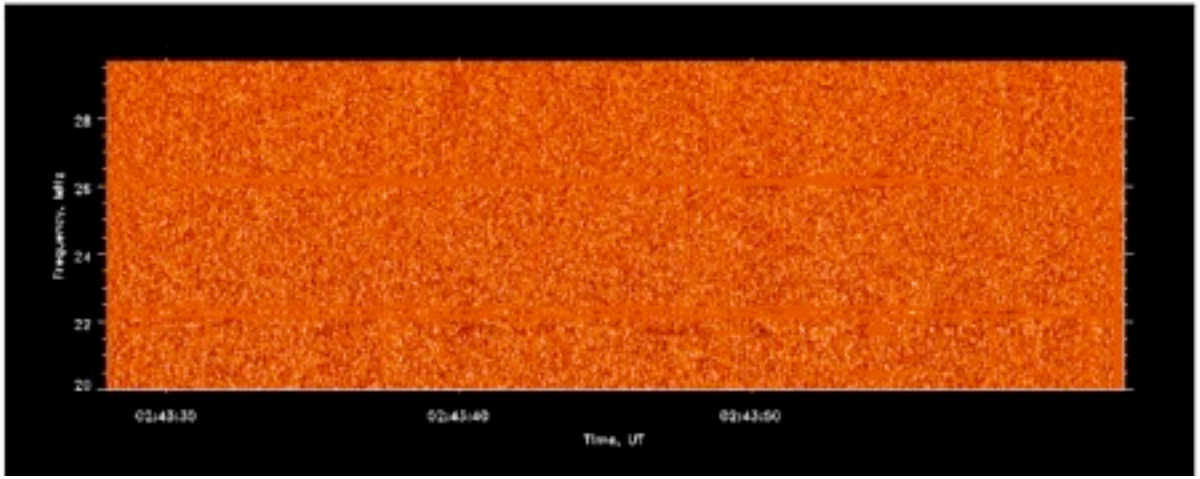
RAW SPECTRUM



AFTER PREPROCESSING (high pass filtering and normalization)

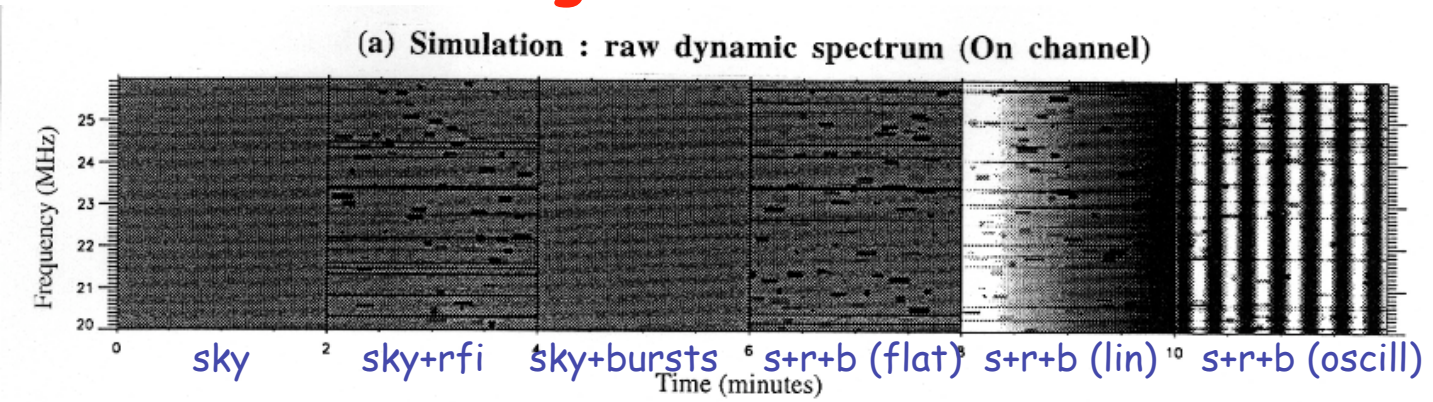


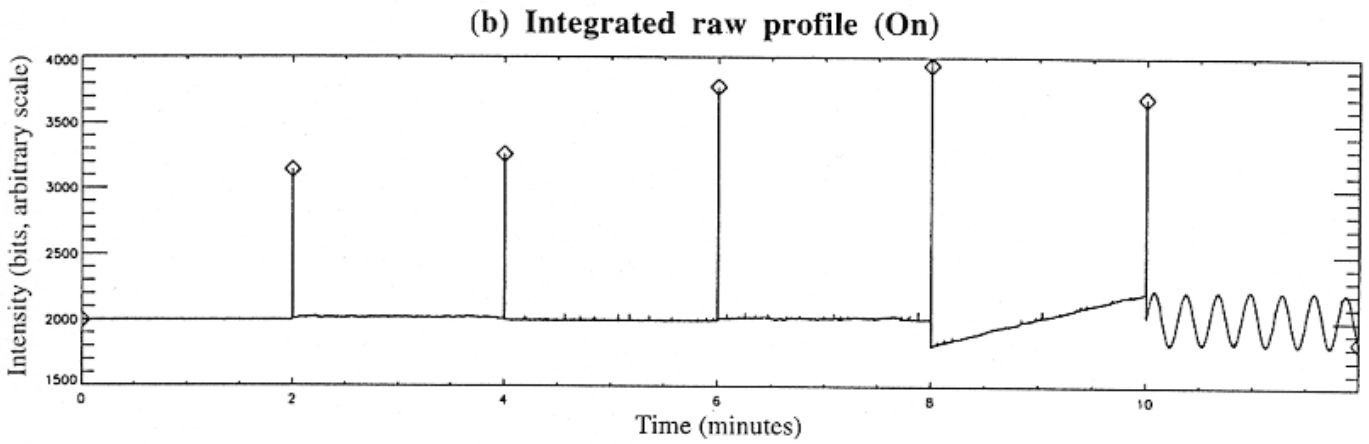
AFTER INTERFERENCE ELIMINATION

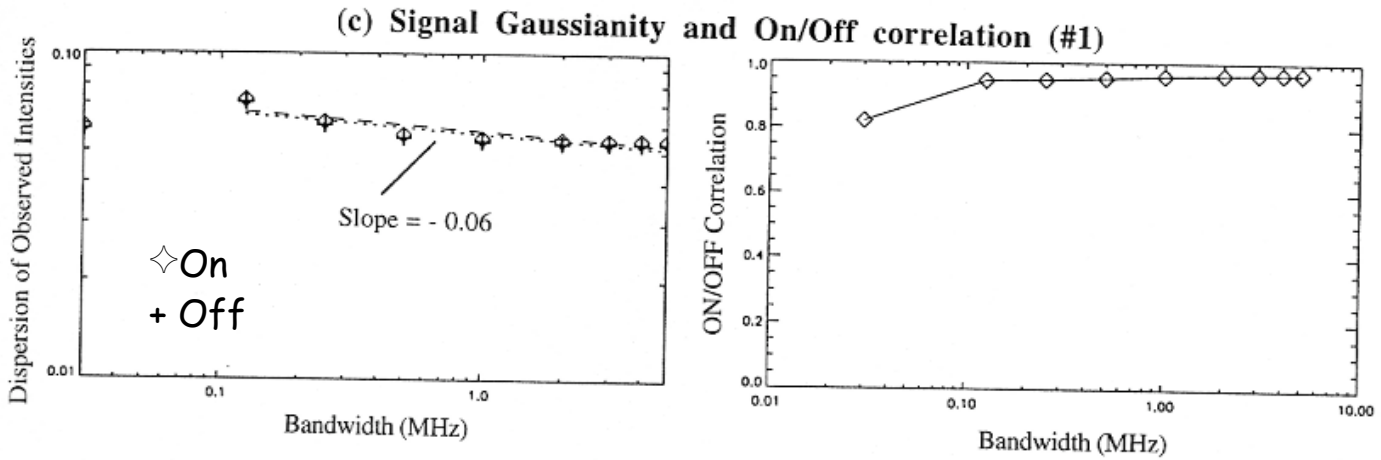


P. Zarka, J. Queinnec, B. P. Ryabov, V. B. Ryabov, V. A. Shevchenko, A. V. Arkhipov, H. O. Rucker, L. Denis, A. Gerbault, P. Dierich, and C. Rosolen : Ground-Based High Sensitivity Radio Astronomy at Decameter Wavelengths, in "Planetary Radio Emissions IV", H. O. Rucker et al. eds., Austrian Acad. Sci. press, Vienna, p. 101-127, 1997.

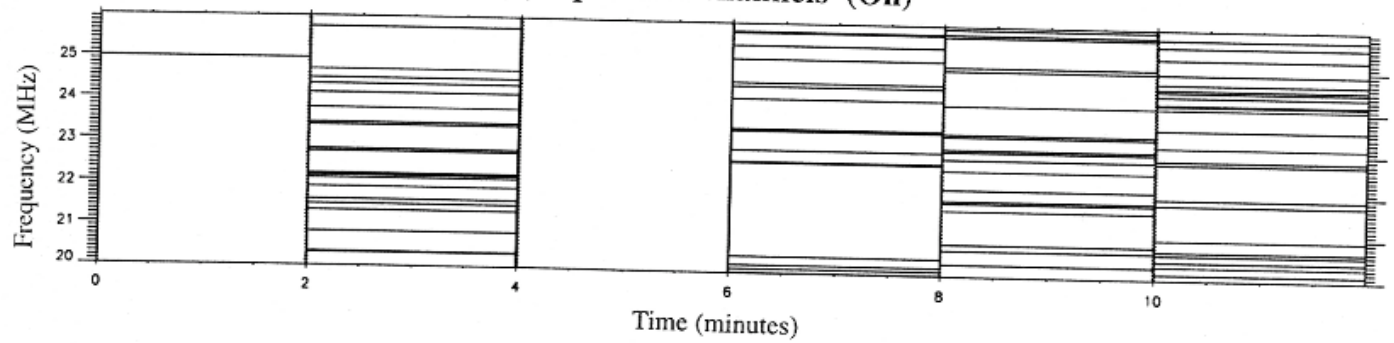
Processing of simulated data



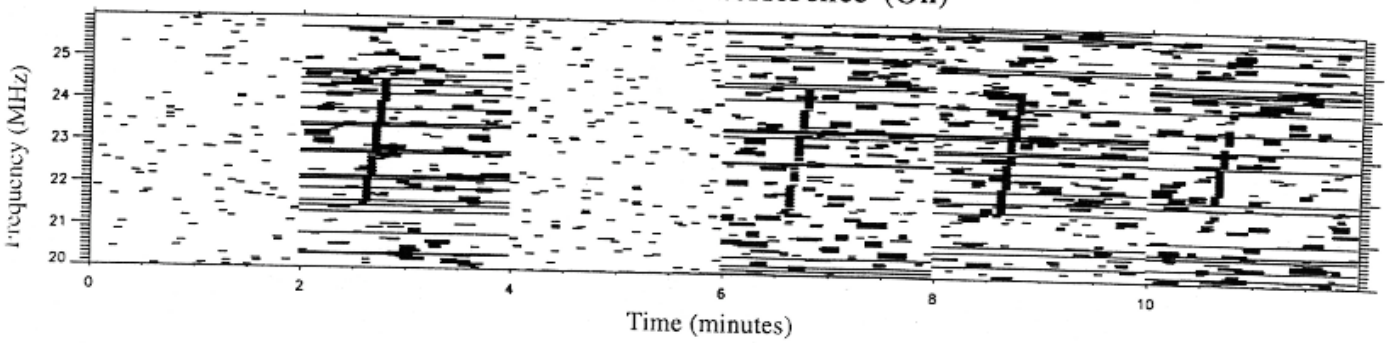




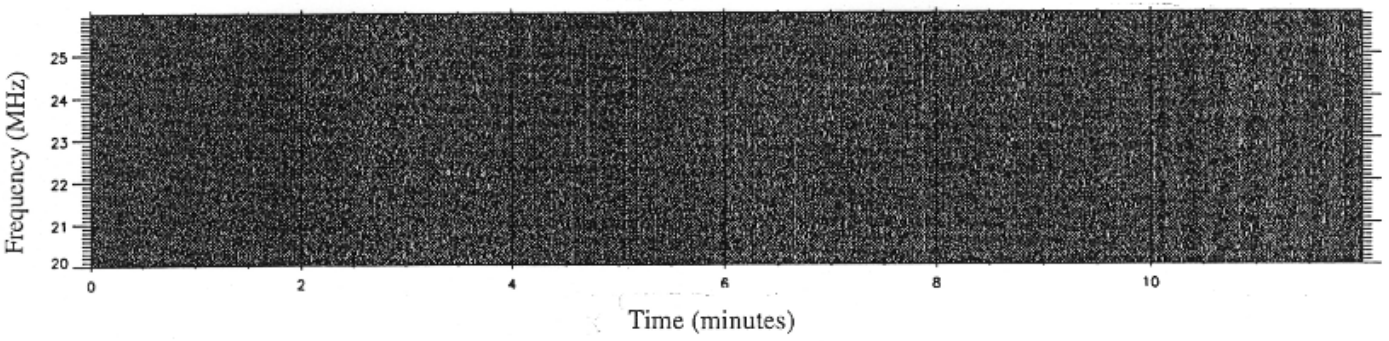
(d) Spurious channels (On)



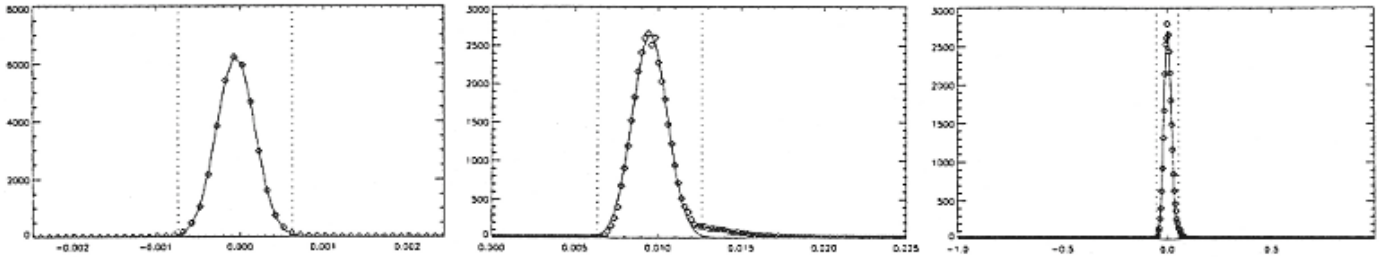
(e) Intermittent interference (On)



(f) Time-filtered dynamic spectrum (On)

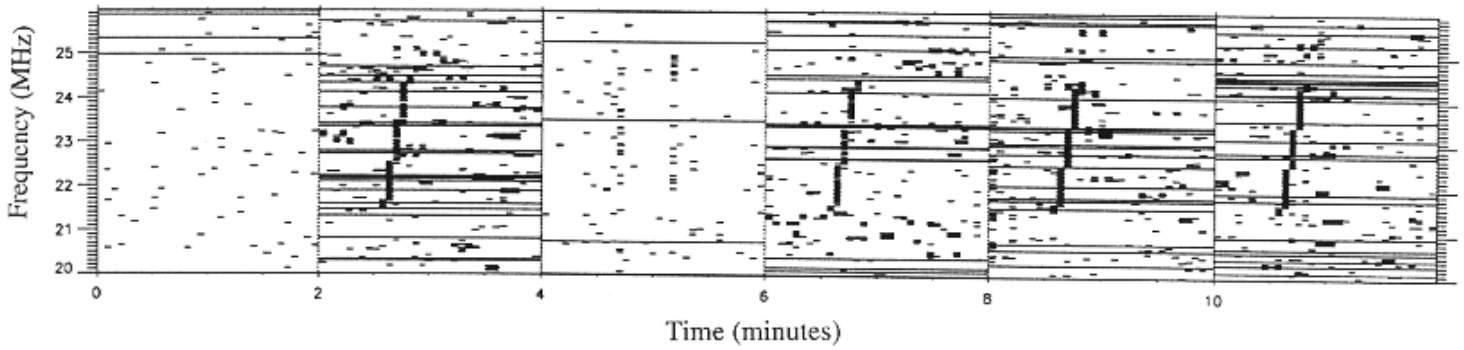


(g) **Distribution of statistical moments of 30 pixel-samples (On dyn. spect.)**

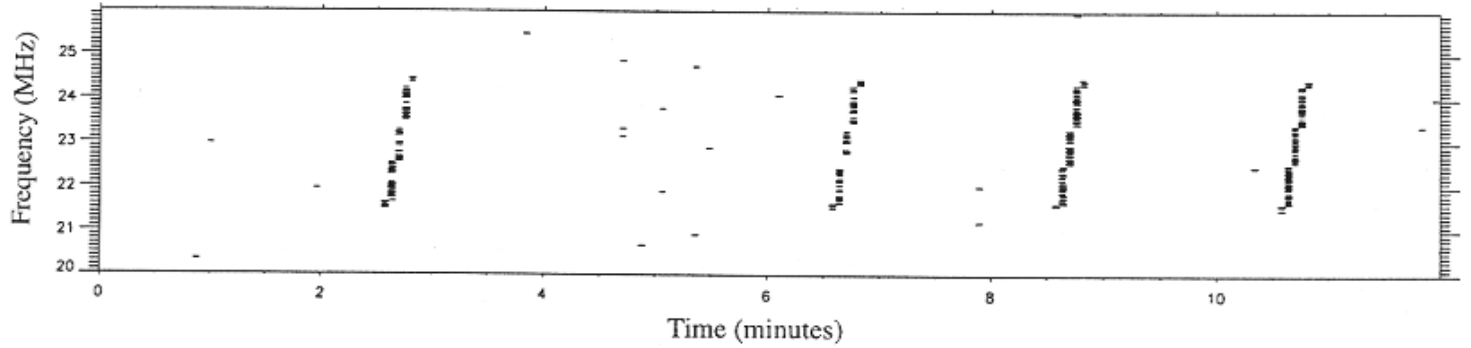


Averages | Dispersions | Correlation of adjacent frequencies

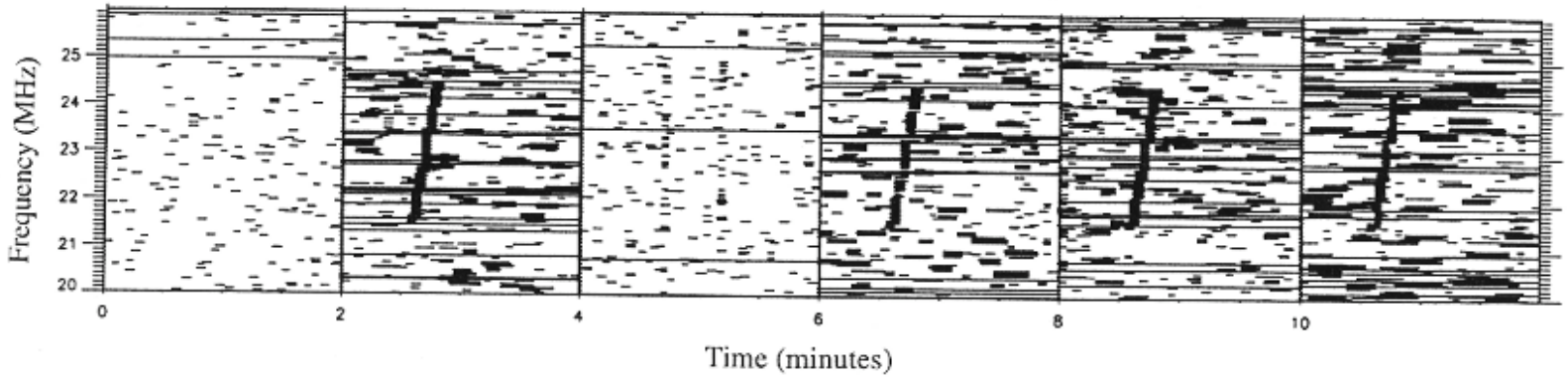
(h) **"Anomalous" 30 pixel-samples (On)**



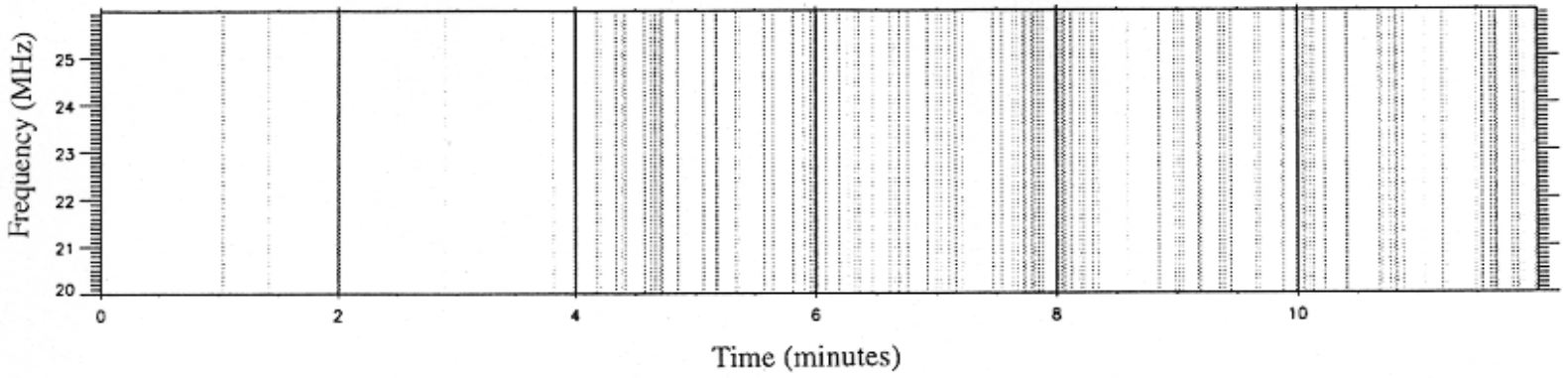
(i) **On/Off correlations (30 pixel-samples)**



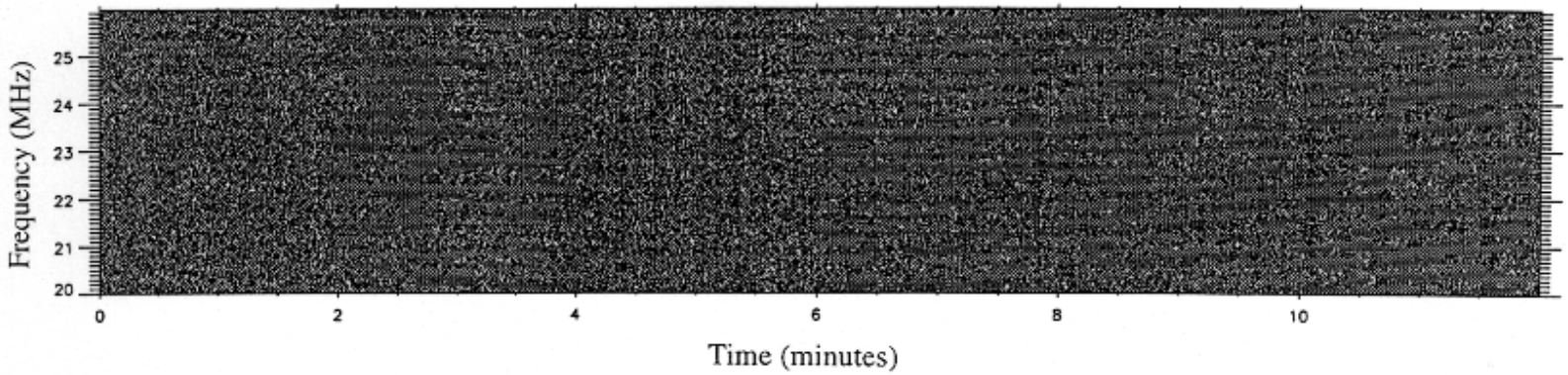
(j) **Final bad pixels mask (On)**

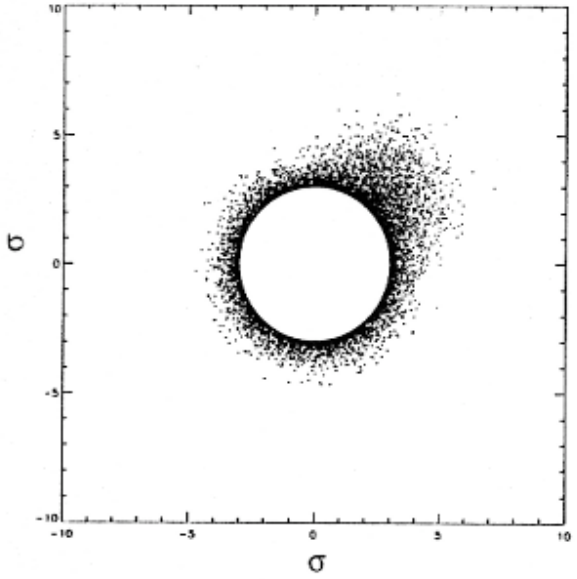


(k) **Wideband spikes mask (On)**



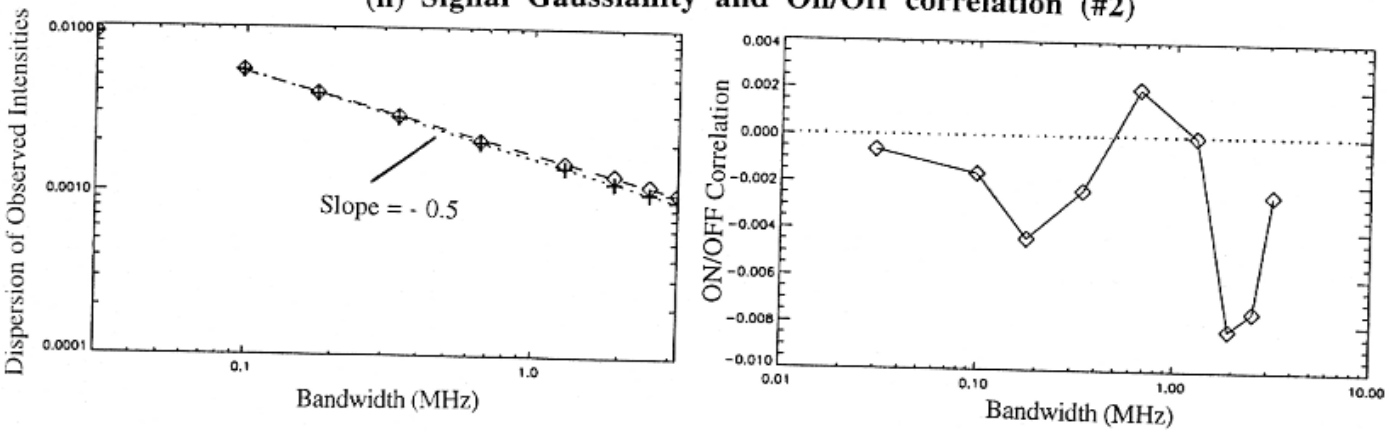
(l) **"Cleaned" dynamic spectrum (On)**



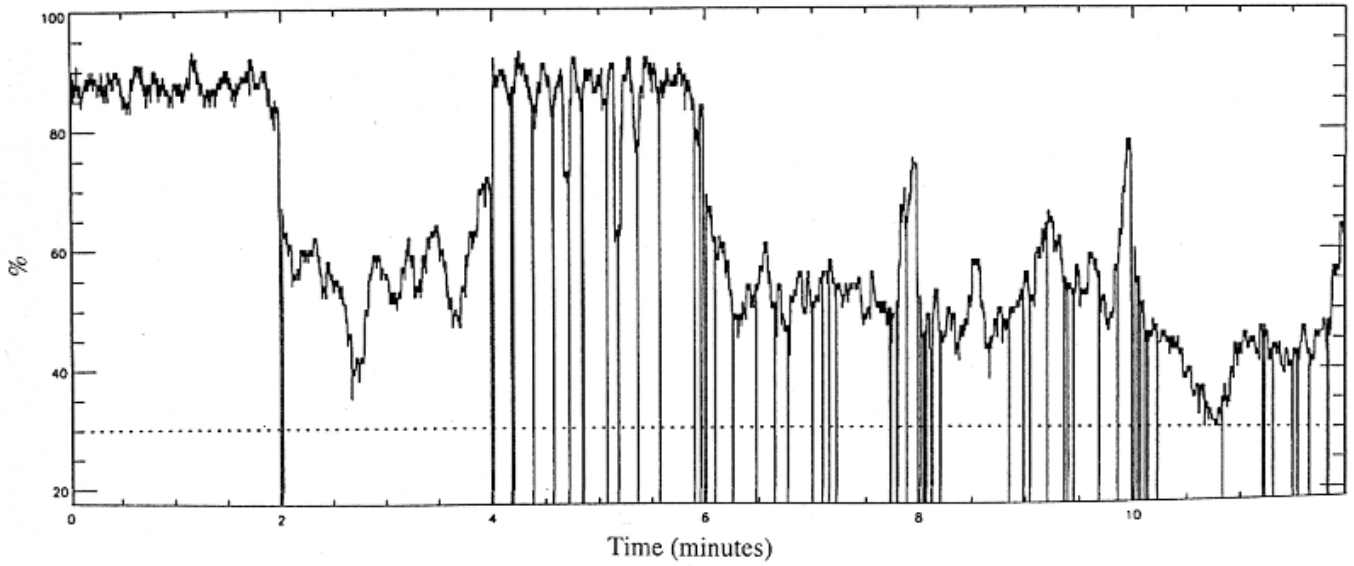


(m) **Normalized intensities (On vs Off)**

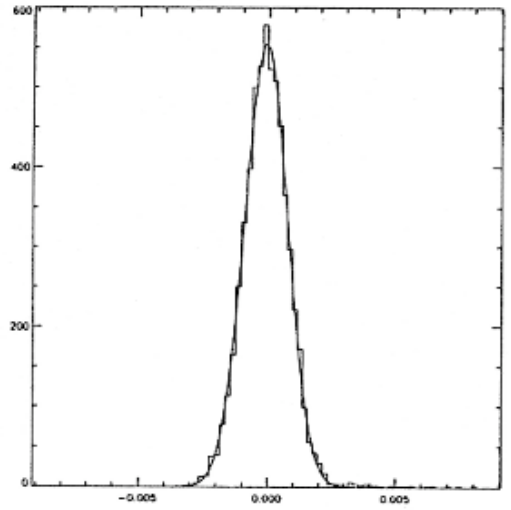
(n) Signal Gaussianity and On/Off correlation (#2)



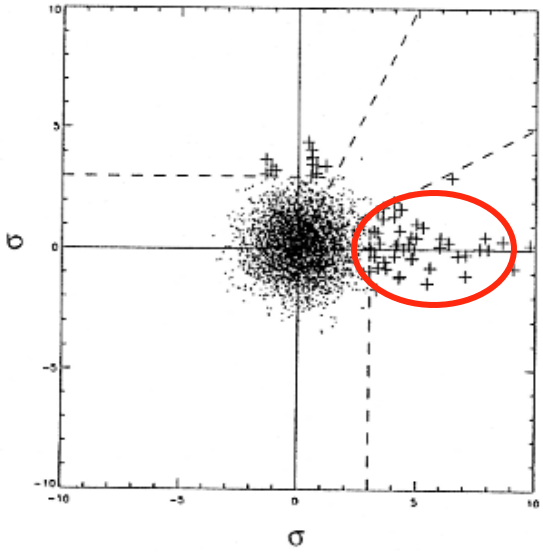
(o) Clean pixels per spectrum



(p) Distribution of integrated intensities (On)

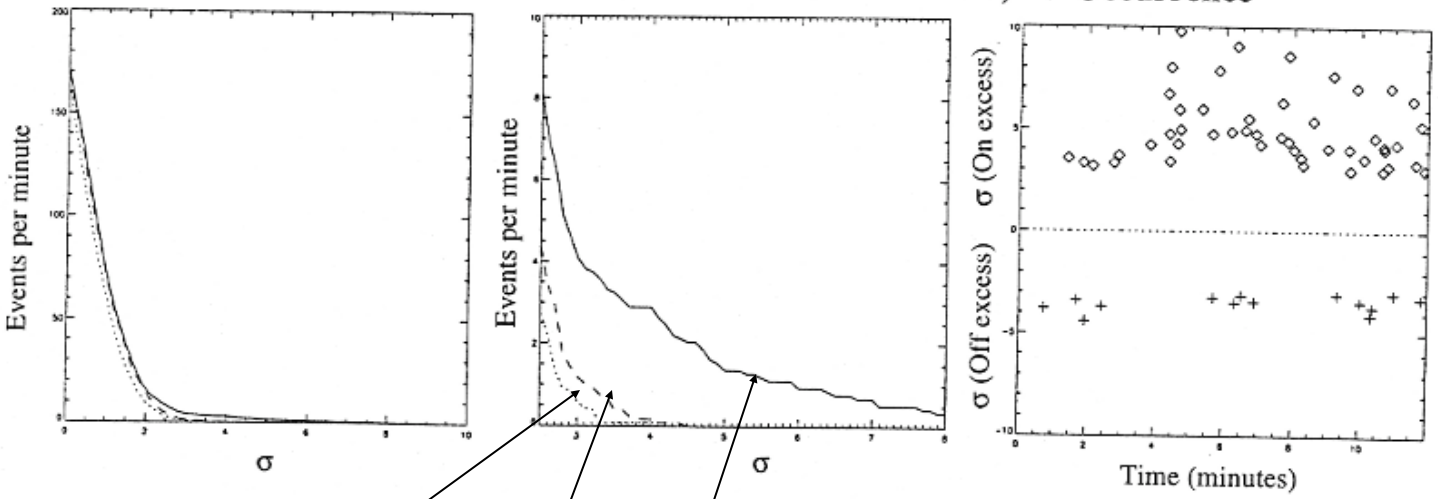


(q) Normalized intensities (On vs Off)



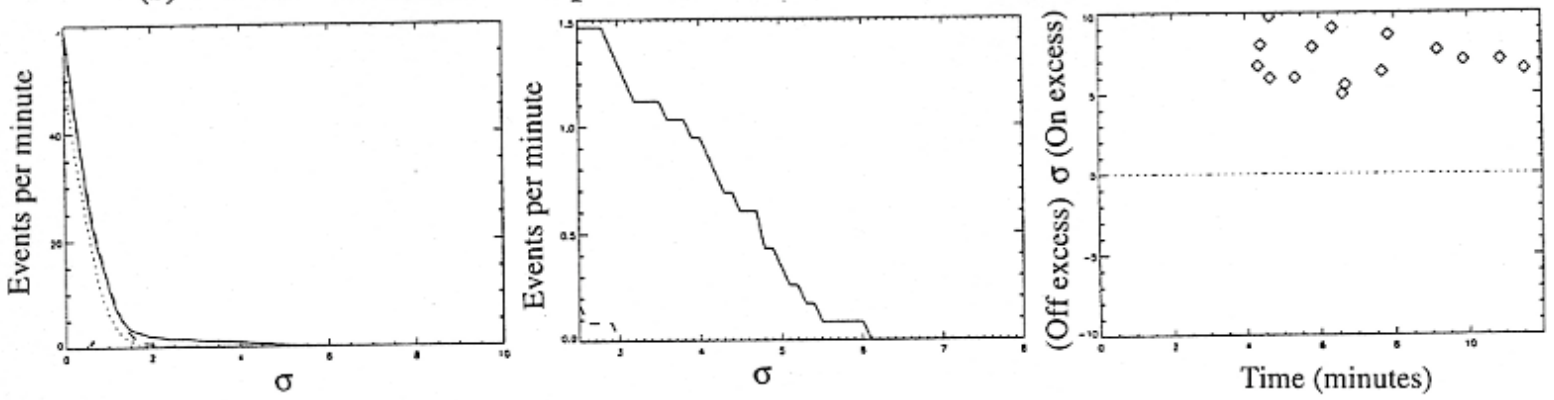
Expected signal

(r) Excess of wideband spikes (On/Off & Off/On) & Occurrence

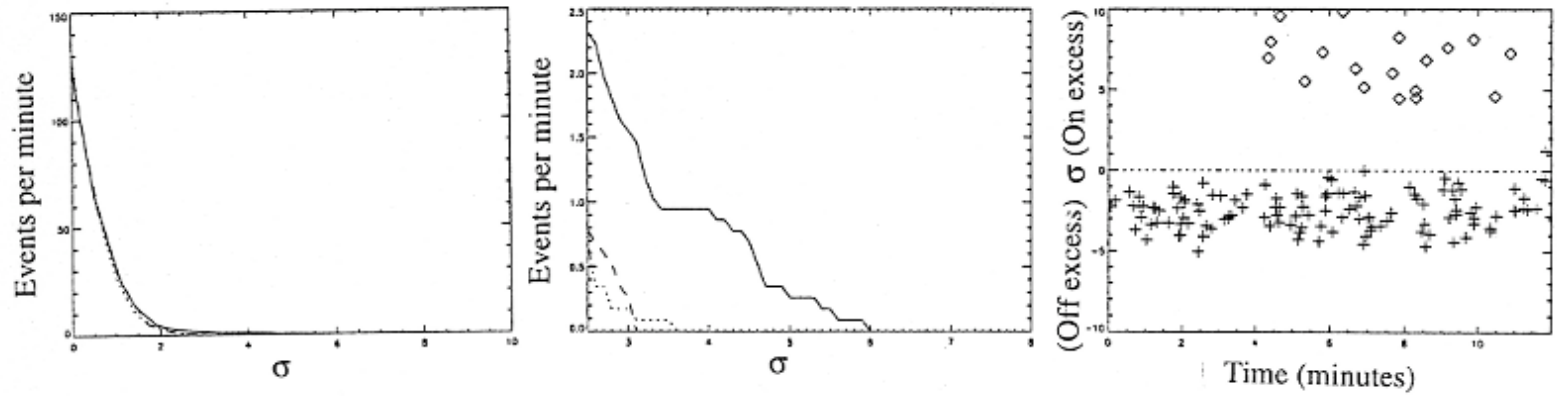


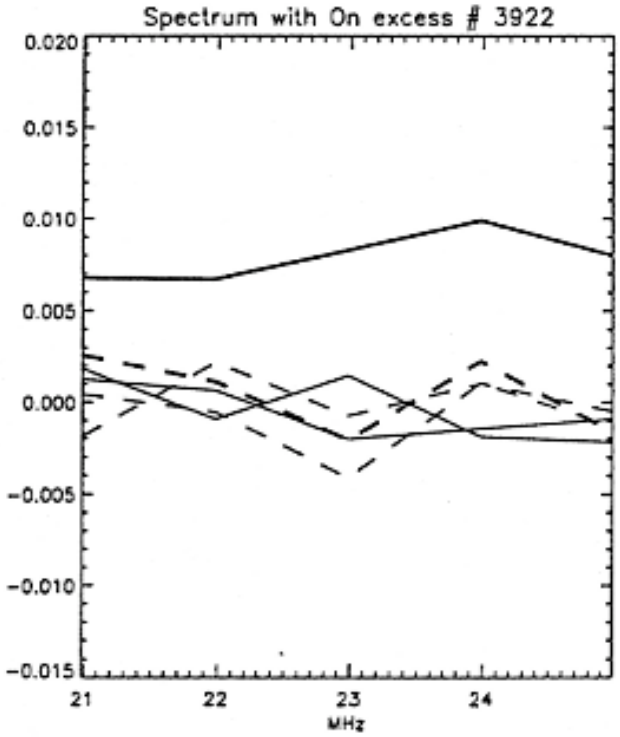
Gauss Off>On On>Off

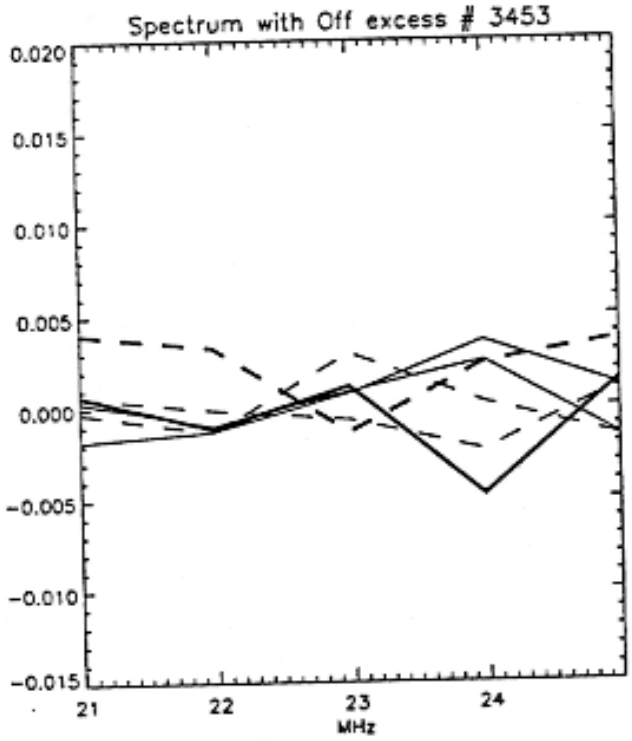
(s) Excess of wideband spikes (On/Off & Off/On) & Occurrence [2 bands]



(t) Excess of wideband spikes (On-Off & Off-On) & Occurrence [2 bands]







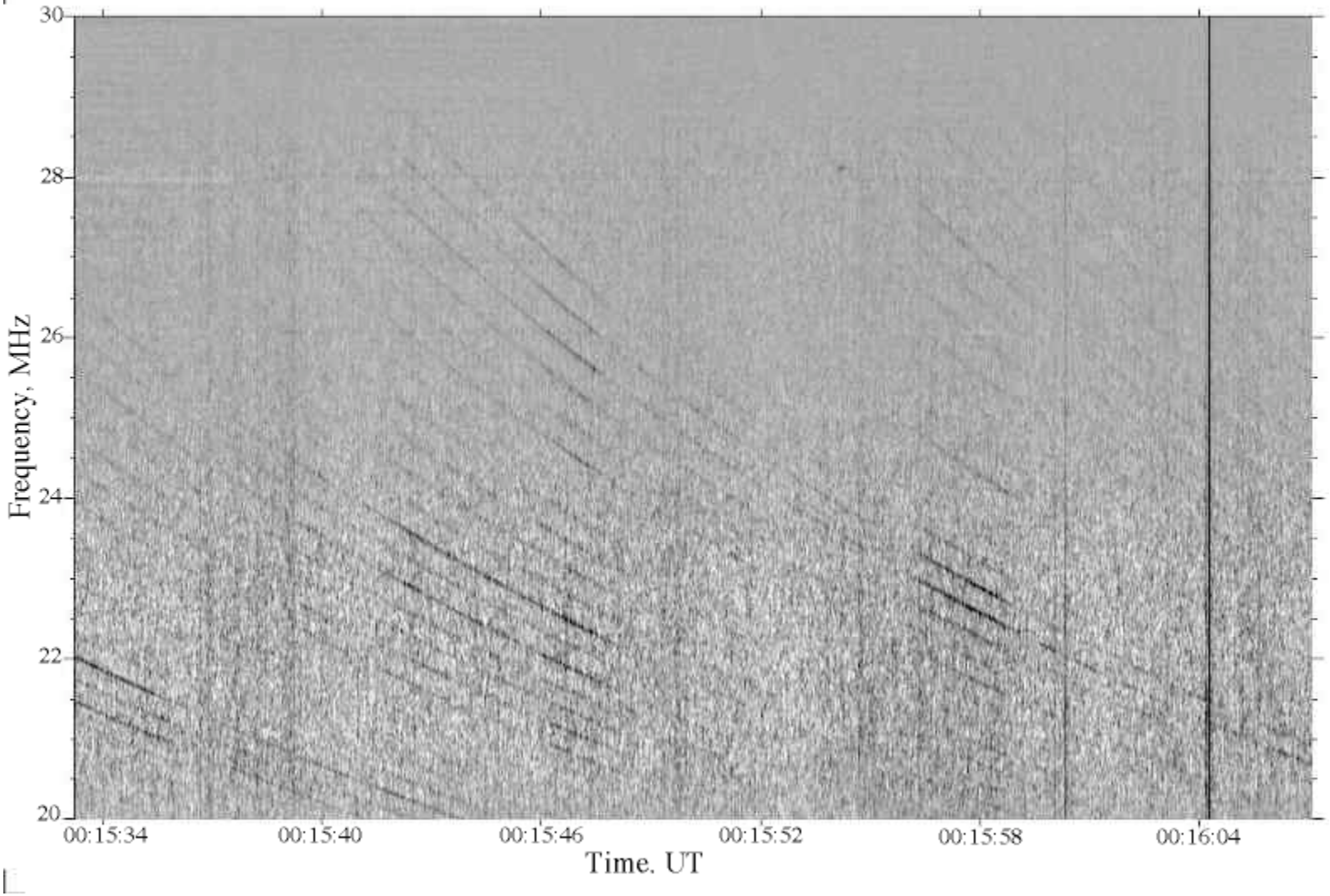
- <100% interference eliminated
- non-spurious pixels eliminated

®simplify scheme ?

® need for night-time, winter-time observations !

Pulsar Observations :

PSR 0809+74, 17 december 1997, BPR, VBR, PZ



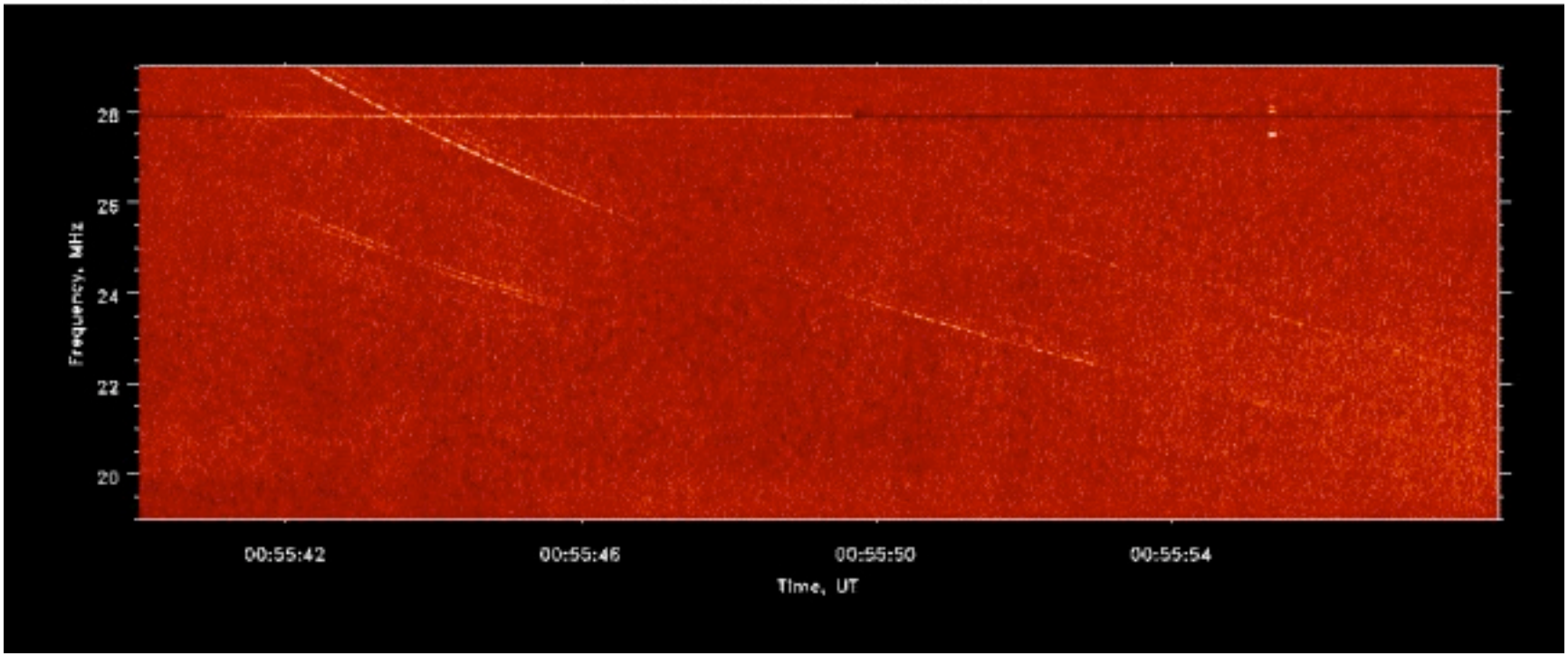
- Dispersion : $\Delta t(sec) = 4150\ [DM] / f^2$ (f in MHz)
- $\tau_B \propto f^{-4.4}$ (Kolmogorov)
- [DM] < 1 pc/cm^3 for nearby stars

	DISPERSION Time delay (sec) [wrt f = ∞]		TEMPORAL BROADENING (msec)	
Frequency (MHz)	for *DM* (pc.cm^{-3})		for *DM* (pc.cm^{-3})	
	1	10	1	10
20	10.4	104	19	119
25	6.6	66	7	45
30	4.6	46	3	20

Table 2 : *Time-delays and broadenings of radio spikes versus frequency and dispersion measure.*

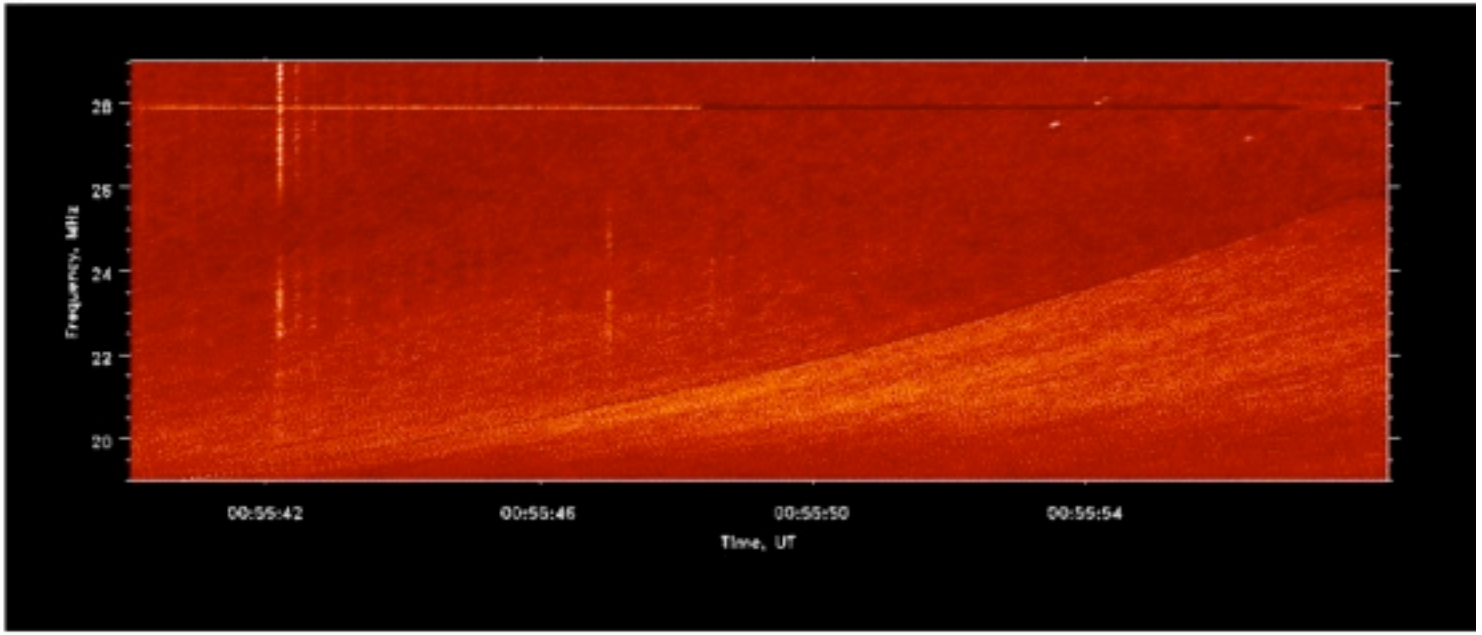
PSR0950+08. DM=2.97 pc. cm^{-3}. December 29, 2001

RAW DATA

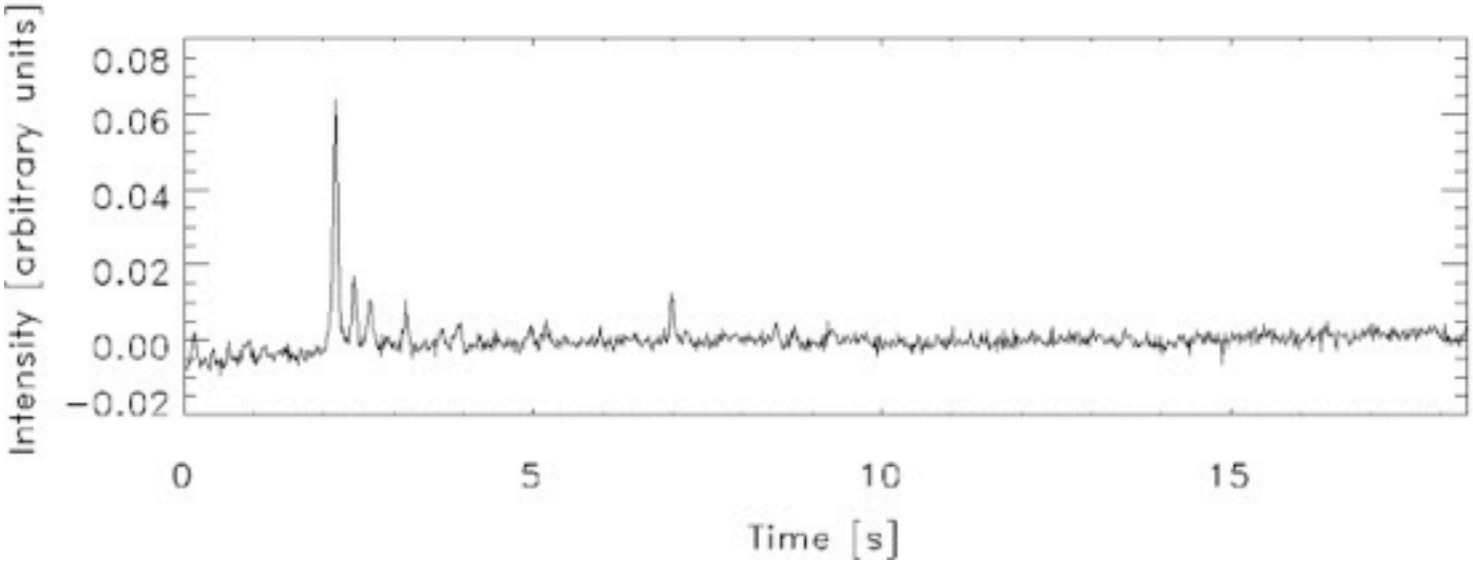


V. B. Ryabov, P. Zarka, and B. P. Ryabov: Search of exoplanetary radio signals in the presence of strong interference: Enhancing sensitivity by data accumulation, Planet. Space Sci., submitted, 2004.

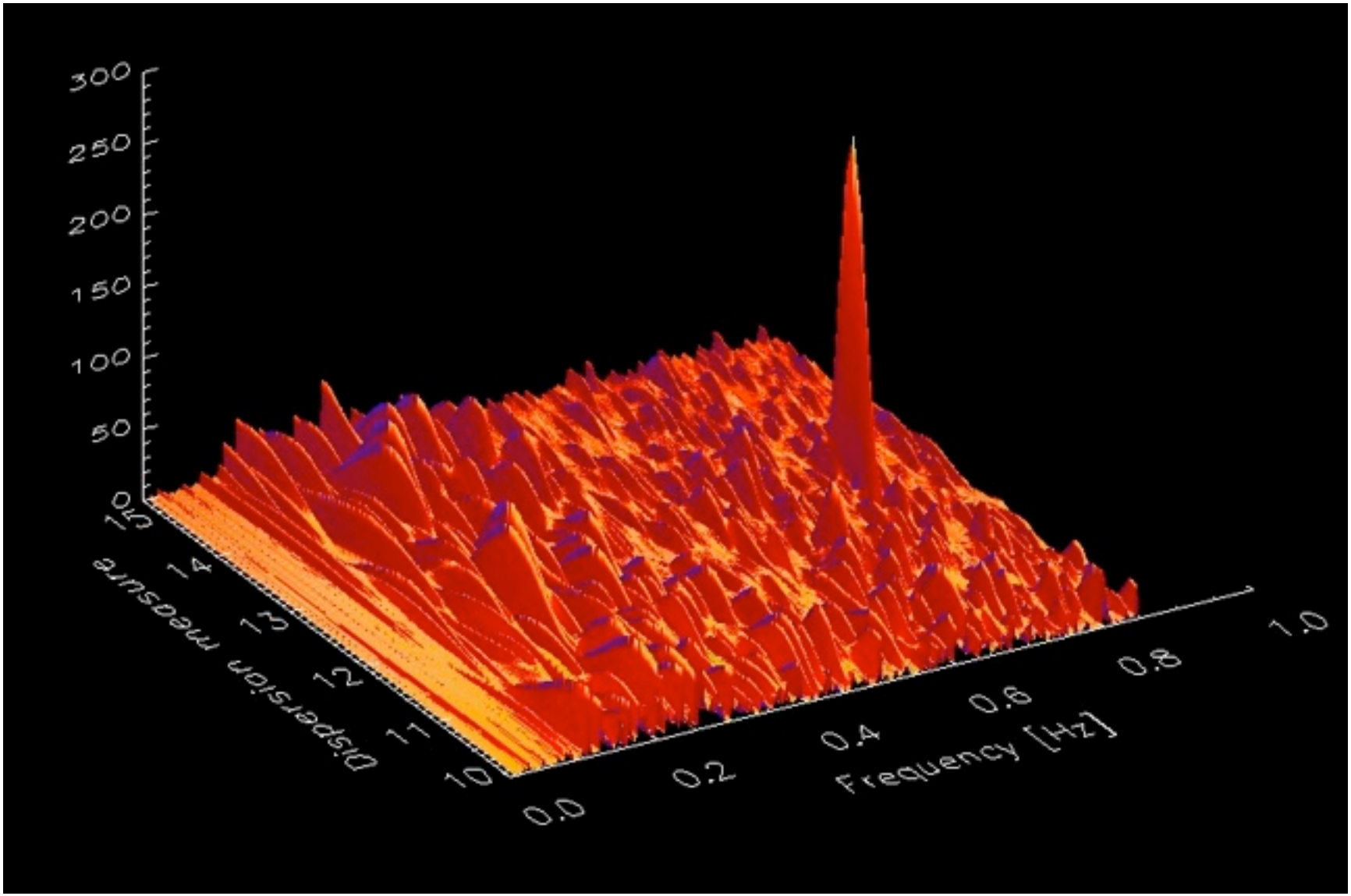
DEDISPERSED DATA



INTEGRATED INTENSITY



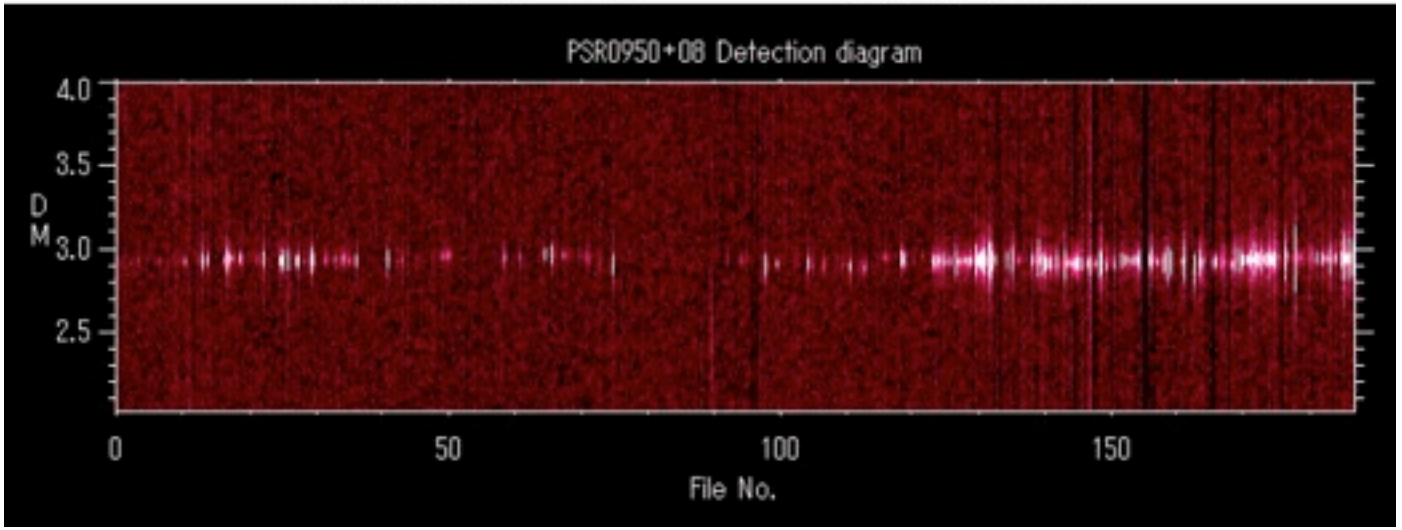
Synchronous pulse detection (FT)



« Accumulated » pulse detection (FT)

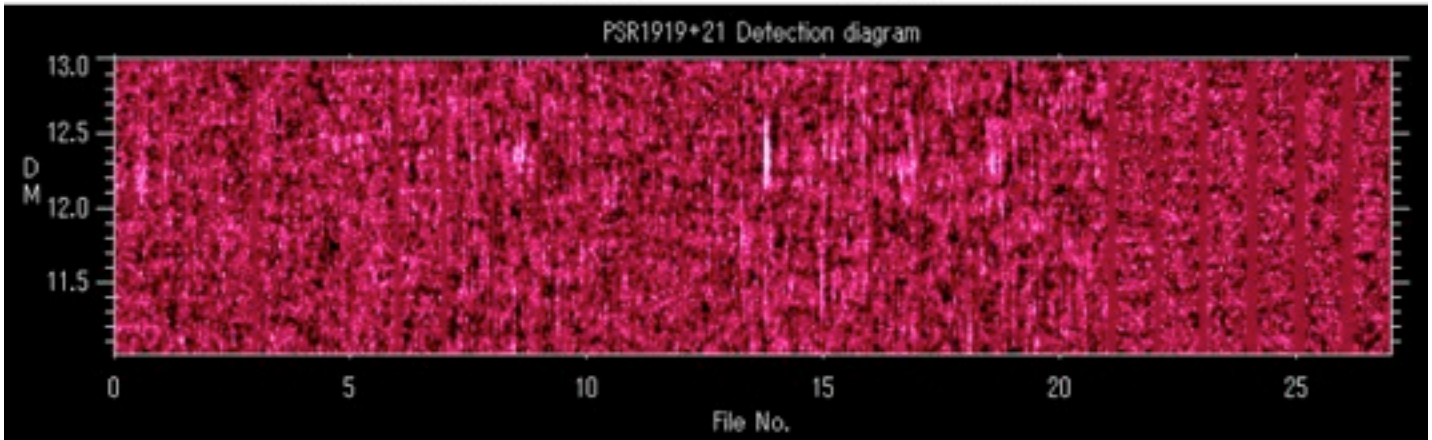
Example of pulse detection: strong signal

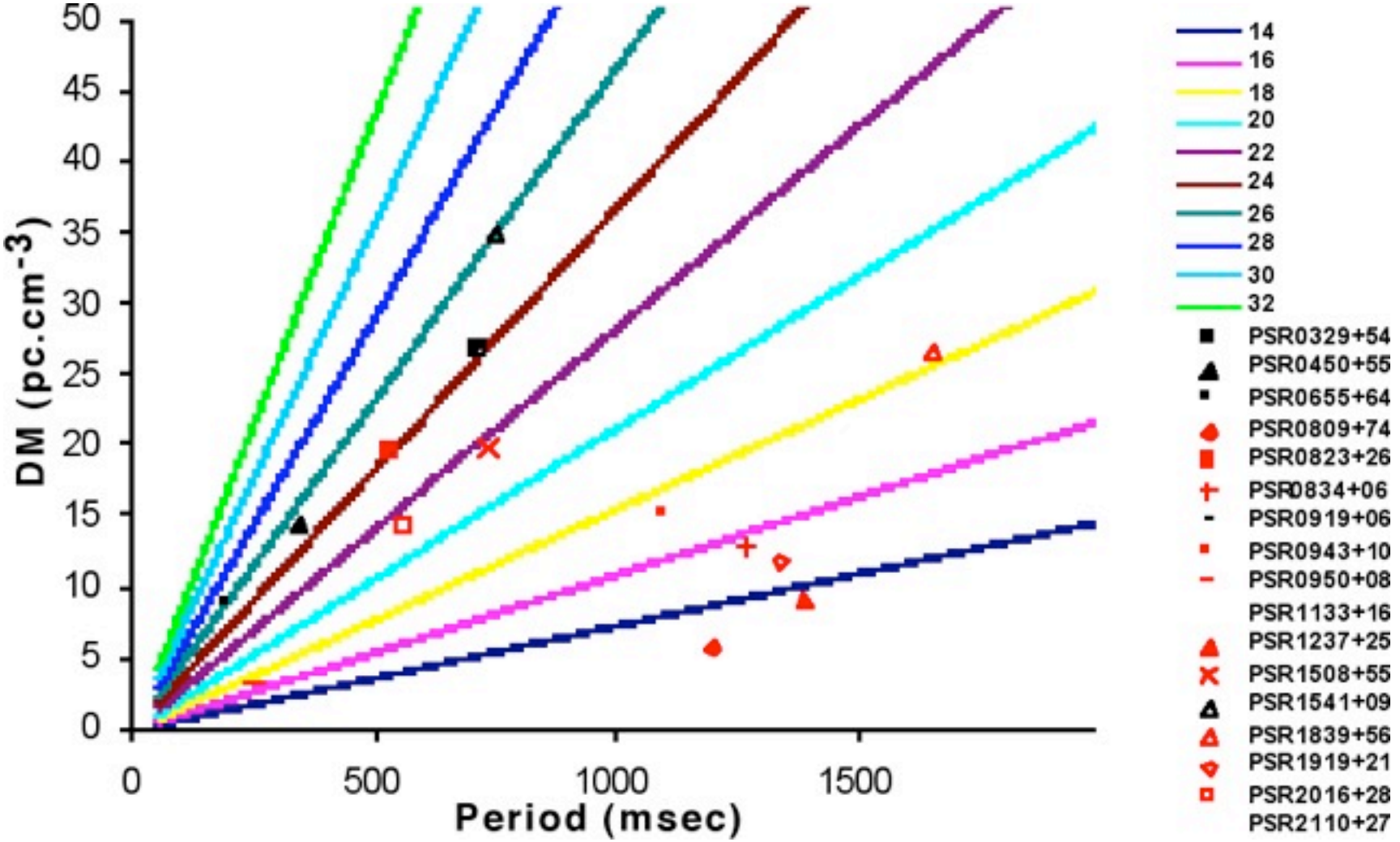
PSR0950+08 DM=2.95



Example of pulse detection: weak signal

PSR1919+21 DM=12.4




DM (pc.cm-3)
Period (msec)
0
5
10
15
20
25
30
35
40
45
50
0
500
1000
1500
14
16
18
20
22
24
26
28
30
32
PSR0329+54
PSR0450+55
PSR0655+64
PSR0809+74
PSR0823+26
PSR0834+06
PSR0919+06
PSR0943+10
PSR0950+08
PSR1133+16
PSR1237+25
PSR1508+55
PSR1541+09
PSR1839+56
PSR1919+21
PSR2016+28
PSR2110+27

Exoplanet search :

Normal stars

Parent Star	Spectral type	Distance from the Sun (pc)	Number of acquisition files (~5 min each)
Ups Andromeda (HD 9826)	F7V/F8V	13.5	57
55 Cnc (HD 75732)	G8V	12.5	113
Rho CrB (HD 143761)	G0Va/G2V	17.4	93
Tau Bootes (HD 120136)	F6IV	15.6	92
70 Vir (HD 117176)	G4V	18.1	88
HD114762	F9V	28	71
Hd130322	K0V	30	4
Hd187123	G5	50	14
Hd38529	G4	42.4	30
Hd52265	G0V	28	12
Bd103166	K0V	<200	44
eps Eri	K2V	3.3	76
Lalande 21185 (HD 117176)	M2	2 - 2.5?	134

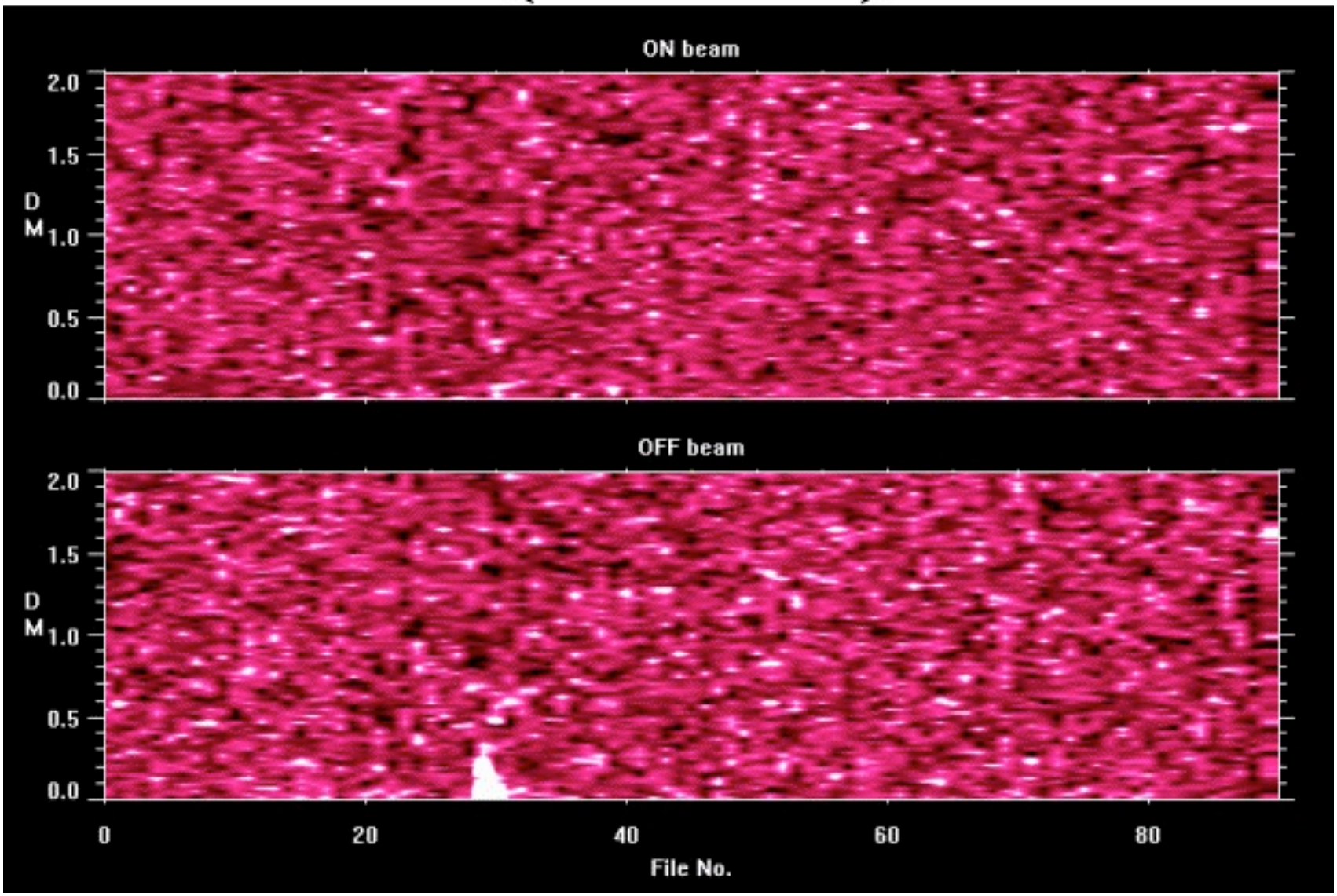
Brown dwarfs

HD 283750	K2	16.5	102
Hd110833	K3V	17	21
Hd112758	K0V	16.5	11
Hd140913	G0V	48	4
Hd89707	G1V	25	49
Hd98230	F8.5 V	7.7	32

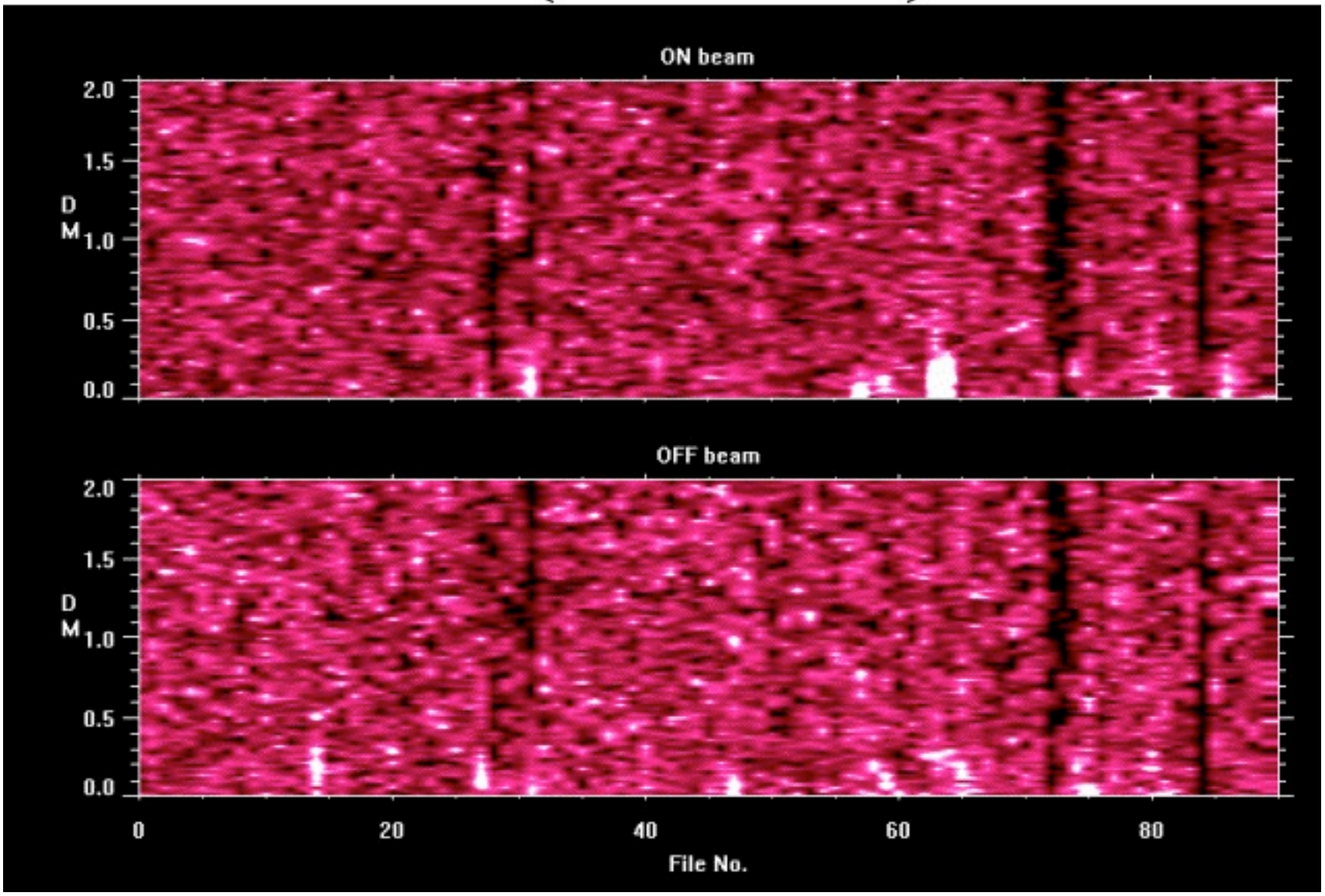
Nearby stars

L1159 - 16	M4.5VE	4.5	12

55 Cnc (HD 75732)



Rho CrB (HD 143761)



Normal stars

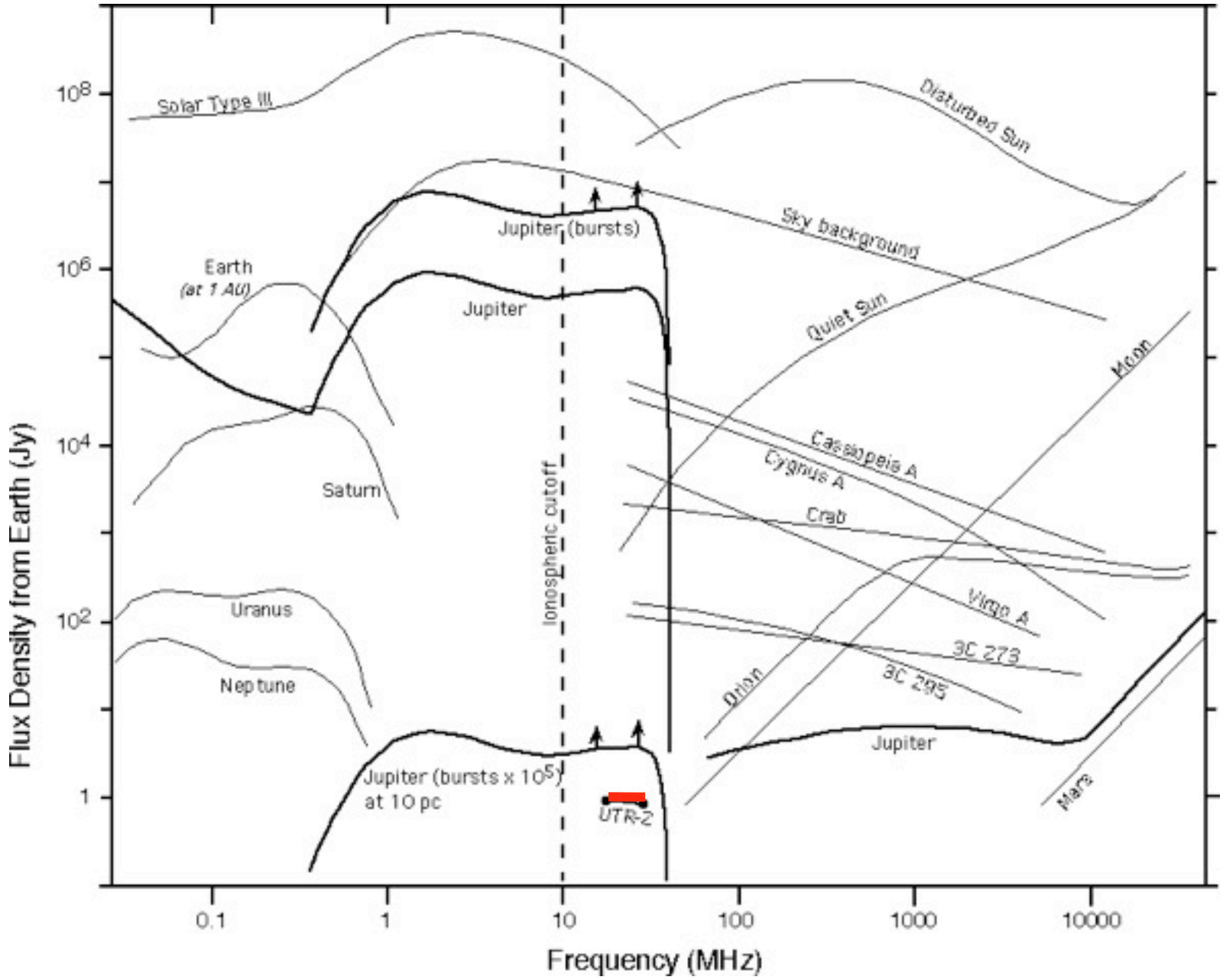
Parent Star	Maximal sensitivity reached (at 300 ms integration time) [mJy]
Ups Andromeda (HD 9826)	240
55 Cnc (HD 75732)	130
Rho CrB (HD 143761)	160
Tau Bootes (HD 120136)	160
70 Vir (HD 117176)	165
HD114762	190
Hd130322	>1600
Hd187123	>1600
Hd38529	1000
Hd52265	>1600
Bd103166	400
eps Eri	190
Lalande 21185 (HD 117176)	100

Brown dwarfs

HD 283750	130
Hd110833	>1600
Hd112758	>1600
Hd140913	>1600
Hd89707	400
Hd98230	1000

Nearby stars

L1159 - 16	>1600


Flux Density from Earth (Jy)
Frequency (MHz)
Solar Type III
Disturbed Sun
Sky background
Jupiter (bursts)
Earth
(at 1 AU)
Jupiter
Quiet Sun
Moon
Cassiopeia A
Cygnus A
Crab
Saturn
Ionospheric cutoff
Virgo A
3C 273
3C 295
Orion
Uranus
Neptune
Jupiter
Jupiter (bursts x 10^5)
at 10 pc
UTR-2
Mars
10^8
10^6
10^4
10^2
1
0.1
1
10
100
1000
10000

Why no detection?

- No storm detected from exoplanet candidates during observational campaigns (< 10 hours for each).
- No strong Io-Jupiter radio bursts.
- Emission in different frequency band (B >> or << $B_{jupiter}$?).
- Sensitivity of UTR-2 not sufficient (≤ 1 Jy) / signal too weak.
- Interference signals not completely removed.
- Exoplanetary signals identified and removed as interference.
- Signal detection algorithm not optimized to match the (unknown) characteristics of the signal.
- Broadband bursts are drifting (in addition to interstellar dispersion).

Maximum distance of detectability of Jovian bursts

$$d_{max} = (\alpha S_j A_e / 2 n k T_s)^{1/2} \times (b \tau)^{1/4}$$

$\sim 10^{-18}$ $Wm^{-2}Hz^{-1}$ (10^8 Jy) from 1 AU distance (25 μ-Jy from 10 pc, peak ≥ ×10 ~mJy)

~3

~2×10^4 K @ 30 MHz (10^3 K @ 100 MHz, 3×10^5 K @ 10 MHz)

$\Rightarrow$ for $\alpha = 1$ $\quad d_{max}$ (pc) = $2.5\ 10^{-6}\ A_e^{1/2}\ (b\tau)^{1/4}$

	$b\tau = 10^6$ (1 MHz, 1 sec)	$b\tau = 2\times10^8$ (3 MHz, 1 min)	$b\tau = 4\times10^{10}$ (10 MHz, 1 hr)
$A_e = 10^4$ m^2 (Nançay)	**0.013**	**0.05**	**0.17**
$A_e = 10^5$ m^2 (Kharkov)	**0.040**	**0.15**	**0.55**

$\Rightarrow$ $\alpha \sim 10^5$ required ! (see next talk)

Correlation mode :

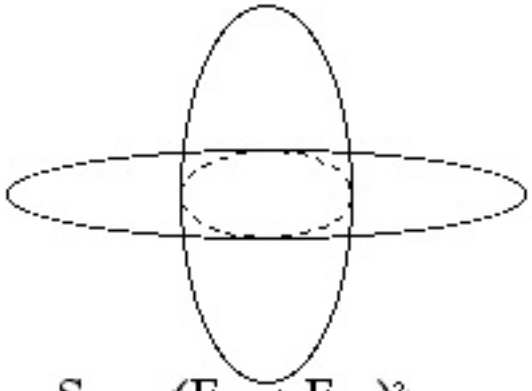
• Problem : 2 data channels only in AOS

→ How to get simultaneous On/Off measurements in pencil mode ?

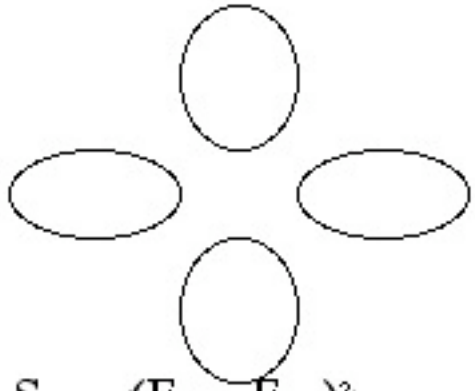
→ Compute $\langle(E_{NS}+E_{EW})^2\rangle - \langle(E_{NS}-E_{EW})^2\rangle = \langle 4\, E_{NS} \times E_{EW}\rangle$

• Difficulty = calibration of two data channels

® Synchronous channel switching

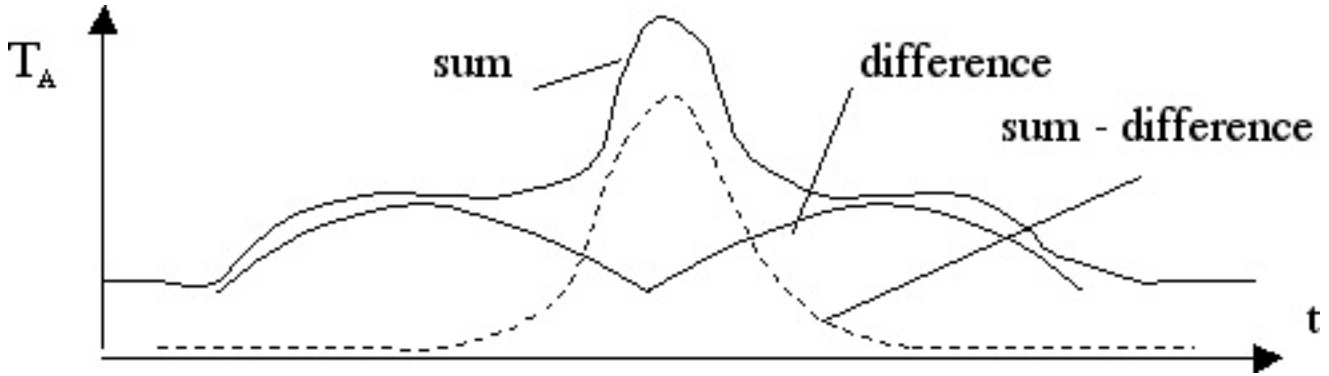


$S_1 = \langle (E_{NS} + E_{EW})^2 \rangle$



$S_2 = \langle (E_{NS} - E_{EW})^2 \rangle$

$\rightarrow \quad S_1 - S_2 = \langle (E_{NS} + E_{EW})^2 \rangle - \langle (E_{NS} - E_{EW})^2 \rangle = \langle 4\, E_1\, E_2 \rangle$



Broadband noise calibration of BSU "upstream" of the switch :

Identical noise sources (S) at input of IF channels 1 & 2

B_1 & B_2 characterize the gain / frequency response of BSU "upstream" of switching

G_1 & G_2 characterize the gain / frequency response of IF + AOS "downstream" of switching

	channel 1	channel2
before switching (spectrum 2n)	$S(f) \times B_1(f) \times G_1(f)$	$S(f) \times B_2(f) \times G_2(f)$
after switching (spectrum 2n+1)	$S \times B_2 \times G_1$	$S \times B_1 \times G_2$
after permutation of spectra (2n+1)	$S \times B_1 \times G_2$	$S \times B_2 \times G_1$
final response after summation of consecutive spectra 2 by 2	$S \times B_1 \times (G_1 + G_2)$	$S \times B_2 \times (G_1 + G_2)$

→ ratio of channel 1 / 2 gives B_1/B_2 = relative gain between channels 1 / 2 of BSU

→ synthesized correlation mode will thus be obtained by :

$$R_1 - R_2 \times B_1/B_2 = (S_1 - S_2) \times B_1 \times (G_1 + G_2)$$

with

$$R_1 = S_1 \times B_1 \times (G_1 + G_2)$$

$$R_2 = S_2 \times B_2 \times (G_1 + G_2)$$

Future

- Correlation mode

- Better RFI mitigation

- Correction of ON by OFF → slow variations, longer integration time

- Other receivers → funding ?