An Algorithm For Type III Solar Radio Bursts Recognition

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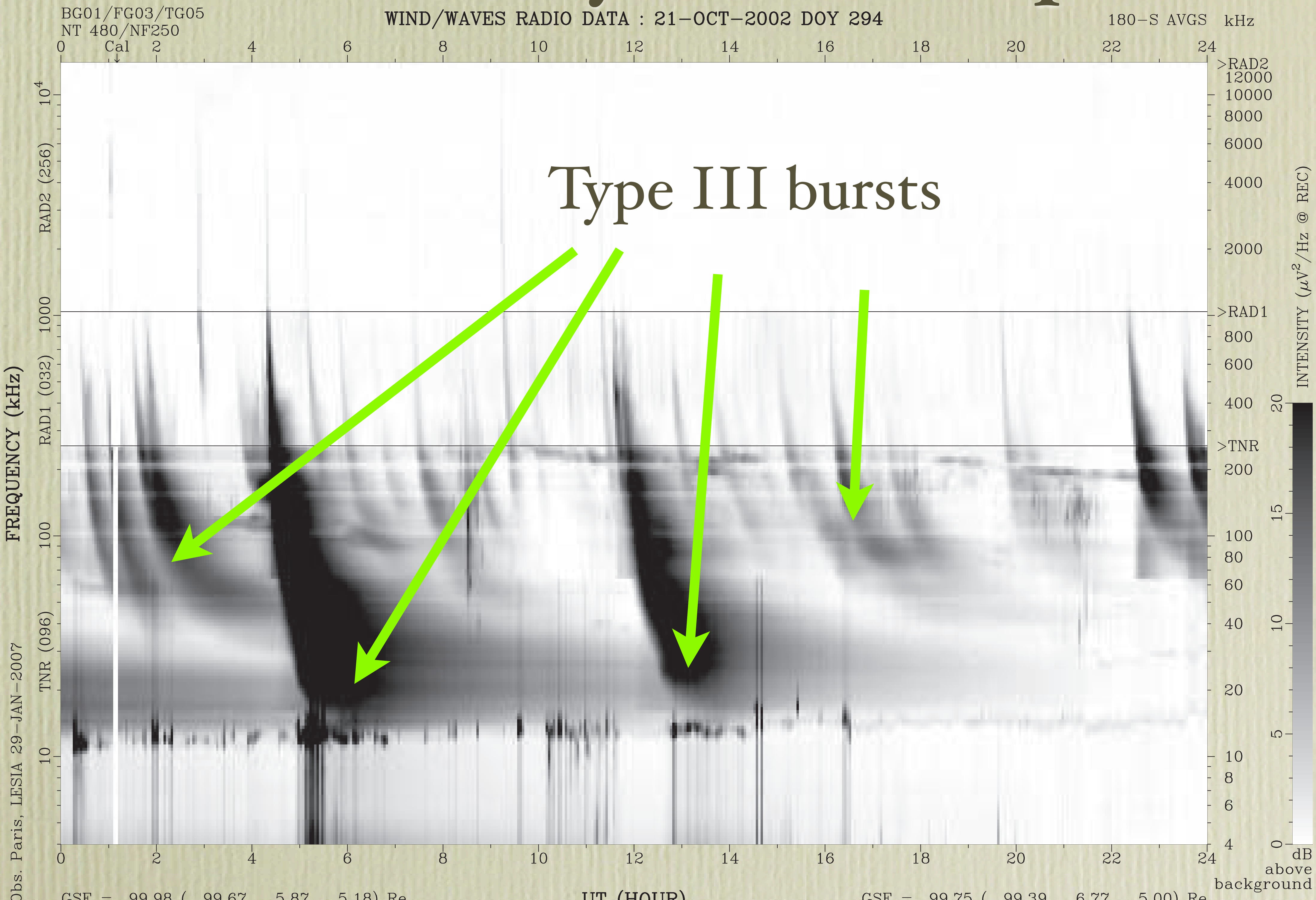
Motivation

- Large amounts of data are already recorded and stored - they continue to grow every day.
- People have no time to analyze this data - human attention has become the precious resource.
- So, we must find ways to automatically analyze the data, to automatically classify it, summarize it, to discover and characterize trends in it, to automatically flag anomalies etc.

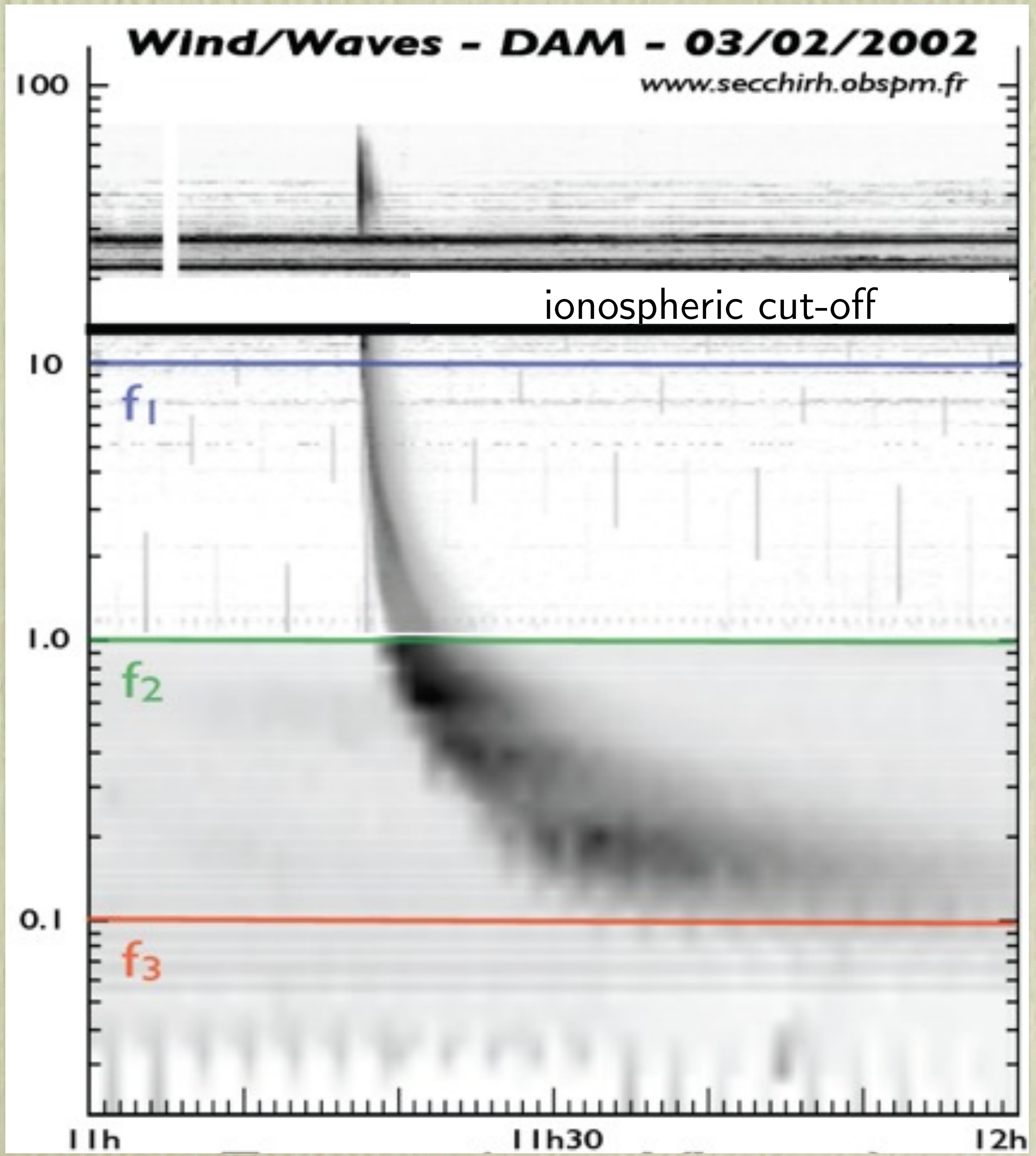
Observations, dynamical spectrum

Frequency [4 kHz- 14 MHz]



Time [24 h]

Type III Bursts from the Sun



- Short (sec → hrs) & very intense (→10-14 Wm-2Hz-1) radio emissions;
- Emission frequencies decrease rapidly with time (GHz → kHz);
- Emission at fundamental plasma frequency or at its harmonic;
- Often associated with solar flares;
- Associated with the propagation of electrons supra-thermal (c/10 → c/3);

TIII's Frequency Drift*) (1/2)

- The frequency, related to the local plasma frequency ($f_{pl} \propto \sqrt{n_e}$, $n_e \propto 1/R^2$, $f_{pl} \propto 1/R$), drifts downward as the emission region rapidly propagates outward.
- Since the radio burst is generated by local plasma emission processes, radio emissions at high frequencies (high plasma densities) occur very near the Sun ~ $2R_\odot$ for 16 MHz, while those at low frequencies (low plasma densities) occur far from the Sun (~ 1 AU) for 20 kHz.
- Type III radio bursts are therefore characterized by a rapid drift to lower frequencies due to the near-relativistic speeds of the radio emitting electrons.

*) Vidojevic S., Maksimovic M.: P*reliminary Analysis of Type III Radio Bursts from STEREO/SWAVES Data*, XV National Conference of Astronomers of Serbia, 2–5 October 2008, Belgrade, Serbia, Publ. Astron. Obs. Belgrade No. **86** (2009), 287 - 291. http://publications.aob.rs/86/pdf/287-291.pdf

TIII's Frequency Drift*) (2/2)

- For about 100 bursts automatically detected we have computed the frequency drift rates obtained from all the maxima of the power spectral density profiles at each of the covered frequencies. The profiles are fitted by Gram-Charlier type A function.

- Obtained maxima are further aproximated by linear function in log-log scale.

- **$df/dt = -10^a f^\alpha$**. The negative sign denotes that the starting frequency is observed to drift from high to low values. The least square fit of a straight line through all of observed maxima gives:

- **$\alpha = 1.80 \pm 0.05$ and $a = -1.70 \pm 0.03$.**

Modelling*)

- The choice of the best-suited statistical distribution for data modelling is not a trivial issue;
- Unless a sound theoretical background exists for selecting a particular distribution, one will usually try to test various candidates and select a distribution based on its fit to the observed data;
- It is more efficient to define a sufficiently general family that can be used for this purpose.

*) S. Vidojevic Shape Modelling with Family of Pearson Distributions, 9th SerbianConference on Spectral Line Shapes in Astrophysics, Banja Koviljaca, Serbia, May 13-17, 2013, Book of abstracts, p. 52, http://www.scslsa.matf.bg.ac.rs/Book_of_abstracts_9thSCSLSA.pdf

Pearson system - great diversity of shapes:

- unimodal, bimodal, U-shaped, J-shaped and monotone probability distribution functions,
- ...which may be symmetric and asymmetric, concave and convex,
- ...with smooth, abrupt, truncated, long, medium or short tails.

Pearson system*)

- First derivative of probability density function:

$$\frac{1}{f(x)}\frac{\mathrm{d}f(x)}{\mathrm{d}x} = -\frac{a+x}{c_0+c_1x+c_2x^2}$$

- Asymmetry ($As^2 = \beta_1$)

$$\beta_1 = \frac{\mu_3^2}{\mu_2^2}$$

- Excess (β_2)

$$\beta_2 = \frac{\mu_4}{\mu_2^2}$$

Using only 2 parameters: Squared Asymmetry (β_1) and Excess (β_2), calculated from observations, Type of Pearson distribution can be retrieved.

*) Pearson, K.: 1895, *Contributions to the Mathematical Theory of Evolution. II. Skew Variation in Homogeneous Material.* Philosophical Transactions of the Royal Society of London, **186**, 343 – 414

Method of moments

$$c_0 = (4\beta_2 - 3\beta_1)(10\beta_2 - 12\beta_1 - 18)^{-1}\mu_2$$

$$a = c_1 = \sqrt{\beta_1}(\beta_2 + 3)(10\beta_2 - 12\beta_1 - 18)^{-1}\sqrt{\mu_2}$$

$$c_2 = (2\beta_2 - 3\beta_1 - 6)(10\beta_2 - 12\beta_1 - 18)^{-1}$$

$$\kappa = \frac{1}{4}c_1^2(c_0c_2)^{-1} = \frac{1}{4}\beta_1(\beta_2 + 3)^2(4\beta_2 - 3\beta_1)^{-1}(2\beta_1 - 6)^{-1}$$

Classification

I: $\kappa < 0$

II: $\beta_1 = 0,\ \beta_2 < 3$

III: $2\beta_2 - 3\beta_1 - 6 = 0$

IV: $0 < \kappa < 1$

V: $\kappa = 1$

VI: $\kappa > 1$

VII: $\beta_1 = 0,\ \beta_2 > 3$

Method of Maximum Likelihood

Likelihood function

$$L(\boldsymbol{\theta}|\mathbf{x}) \equiv f(\mathbf{x}|\boldsymbol{\theta}) = \prod_{i=1}^{n} f_i(x_i|\boldsymbol{\theta})$$

applying logarithm, one obtain:

$$\mathcal{L}(\boldsymbol{\theta}|\mathbf{x}) = \ln L(\boldsymbol{\theta}|\mathbf{x}) = \sum_{i=1}^{n} \ln f_i(x_i|\boldsymbol{\theta})$$

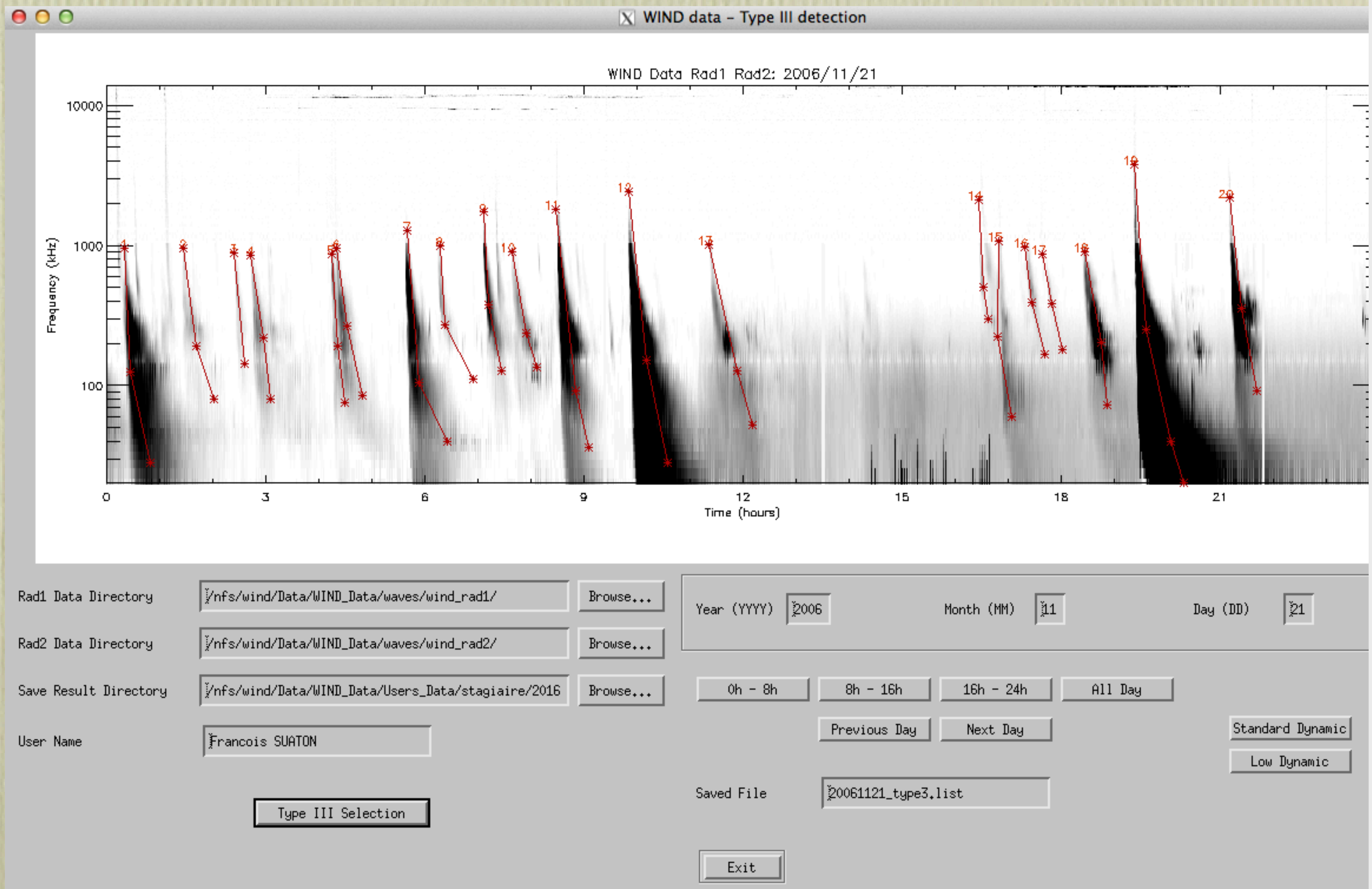
Looking for $\boldsymbol{\theta}^*$

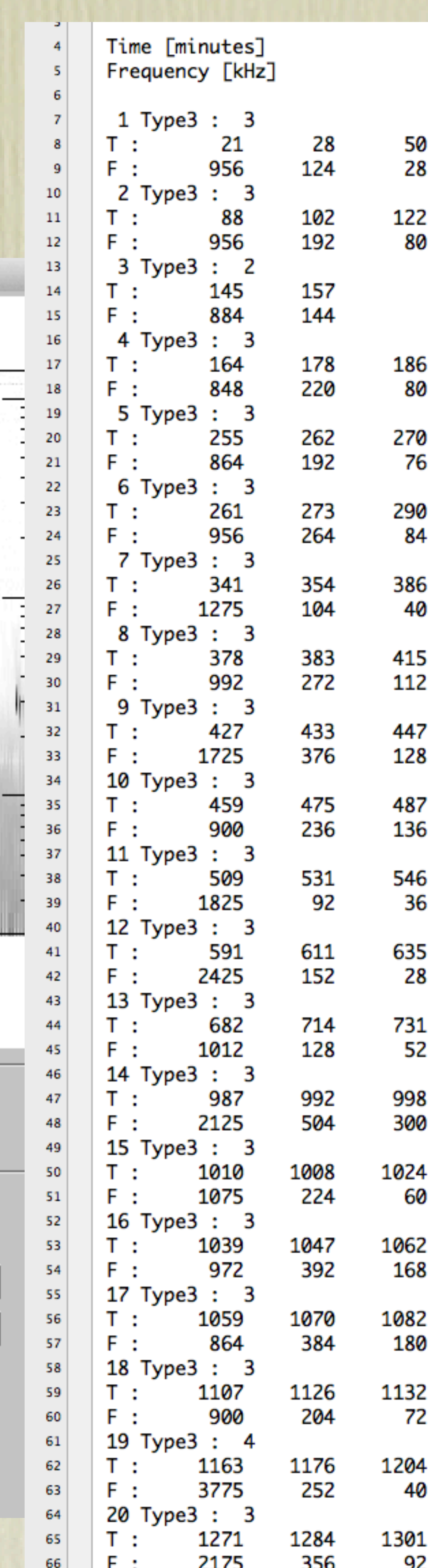
- Looking for $\boldsymbol{\theta}^*$ which maximizes likelihood

$$\mathcal{L}(\boldsymbol{\theta^*}|\mathbf{x}) = \max_{\boldsymbol{\theta}} \mathcal{L}(\boldsymbol{\theta}|\mathbf{x}) = \max_{\boldsymbol{\theta}} \sum_{i=1}^{n} \ln f_i(x_i|\boldsymbol{\theta})$$

- It is not possible to solve this task analytically, thus, we apply numerical methods of optimization.

Manual Detection



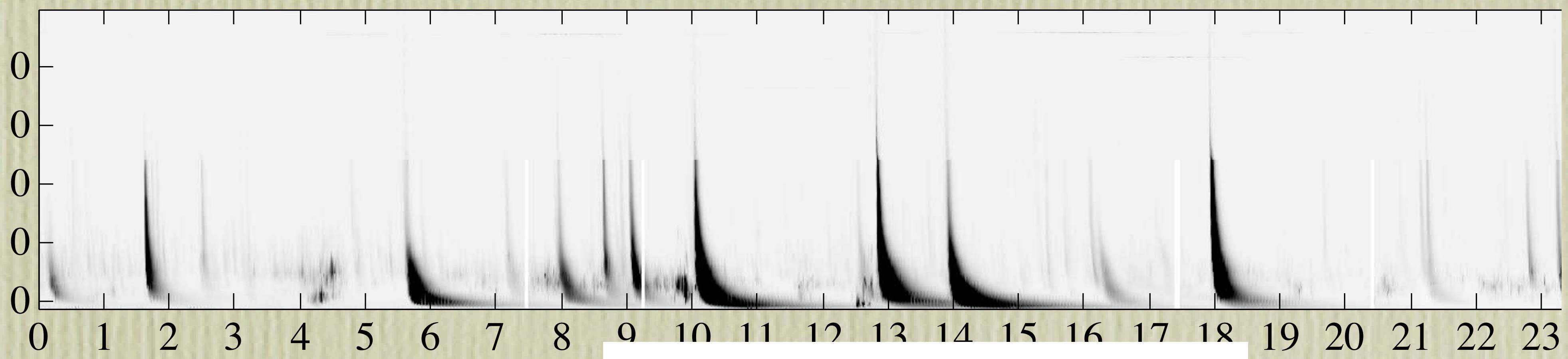


Time [minutes]
Frequency [kHz]

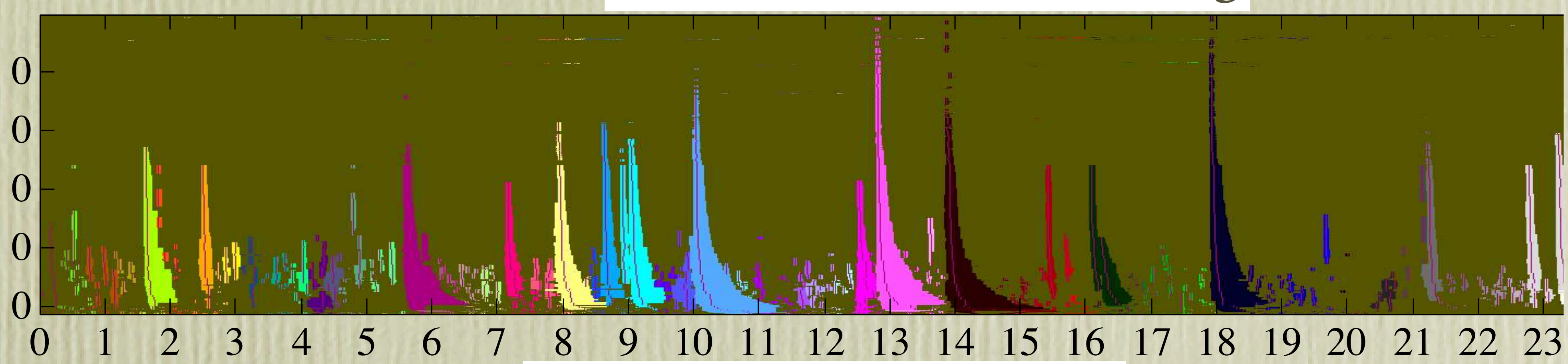
1 Type3 : 3			
T :	21	28	50
F :	956	124	28
2 Type3 : 3			
T :	88	102	122
F :	956	192	80
3 Type3 : 2			
T :	145	157	
F :	884	144	
4 Type3 : 3			
T :	164	178	186
F :	848	220	80
5 Type3 : 3			
T :	255	262	270
F :	864	192	76
6 Type3 : 3			
T :	261	273	290
F :	956	264	84
7 Type3 : 3			
T :	341	354	386
F :	1275	104	40
8 Type3 : 3			
T :	378	383	415
F :	992	272	112
9 Type3 : 3			
T :	427	433	447
F :	1725	376	128
10 Type3 : 3			
T :	459	475	487
F :	900	236	136
11 Type3 : 3			
T :	509	531	546
F :	1825	92	36
12 Type3 : 3			
T :	591	611	635
F :	2425	152	28
13 Type3 : 3			
T :	682	714	731
F :	1012	128	52
14 Type3 : 3			
T :	987	992	998
F :	2125	504	300
15 Type3 : 3			
T :	1010	1008	1024
F :	1075	224	60
16 Type3 : 3			
T :	1039	1047	1062
F :	972	392	168
17 Type3 : 3			
T :	1059	1070	1082
F :	864	384	180
18 Type3 : 3			
T :	1107	1126	1132
F :	900	204	72
19 Type3 : 4			
T :	1163	1176	1204
F :	3775	252	40
20 Type3 : 3			
T :	1271	1284	1301
F :	2175	356	92

Automatic Recognition Example 1

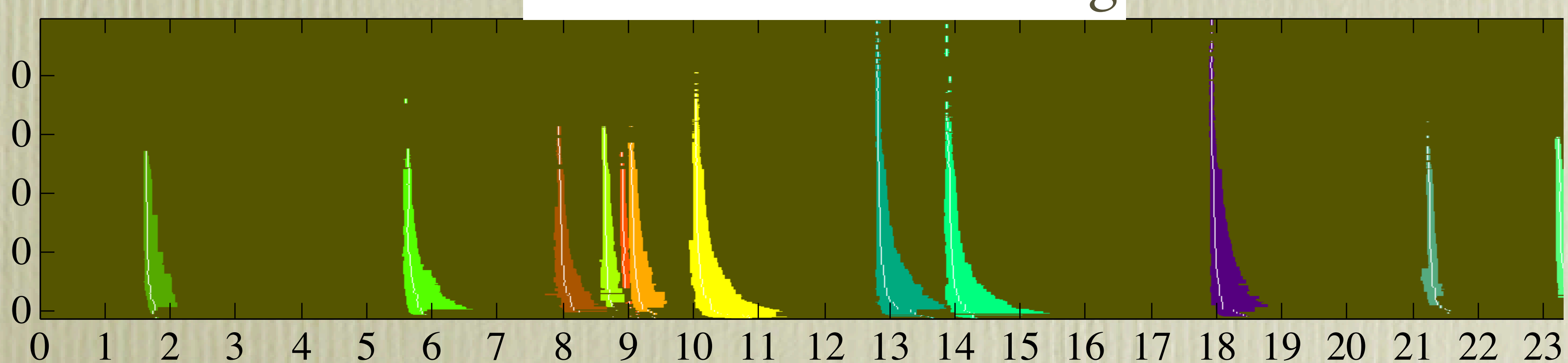
Original data 19971123



Candidates before filtering



Candidates after filtering

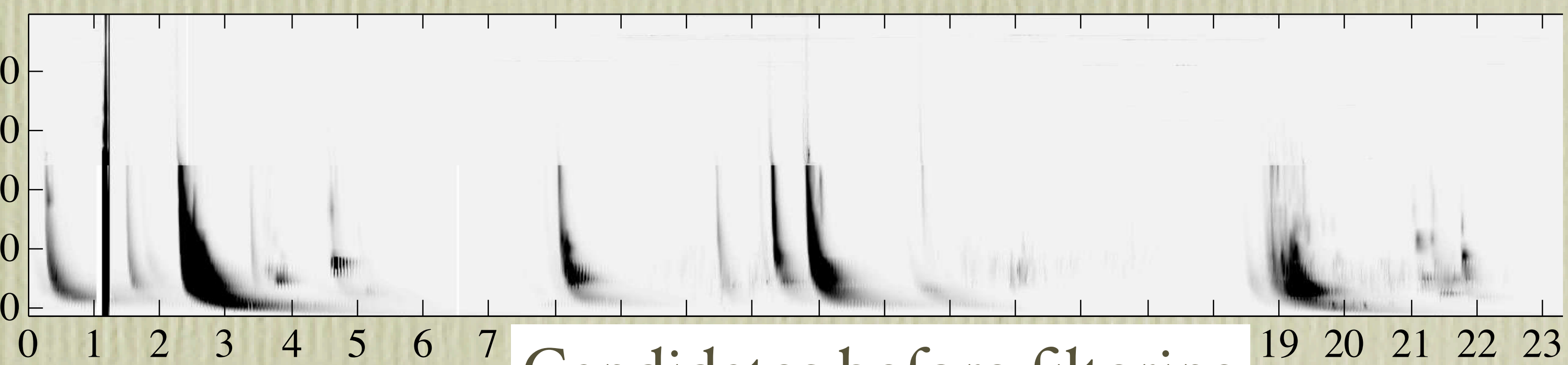


Processing date: 19971123 with parameters:
find_peaks_cutoff: 1.8
find_peaks_slope: 0.2
find_peaks_peakchkdist: 5
find_hills_maxdistforcontnext: 3
find_hills_overlaptol: -4
find_hills_maxdistforcontall: 15
find_hills_peakvalchangetol: [0.5 2]
filter_hills_noisedetect: [4 100 10]
filter_hills_maxdistforcont: 20
filter_hills_minhilllen: 50
filter_hills_notbelowfreq: 1.1
filter_hills_shapecheck: [1 1]
filter_hills_delreport: [0 0 0 0 0 1 1]
image_hills_peakvalue: 50

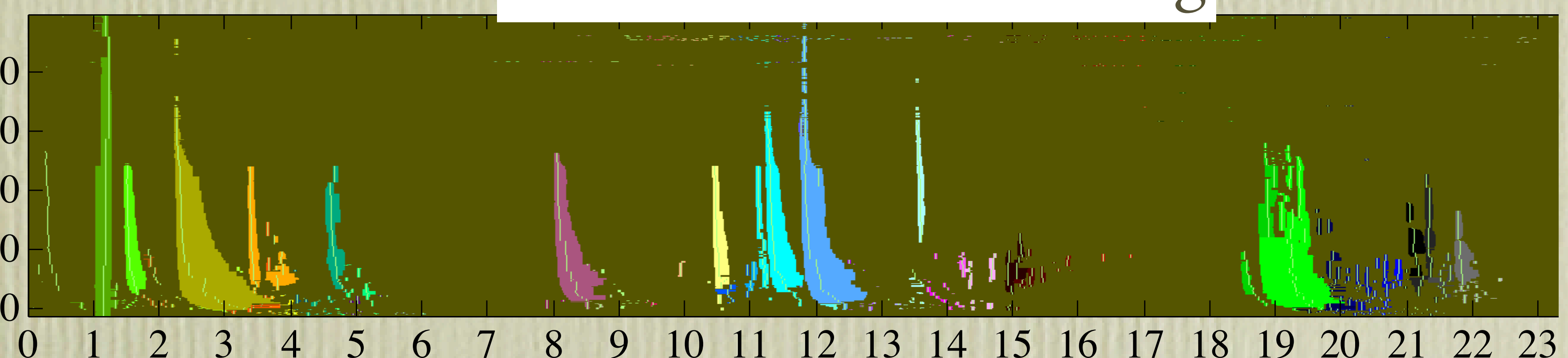
Hills before filtering: 194
Hills after filtering: 12
Results saved to data/19971123_res.mat

Automatic Recognition Example 2

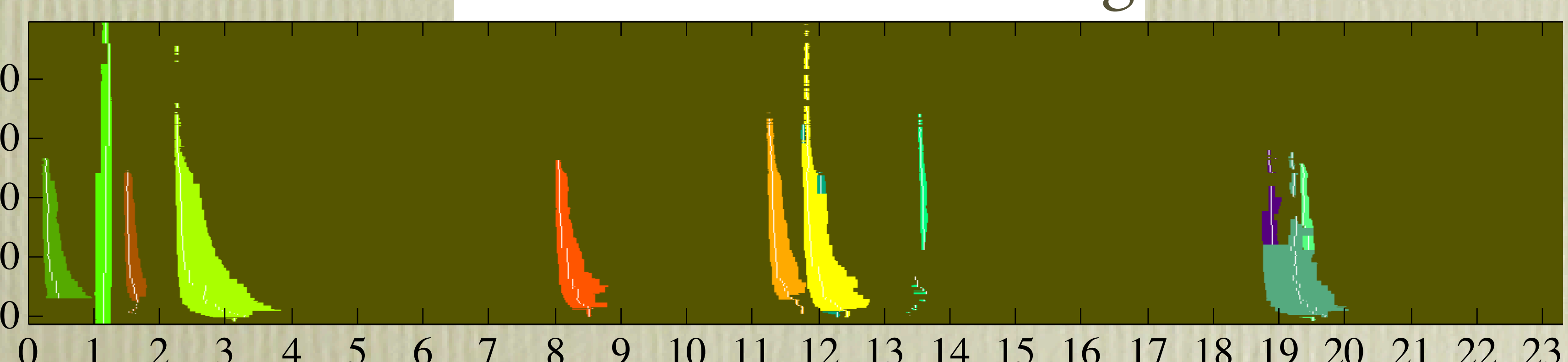
Original data 20020703



Candidates before filtering



Candidates after filtering



- Processing date: 20020703 with parameters:

find_peaks_cutoff: 1.8
find_peaks_slope: 0.2
find_peaks_peakchkdist: 5
find_hills_maxdistforcontnext: 3
find_hills_overlaptol: -4
find_hills_maxdistforcontall: 15
find_hills_peakvalchangetol: [0.5 2]
filter_hills_noisedetect: [4 100 10]
filter_hills_maxdistforcont: 20
filter_hills_minhilllen: 50
filter_hills_notbelowfreq: 1.1
filter_hills_shapecheck: [1 1]
filter_hills_delreport: [0 0 0 0 0 1 1]
image_hills_peakvalue: 50

Hills before filtering: 164
Take out hill 126 at 19.08 h : not convex (-3.719713)
Hills after filtering: 12
Results saved to data/20020703_res.mat

More data - satellites:

- WIND spacecraft, launched 1994, still operating.
- STEREO A and B, launched 2006, still operating.
- Solar Probe Plus, to be launched in 2018.
- Solar Orbiter, to be launched in 2019.

Literature

- Vidojevic S., Maksimovic M.: P*reliminary Analysis of Type III Radio Bursts from STEREO/SWAVES Data*, XV National Conference of Astronomers of Serbia, 2–5 October 2008, Belgrade, Serbia, Publ. Astron. Obs. Belgrade No. **86** (2009), 287 - 291. http://publications.aob.rs/86/pdf/287-291.pdf

- S. Vidojevic Shape Modelling with Family of Pearson Distributions, 9th SerbianConference on Spectral Line Shapes in Astrophysics, Banja Koviljaca, Serbia, May 13-17, 2013, Book of abstracts, p. 52, http://www.scslsa.matf.bg.ac.rs/Book_of_abstracts_9thSCSLSA.pdf

- Pearson, K.: 1895, *Contributions to the Mathematical Theory of Evolution. II. Skew Variation in Homogeneous Material.* Philosophical Transactions of the Royal Society of London, **186**, 343 – 414.

- Sir Ronald Aylmer Fisher (1890-1962) for the first time presented the idea in 1912 (when he was 22 years old) in the article: On an absolute criterion for fitting frequency curves, Messenger of Mathematics (1912), **41,** 155-160.