6T2: Fundamental frequency detection

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- F0 detection in time domain
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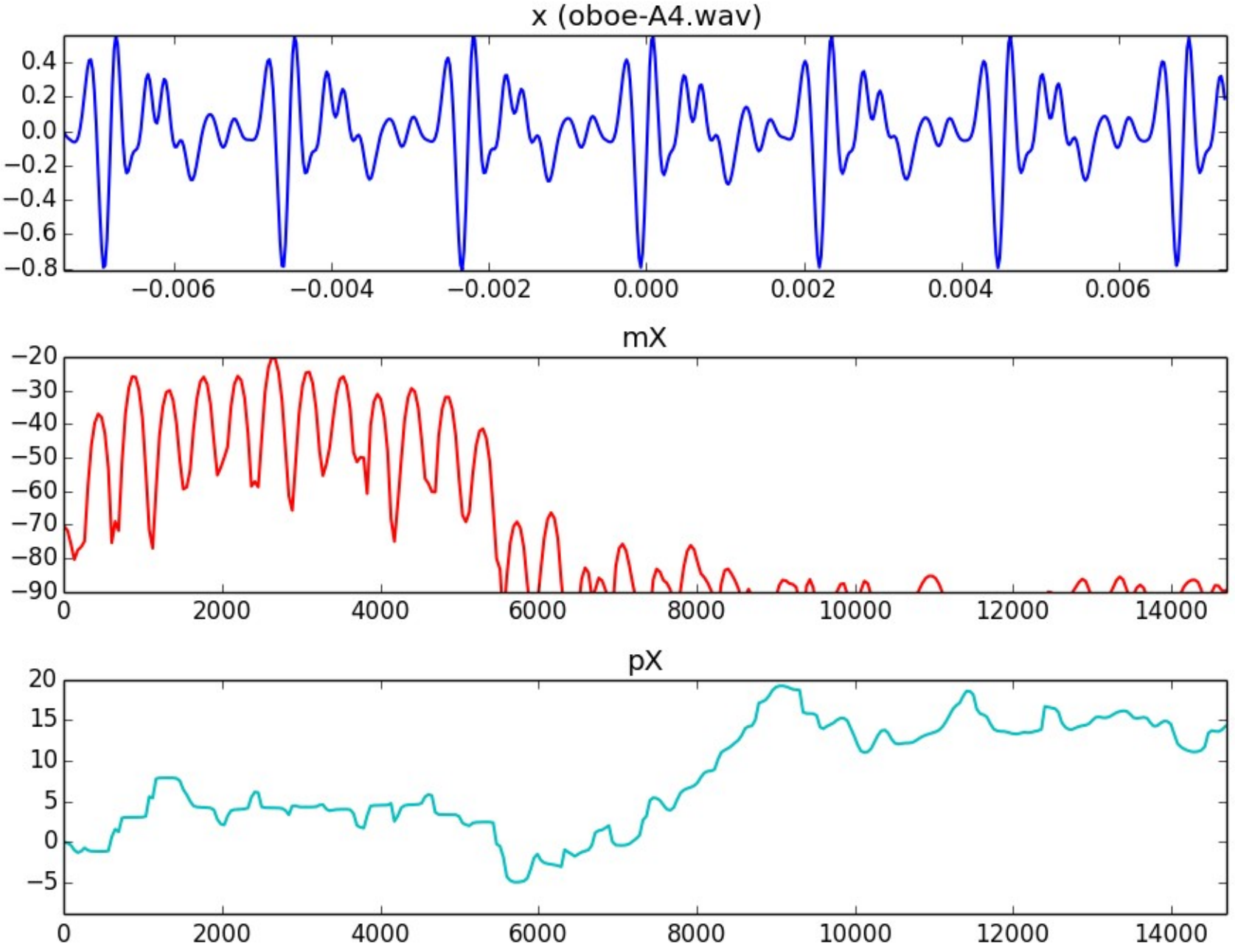
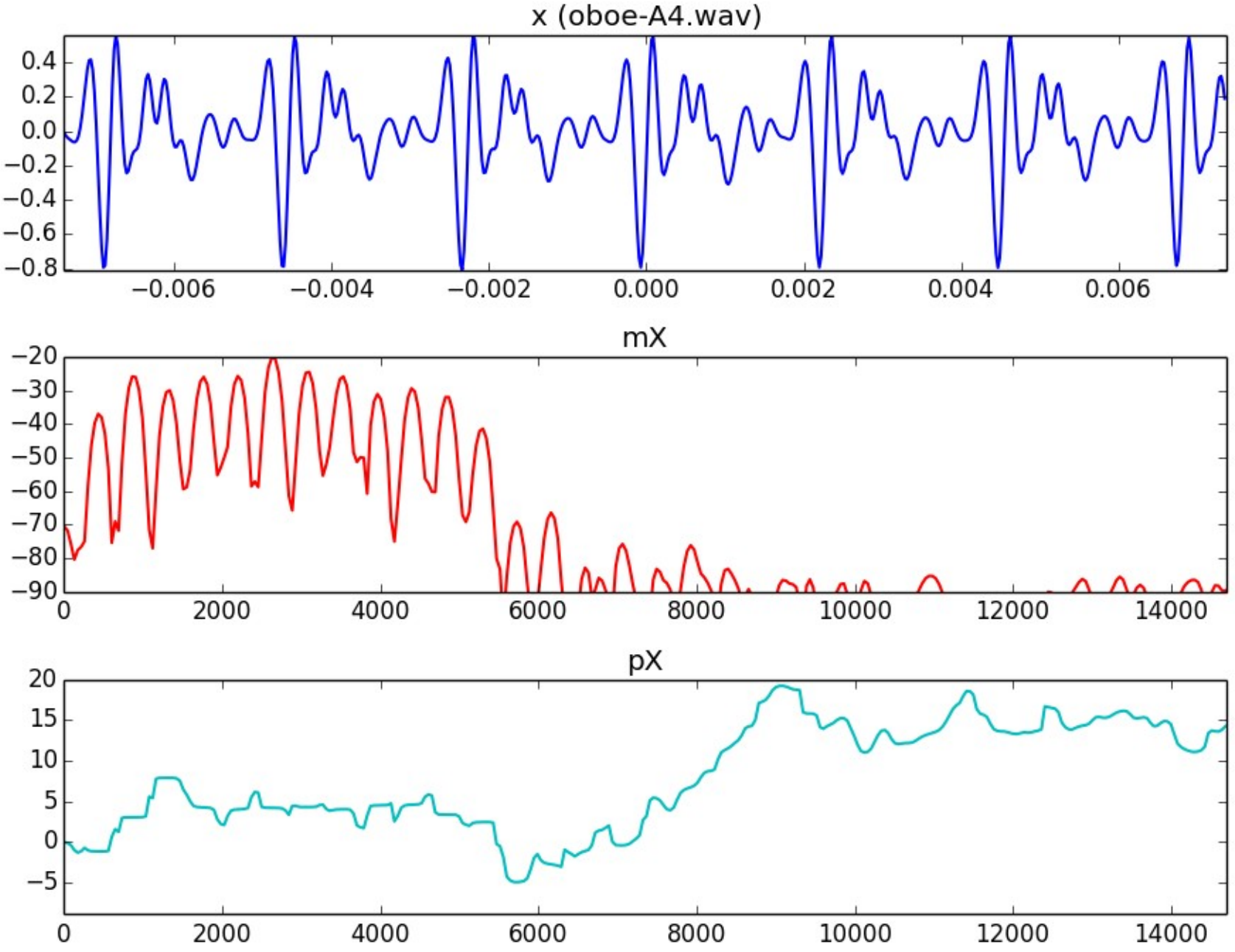

x (oboe-A4.wav)
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−0.006
−0.004
−0.002
0.000
0.002
0.004
0.006
mX
−20
−30
−40
−50
−60
−70
−80
−90
0
2000
4000
6000
8000
10000
12000
14000
pX
20
15
10
5
0
−5
0
2000
4000
6000
8000
10000
12000
14000


x (oboe-A4.wav)
0.4
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−0.2
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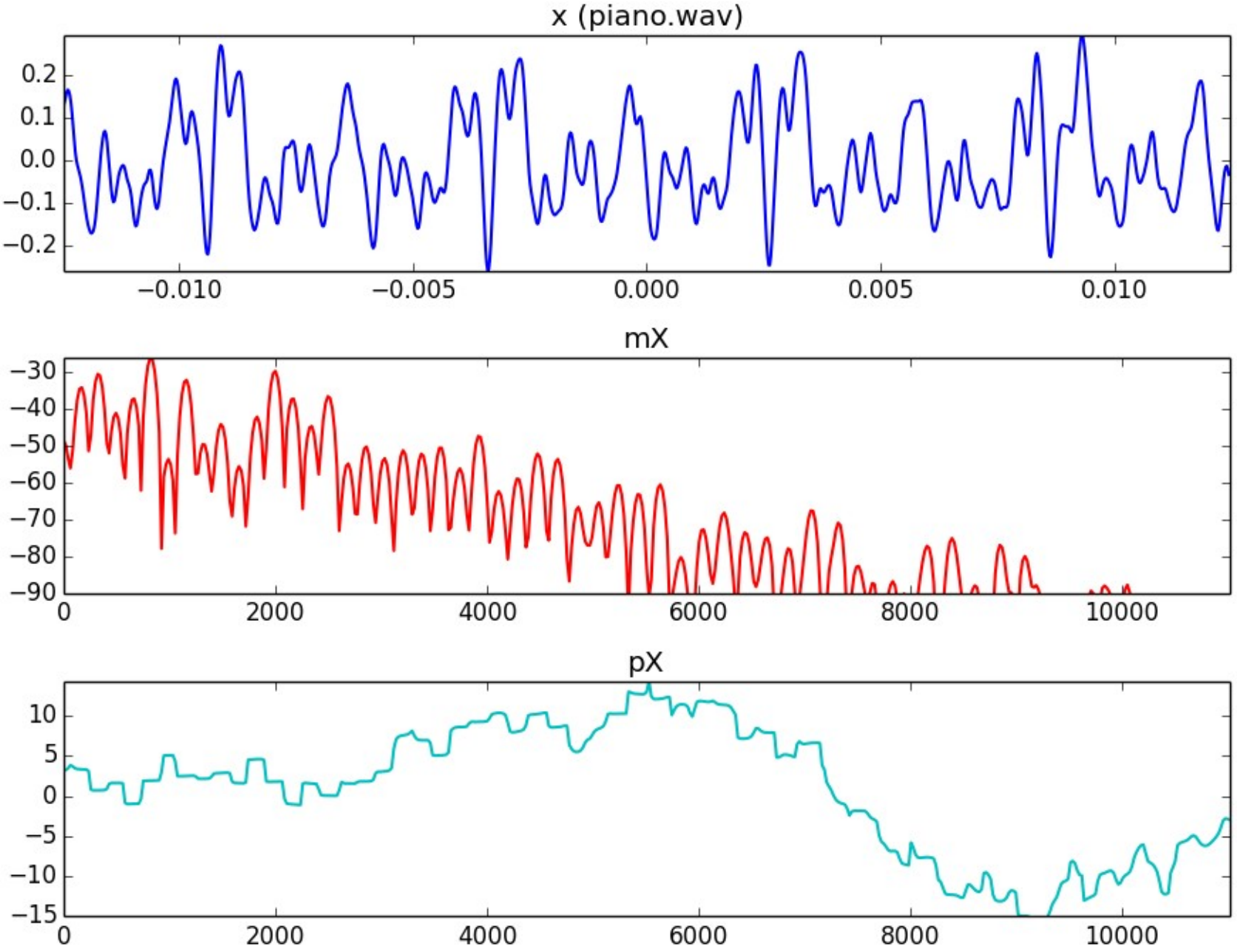
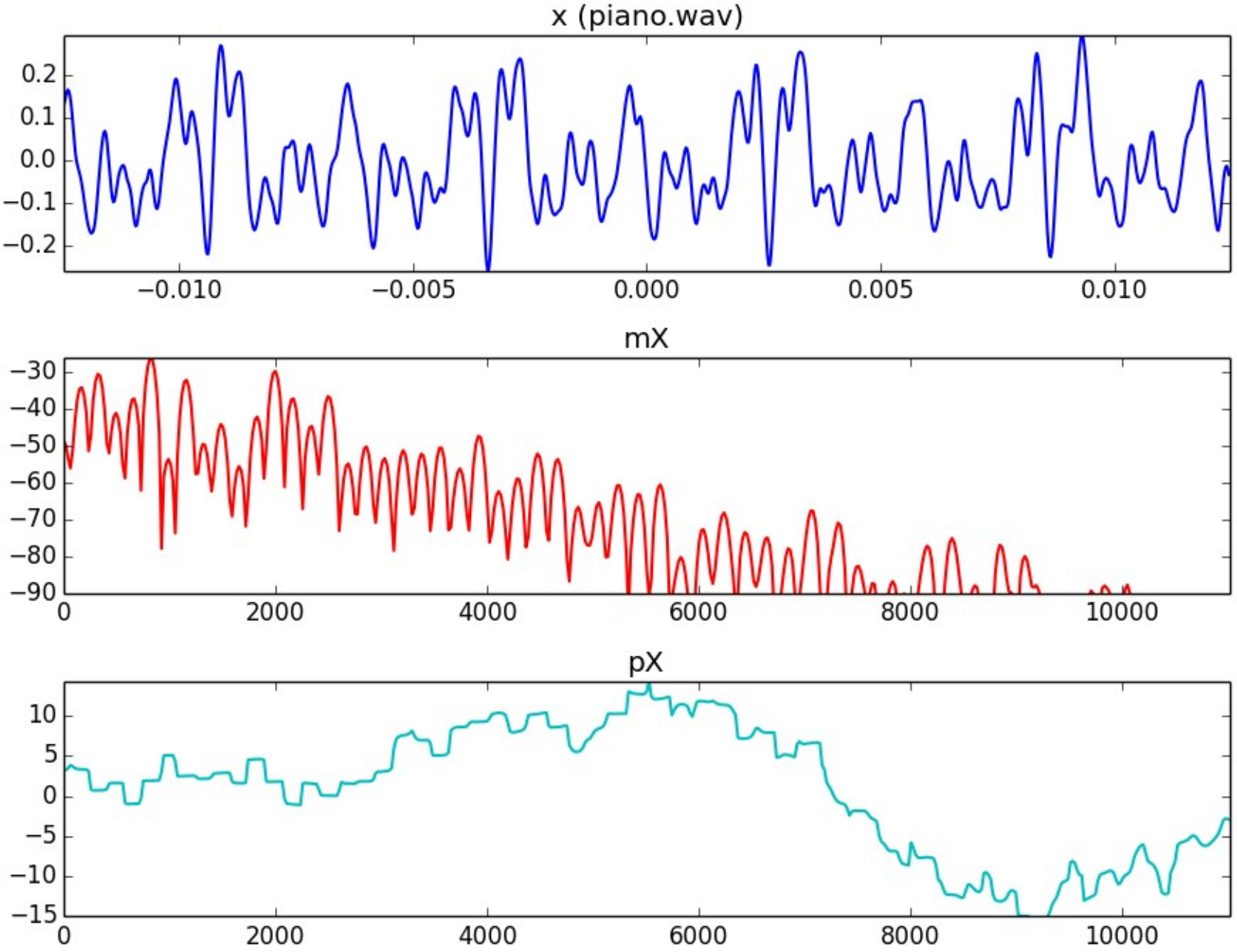
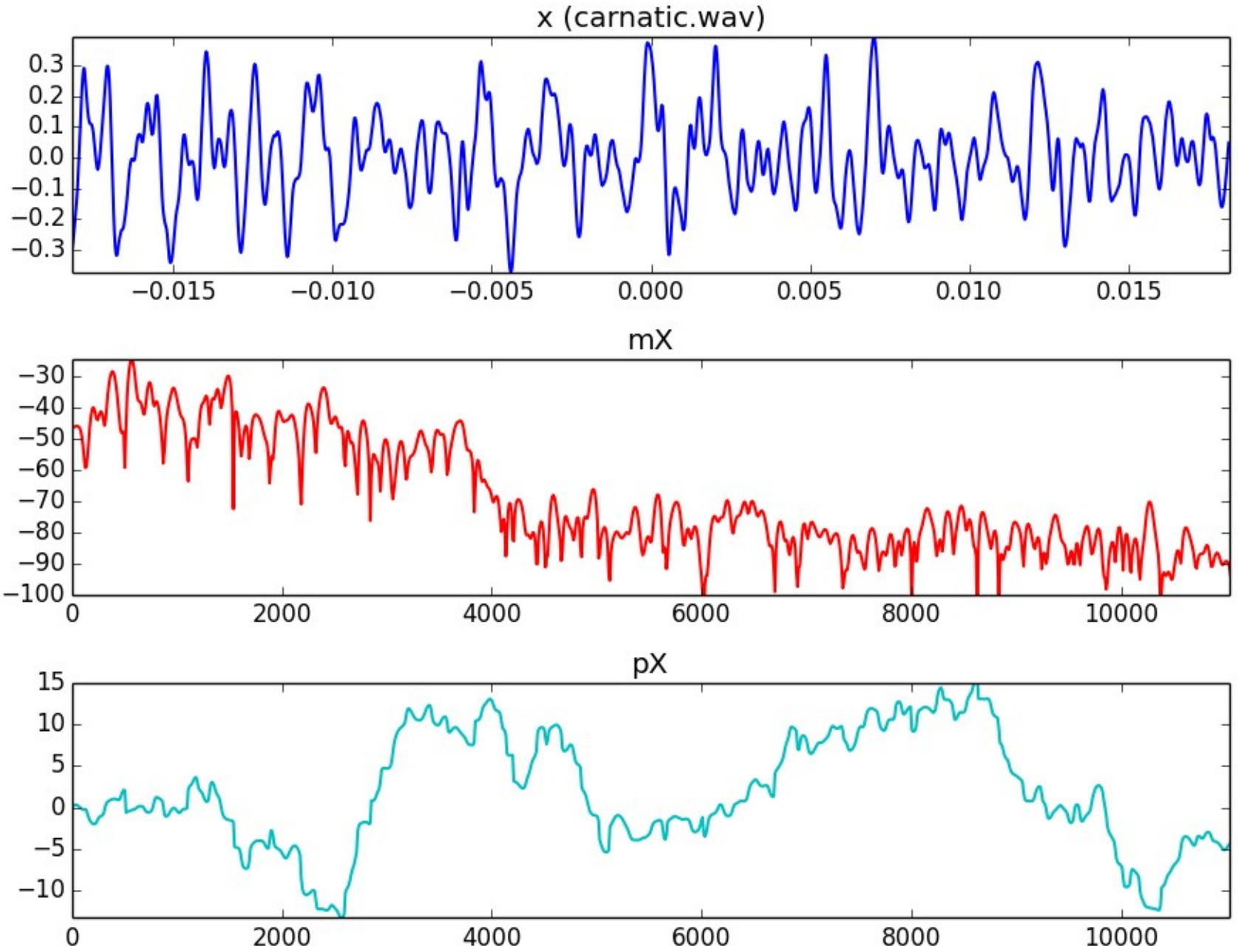
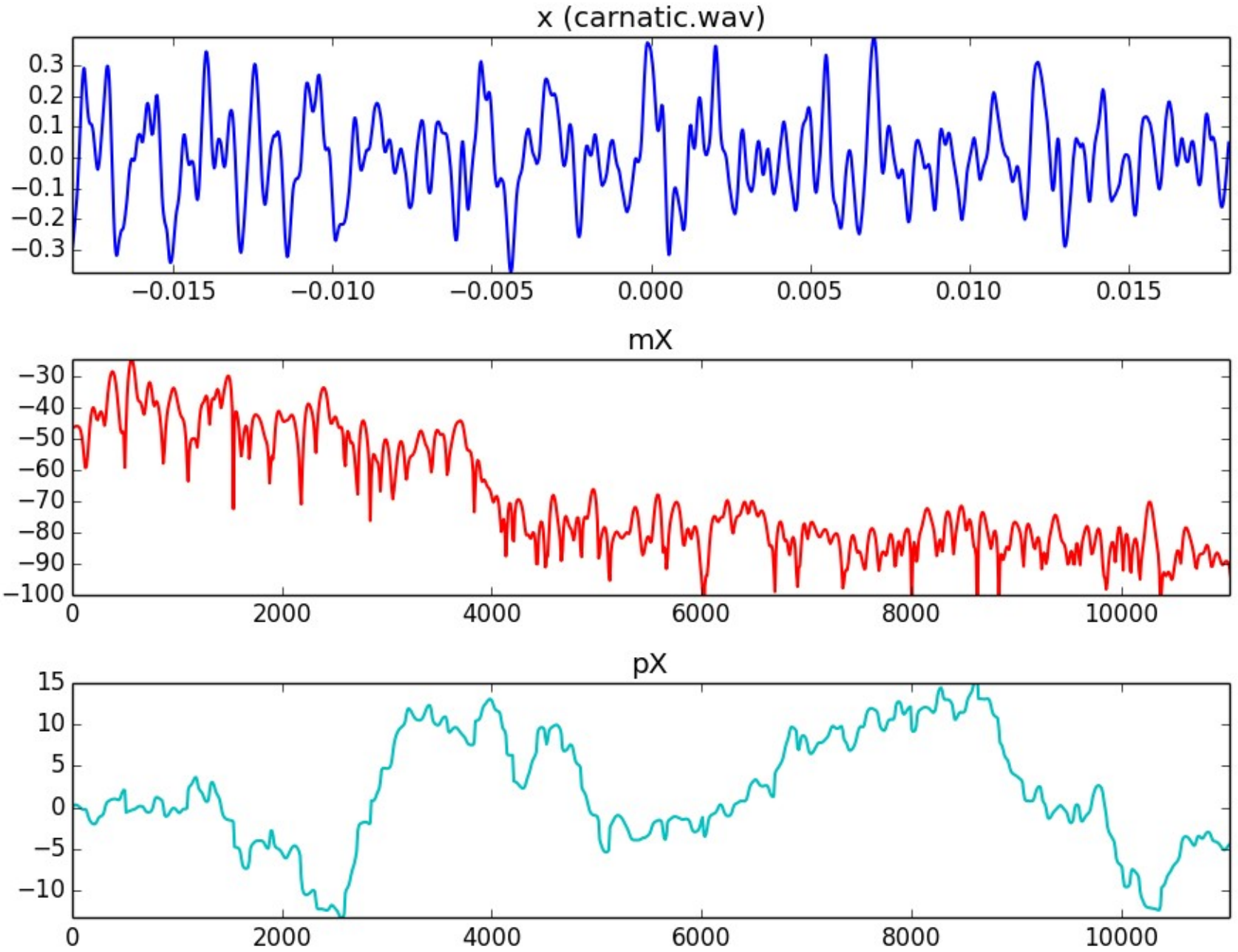
−0.8
−0.006
−0.004
−0.002
0.000
0.002
0.004
0.006
mX
−20
−30
−40
−50
−60
−70
−80
−90
0
2000
4000
6000
8000
10000
12000
14000
pX
20
15
10
5
0
−5
0
2000
4000
6000
8000
10000
12000
14000


x (piano.wav)
0.2
0.1
0.0
−0.1
−0.2
−0.010
−0.005
0.000
0.005
0.010
mX
−30
−40
−50
−60
−70
−80
−90
0
2000
4000
6000
8000
10000
pX
10
5
0
−5
−10
−15
0
2000
4000
6000
8000
10000


x (piano.wav)
0.2
0.1
0.0
−0.1
−0.2
−0.010
−0.005
0.000
0.005
0.010
mX
−30
−40
−50
−60
−70
−80
−90
0
2000
4000
6000
8000
10000
pX
10
5
0
−5
−10
−15
0
2000
4000
6000
8000
10000


x (carnatic.wav)
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.015
−0.010
−0.005
0.000
0.005
0.010
0.015
mX
−30
−40
−50
−60
−70
−80
−90
−100
0
2000
4000
6000
8000
10000
pX
15
10
5
0
−5
−10
0
2000
4000
6000
8000
10000

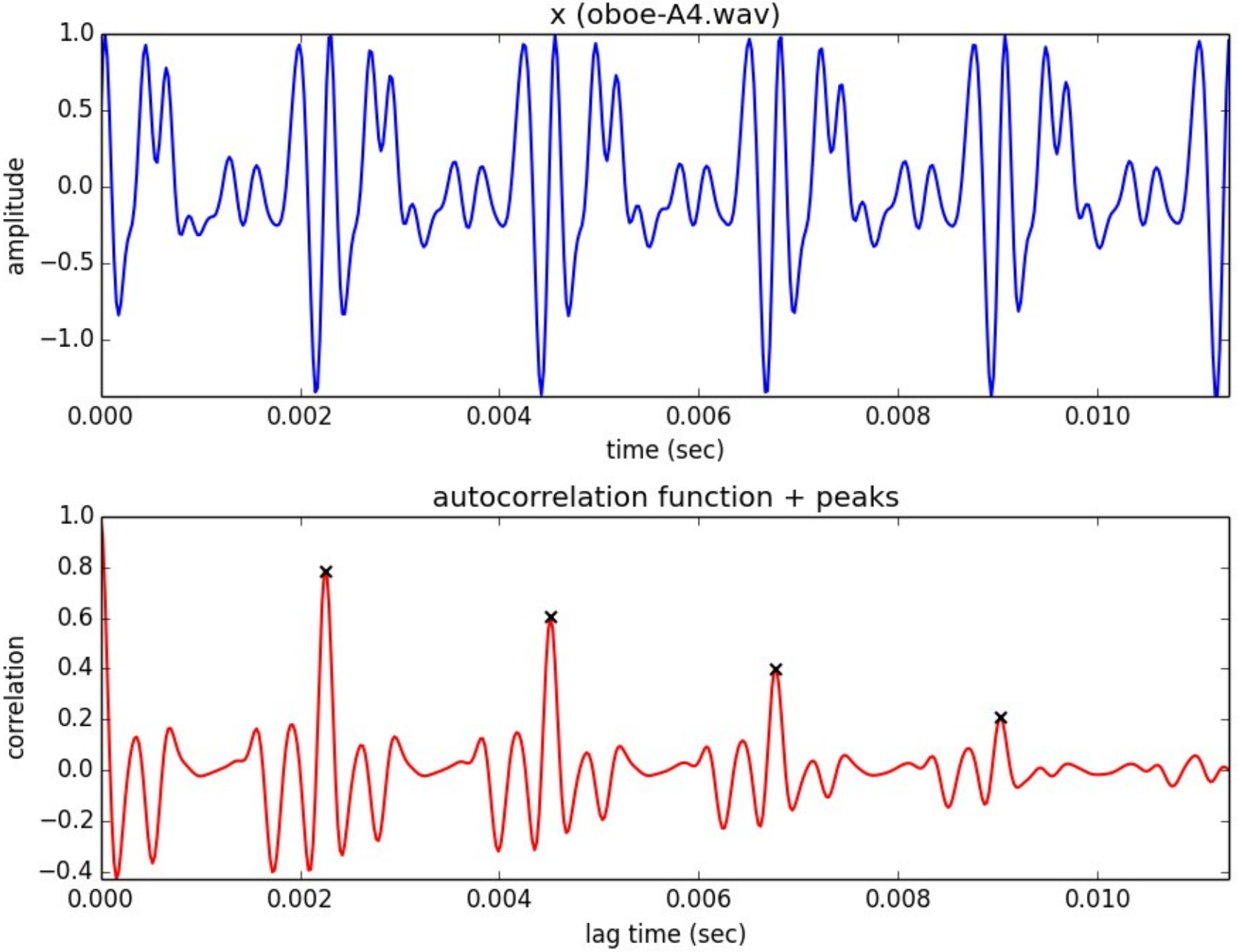

x (carnatic.wav)
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.015
−0.010
−0.005
0.000
0.005
0.010
0.015
mX
−30
−40
−50
−60
−70
−80
−90
−100
0
2000
4000
6000
8000
10000
pX
15
10
5
0
−5
−10
0
2000
4000
6000
8000
10000

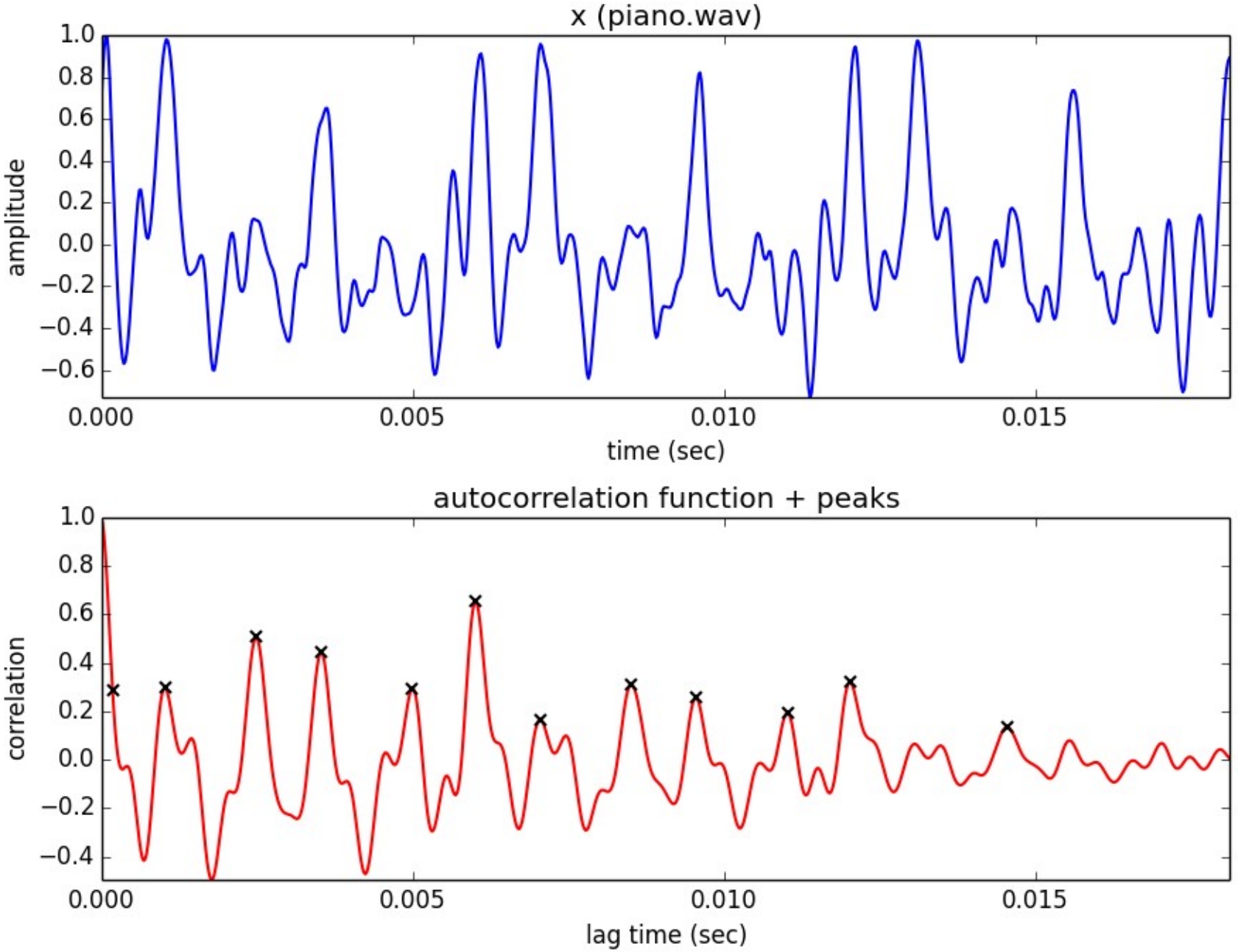
F0 detection in time domain

Autocorrelation function (with tapering)

$$r_x[l] = \sum_{n=0}^{n=N-1-l} x[n]x[n+l] \qquad l = 0,1,\ldots,N-1$$

where $l = \text{lag}$

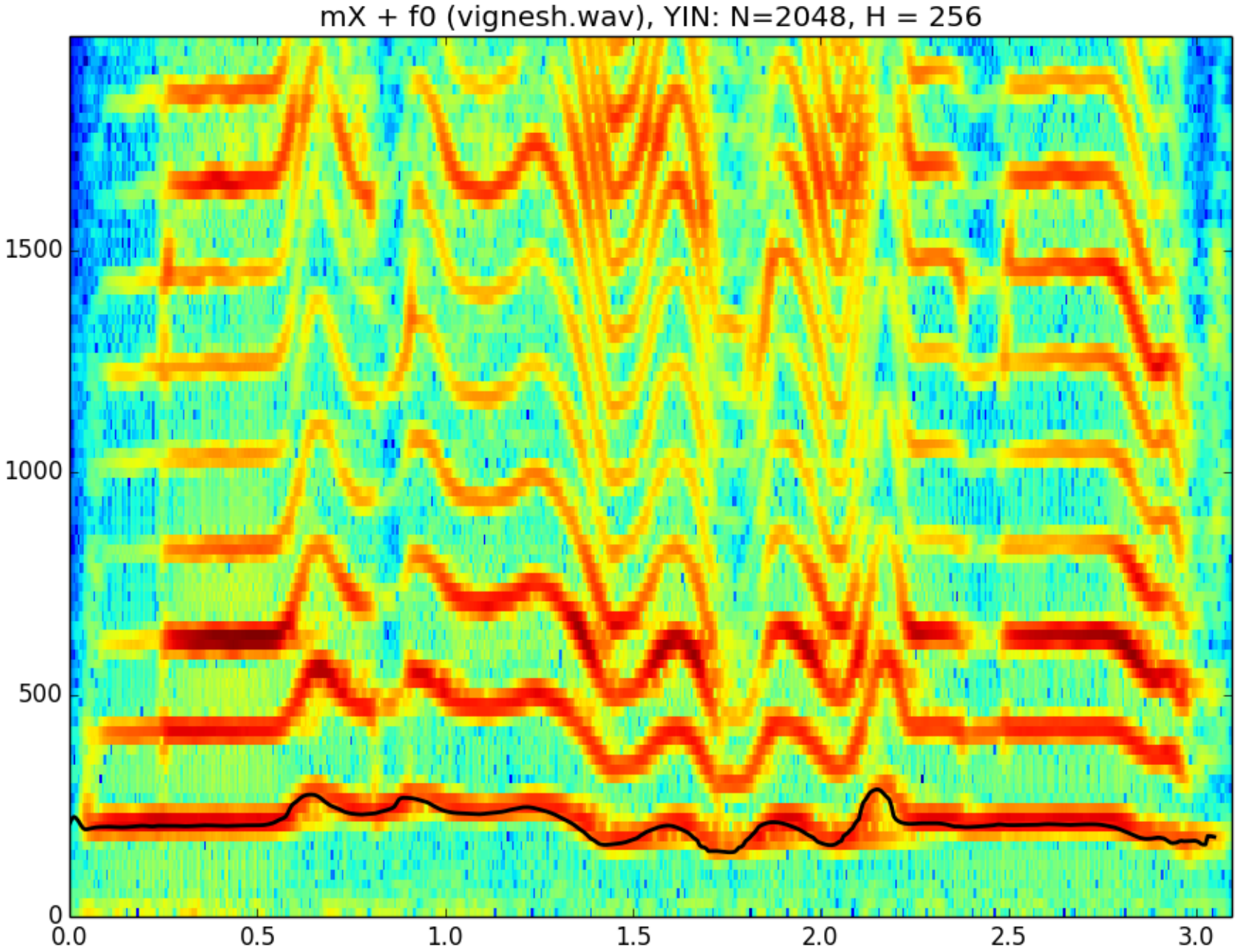

x (oboe-A4.wav)
amplitude
1.0
0.5
0.0
−0.5
−1.0
0.000
0.002
0.004
0.006
0.008
0.010
time (sec)
autocorrelation function + peaks
correlation
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
0.000
0.002
0.004
0.006
0.008
0.010
lag time (sec)

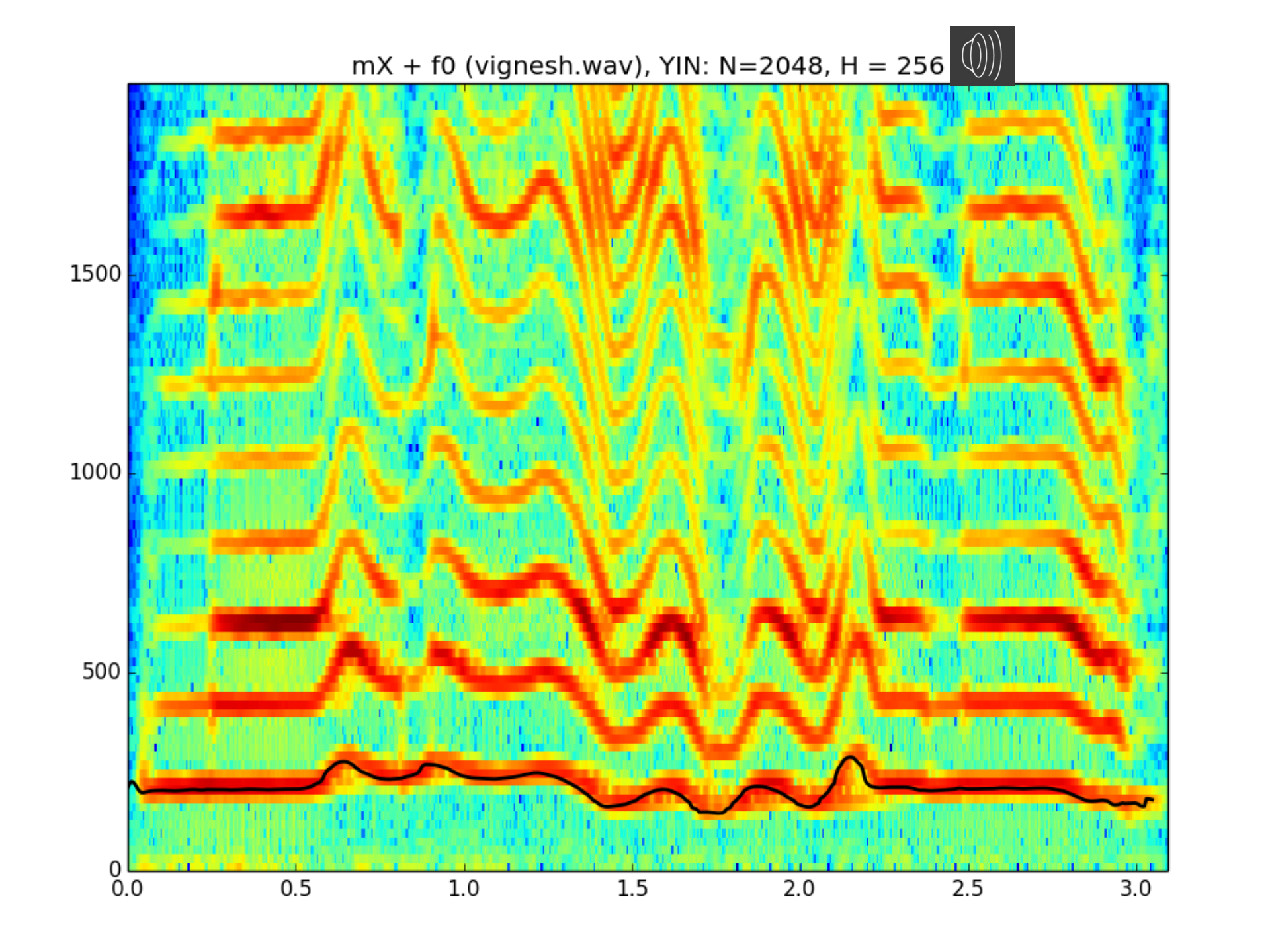

x (piano.wav)
amplitude
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
0.000
0.005
0.010
0.015
time (sec)
autocorrelation function + peaks
correlation
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
0.000
0.005
0.010
0.015
lag time (sec)

YIN Algorithm (Cheveigné and Kawahara, 2002)

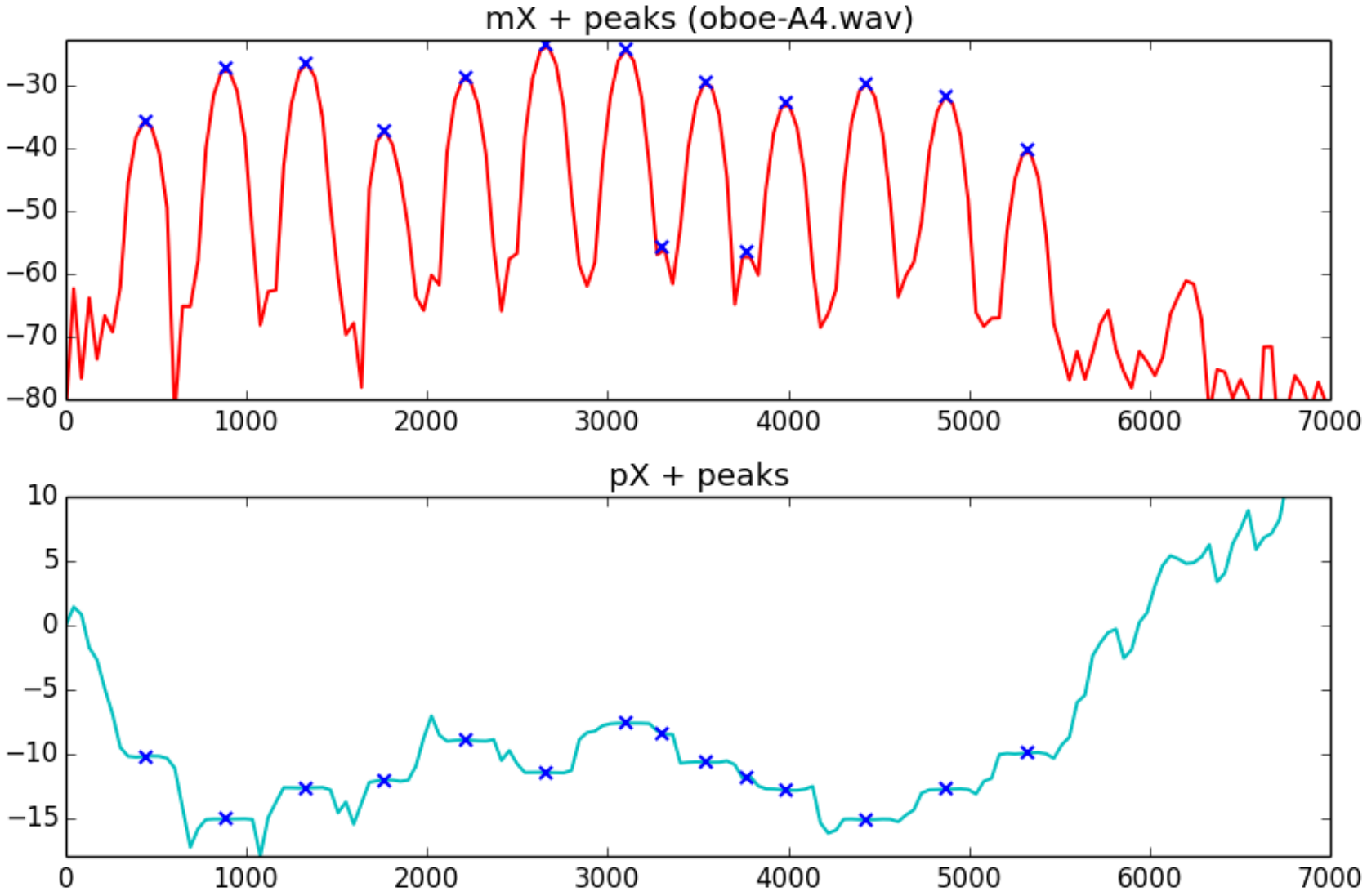
- Based on the difference function

$$d[l] = \sum_{n=0}^{n=N-1-l} \left(x[n] - x[n+l]\right)^2 \qquad l = 0, 1, \ldots, N-1$$


mX + f0 (vignesh.wav), YIN: N=2048, H = 256
1500
1000
500
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0

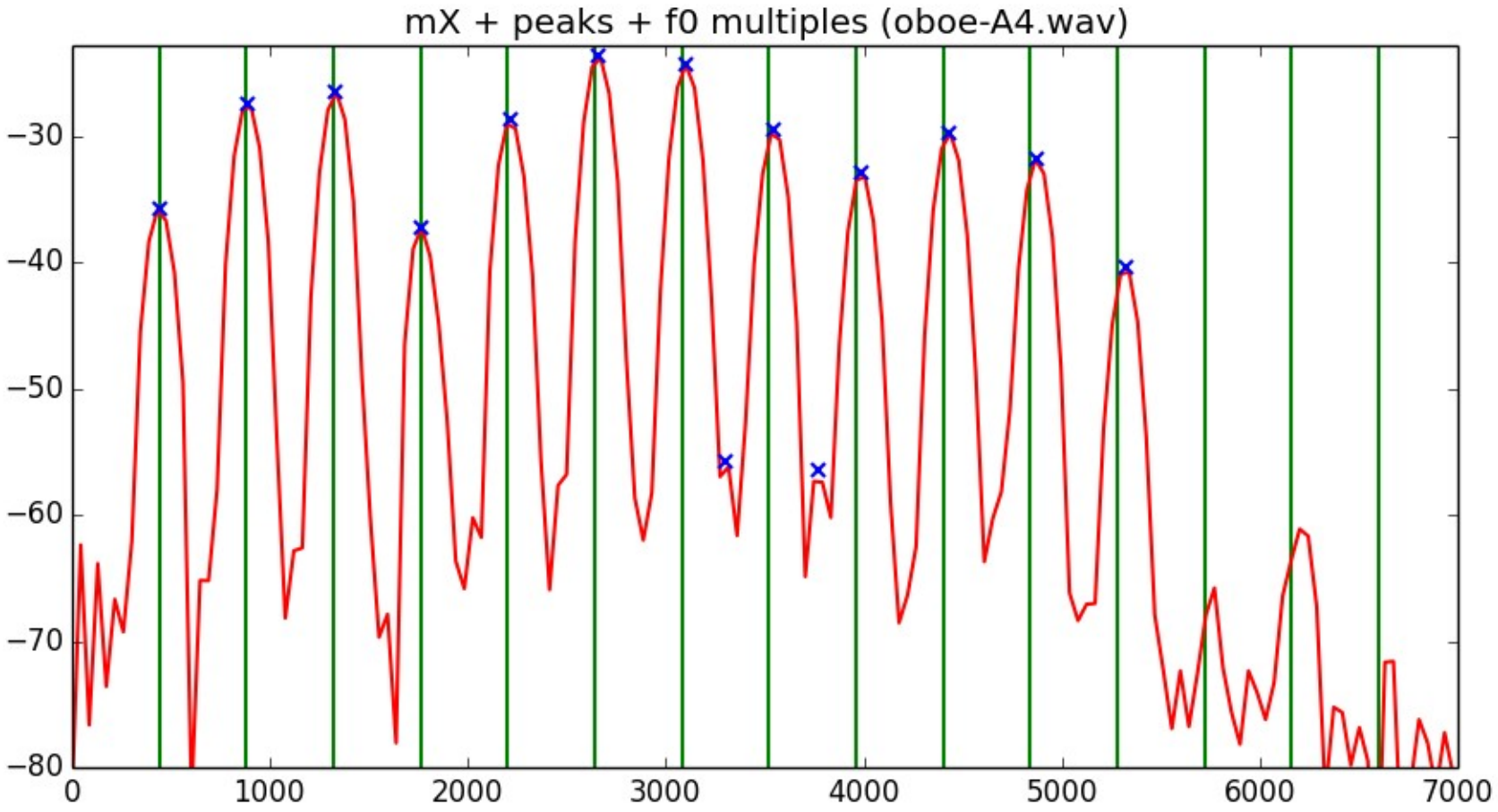

mX + f0 (vignesh.wav), YIN: N=2048, H = 256
1500
1000
500
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0

F0 detection in frequency domain



F0 in the spectrum

The F0 can be defined as the common divisor of the harmonic series that best explains the spectral peaks.



Pattern matching

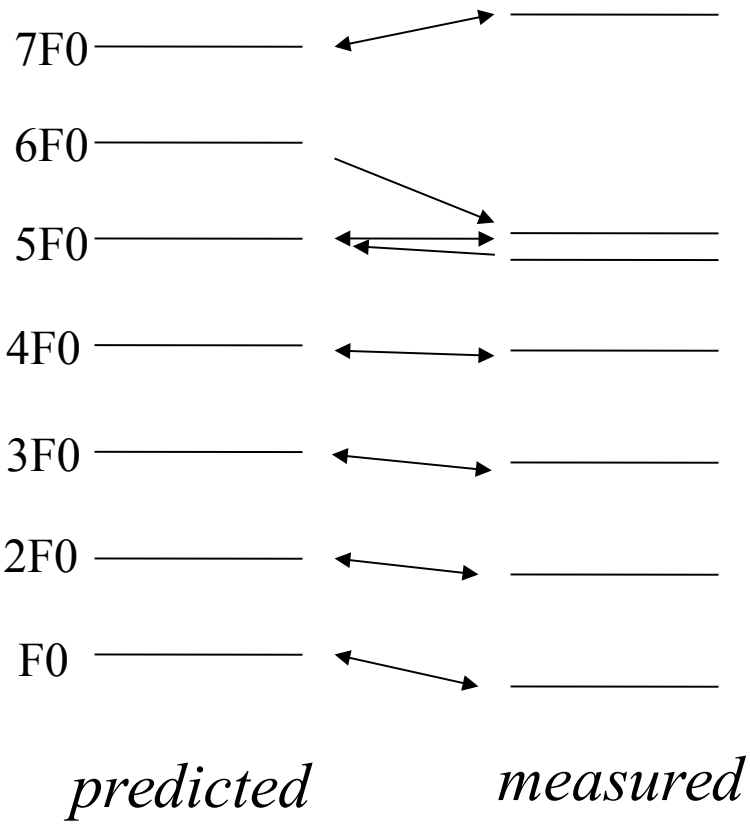
Two-way mismatch algorithm (Maher and Beauchamp, 1994)

$$\mathrm{Err}_{p\to m} = \sum_{n=1}^{N} E_{\omega}\left(\Delta f_n, f_n, a_n, A_{\max}\right)$$
$$= \sum_{n=1}^{N} \Delta f_n \cdot \left(f_n\right)^{-p}$$
$$+ \left(\frac{a_n}{A_{\max}}\right) \times \left[q\,\Delta f_n \cdot \left(f_n\right)^{-p} - r\right]$$

Δf_n : diff. between predicted and the closest measured peaks

f_n, a_n : frequency and magnitude of predicted peaks

$A_{\max}$: maximum peak magnitude



$$\mathrm{Err}_{m\to p} = \sum_{k=1}^{K} E_{\omega}\left(\Delta f_k, f_k, a_k, A_{\max}\right)$$
$$= \sum_{k=1}^{K} \Delta f_k \cdot \left(f_k\right)^{-p} + \left(\frac{a_k}{A_{\max}}\right) \times \left[q\,\Delta f_k \cdot \left(f_k\right)^{-p} - r\right]$$

Δf_k : diff. between predicted and its closest measured peaks

f_k, a_k : frequency and magnitude of predicted peaks

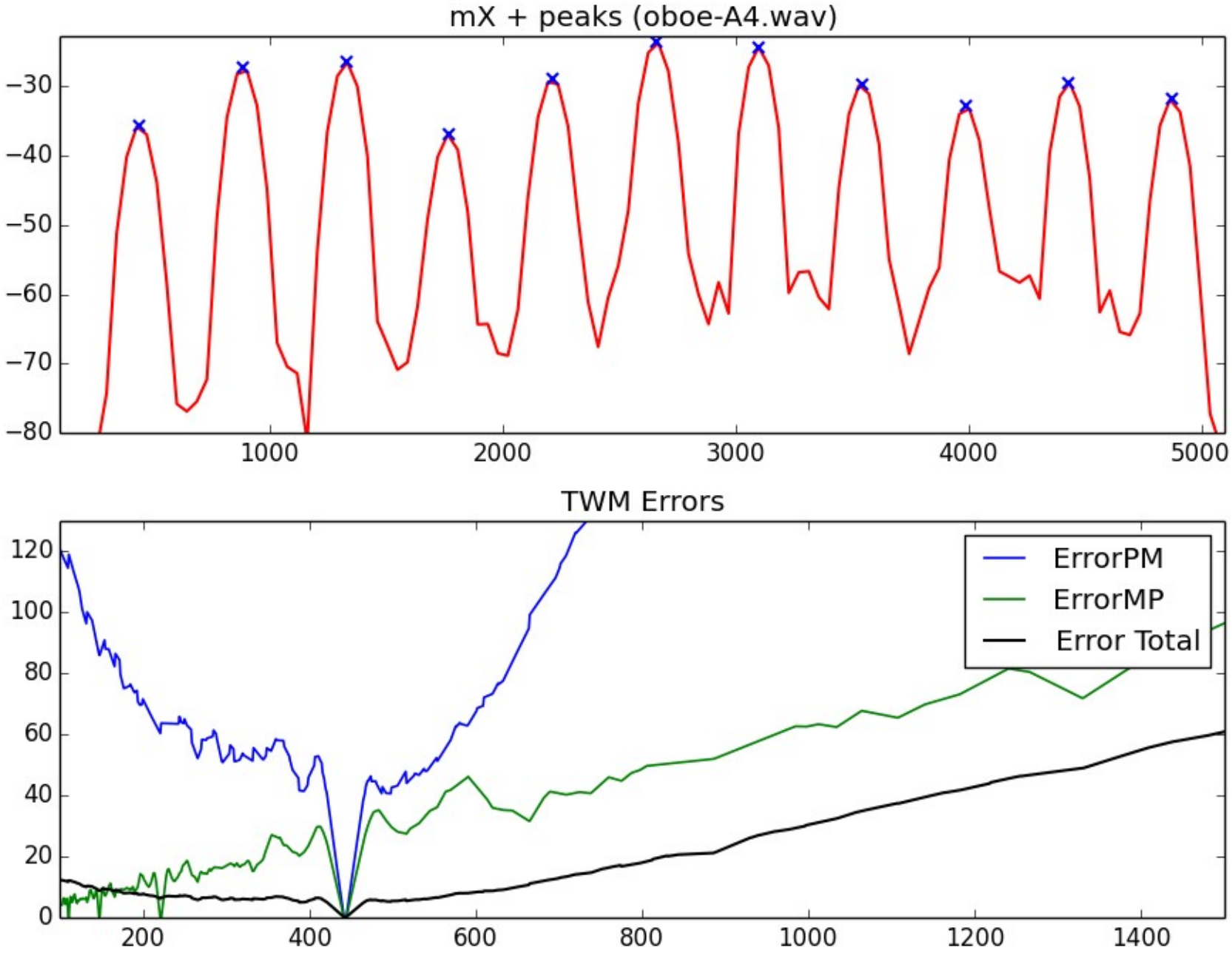
$A_{\max}$: maximum peak magnitude

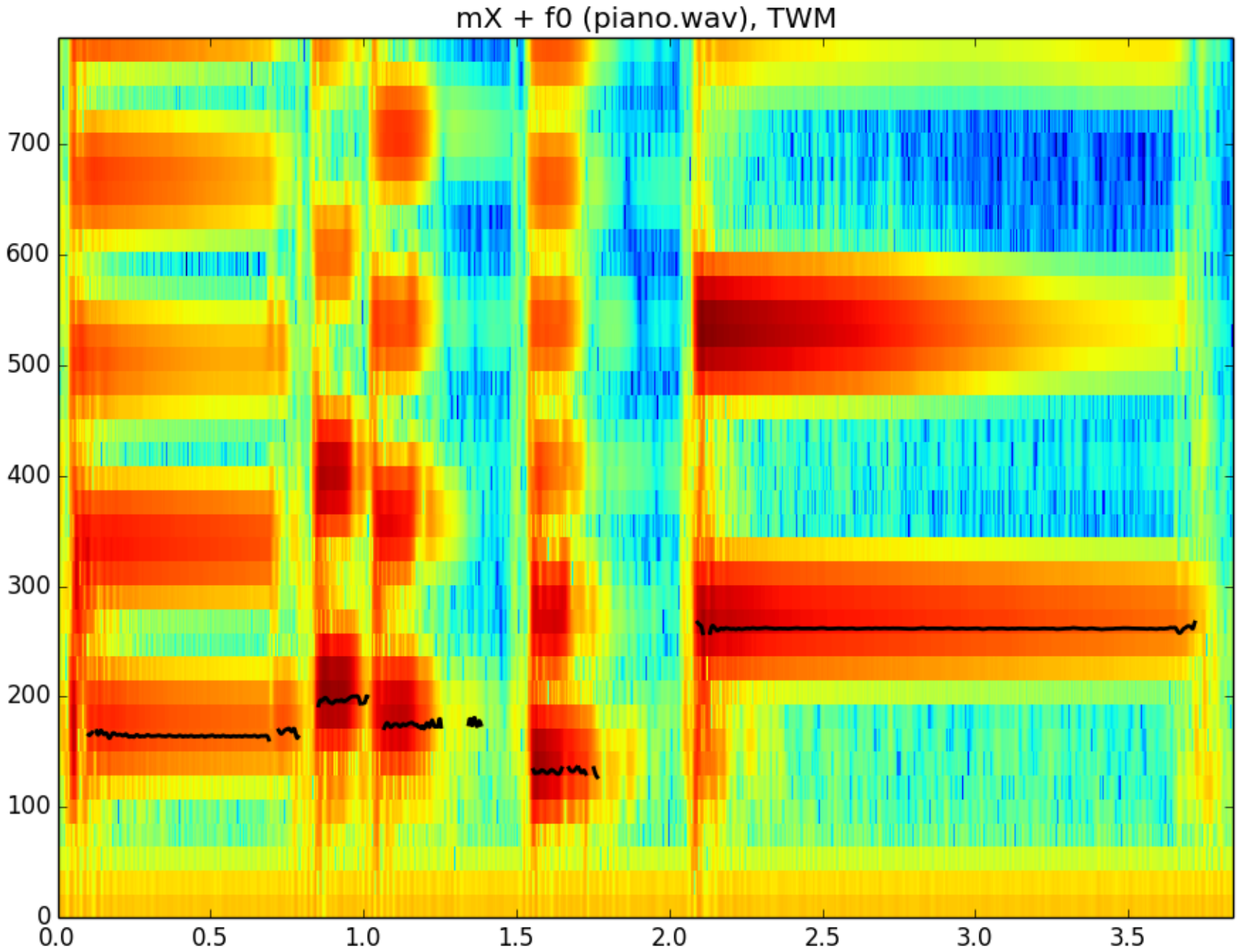
Total error: $\mathrm{Err}_{\mathrm{total}} = \mathrm{Err}_{p\to m}/N + \rho\,\mathrm{Err}_{m\to p}/K$

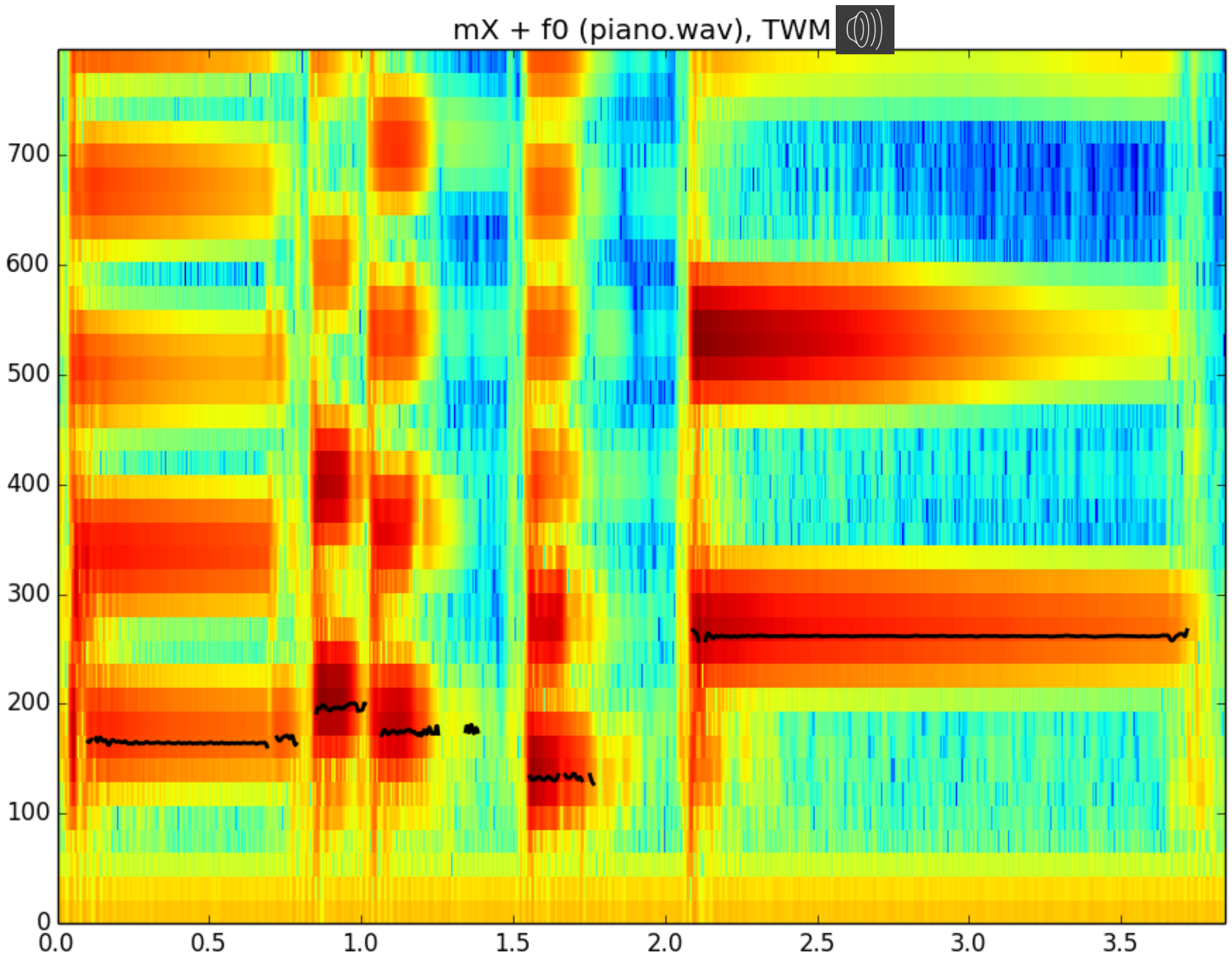
Maher and Beauchamp propose: $p=0.5, q=1.4, r=0.5, \rho=0.33$

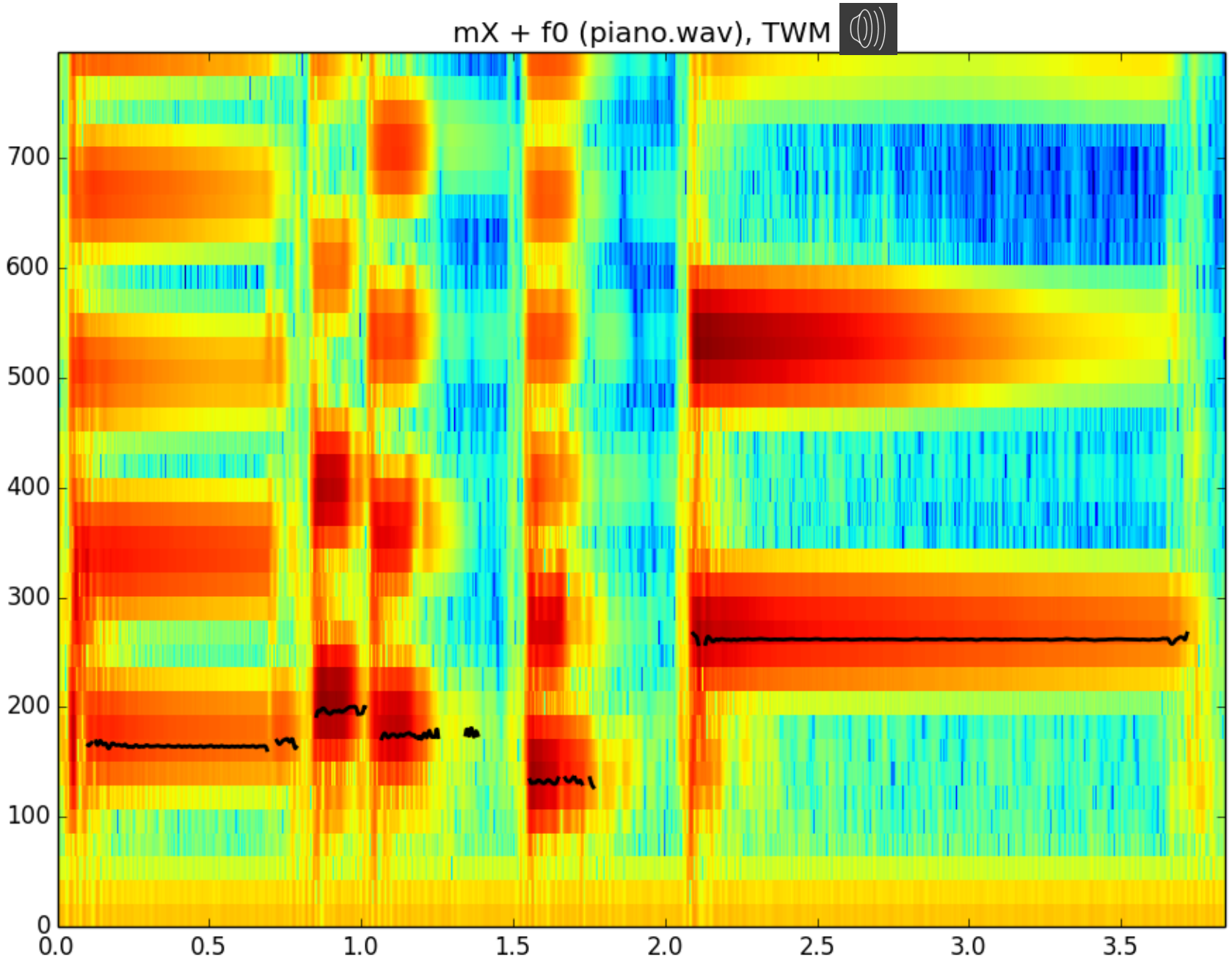
	$Err_{p->m}$	$Err_{m->p}$	Err_{total}
50Hz	122.58	-3.0	7.49
100Hz	32.0	-3.0	3.83
200Hz	10.0	30.66	4.2

TWM error calculation from the frequencies: 200, 300, 500, 600, 700, 800.

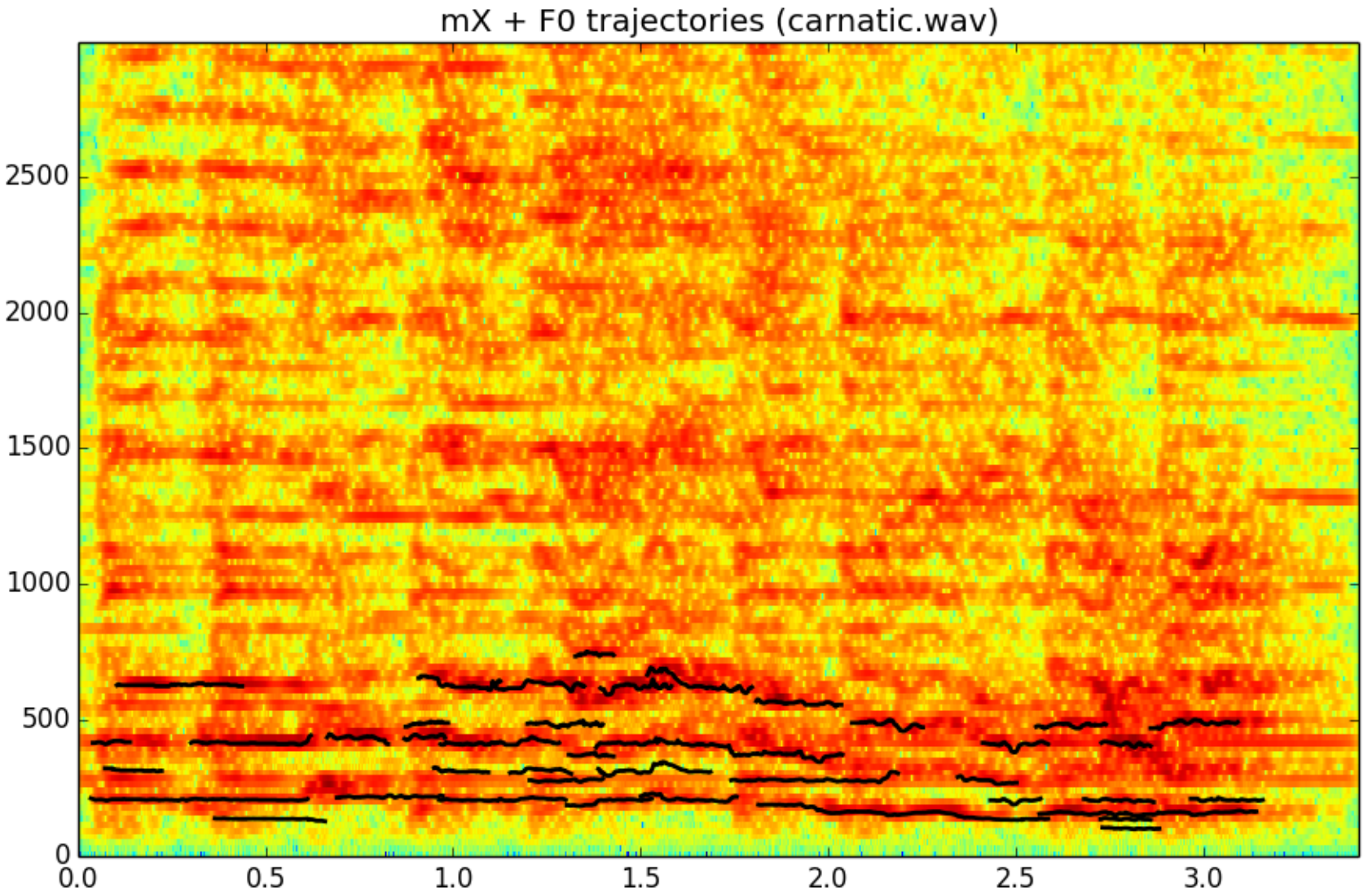

mX + peaks (oboe-A4.wav)
−30
−40
−50
−60
−70
−80
1000
2000
3000
4000
5000
TWM Errors
120
100
80
60
40
20
0
200
400
600
800
1000
1200
1400
ErrorPM
ErrorMP
Error Total


mX + f0 (piano.wav), TWM
700
600
500
400
300
200
100
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

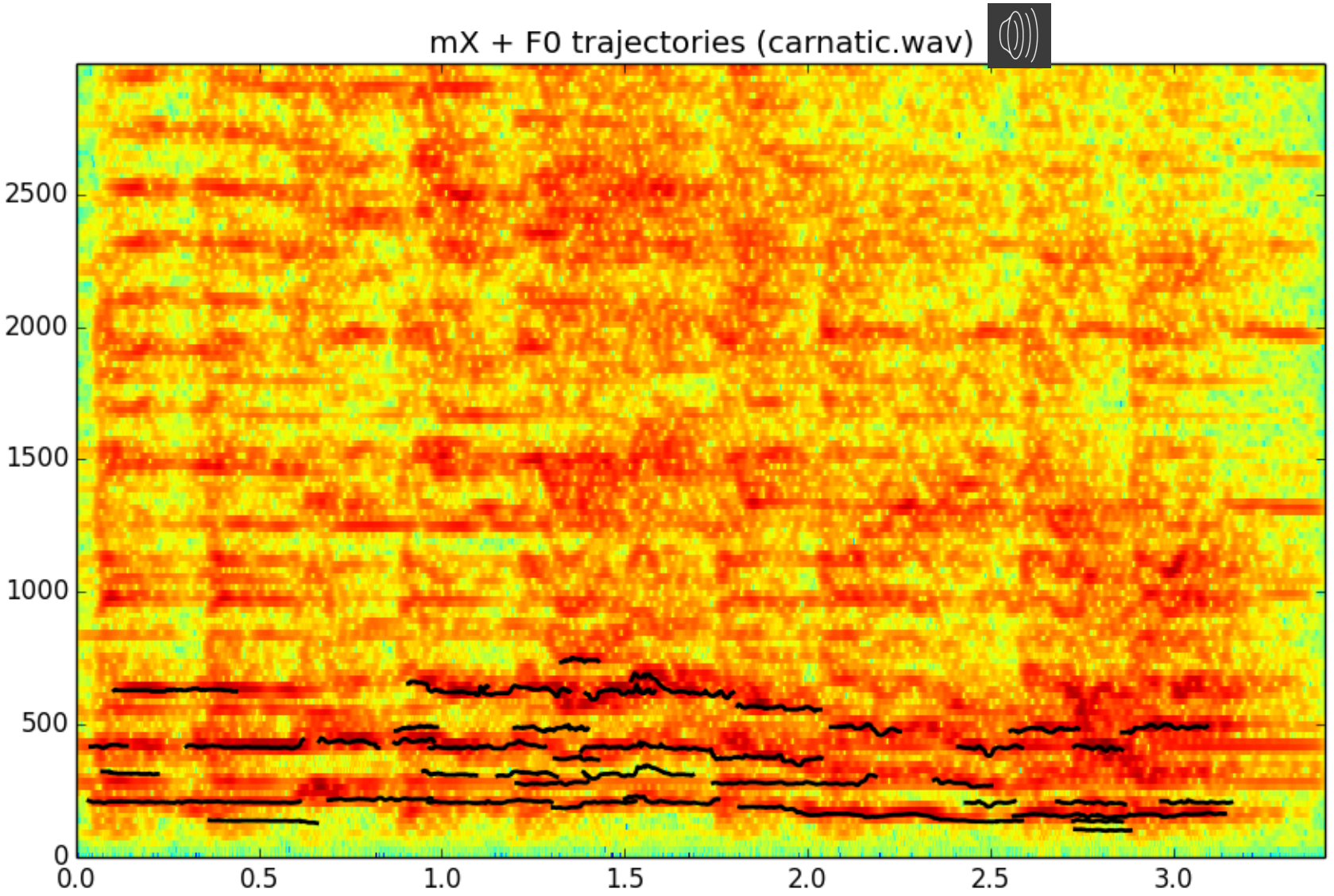

mX + f0 (piano.wav), TWM
700
600
500
400
300
200
100
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5


mX + f0 (piano.wav), TWM
700
600
500
400
300
200
100
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

F0 in polyphonic signals

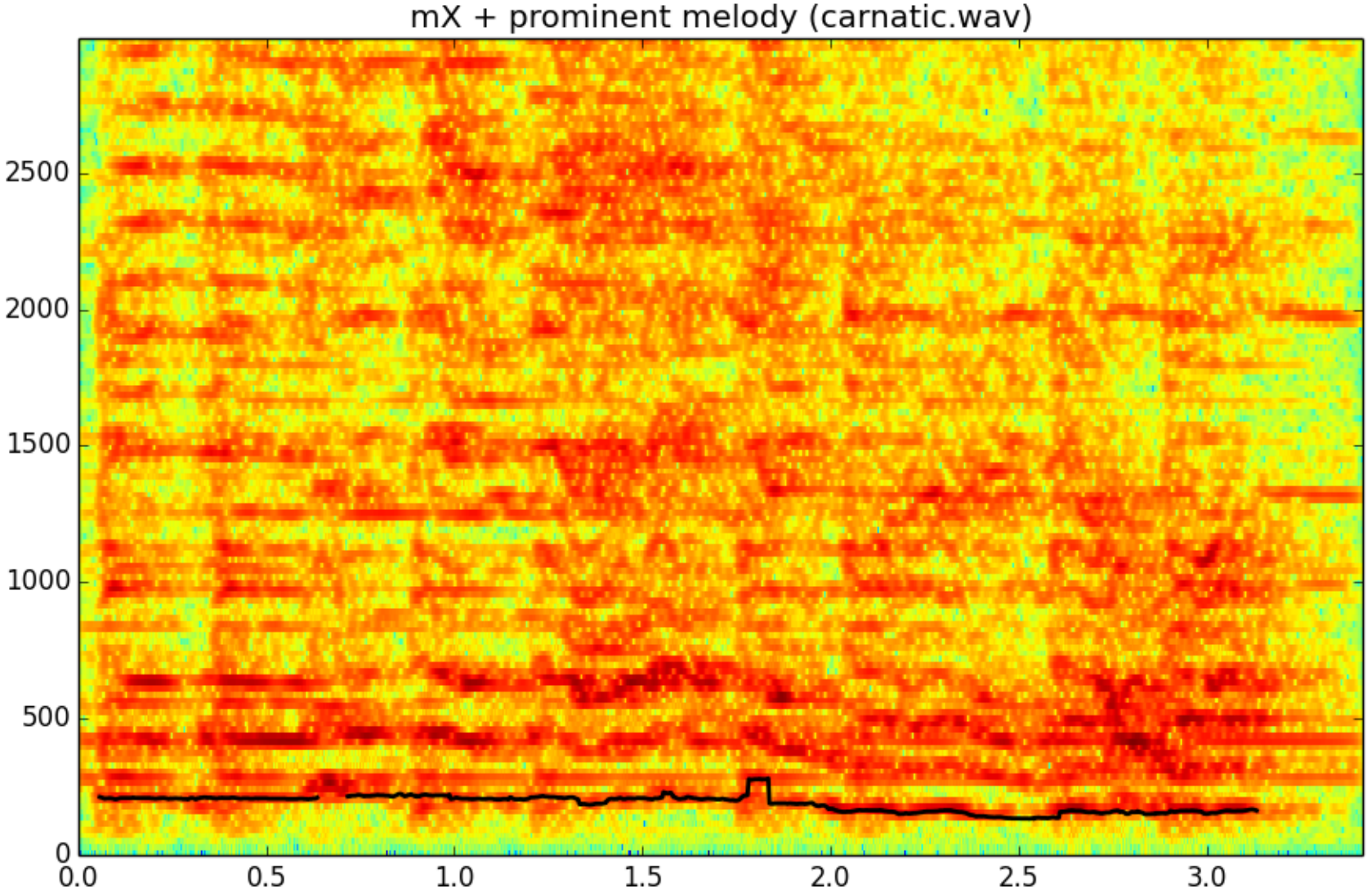


F0 in polyphonic signals



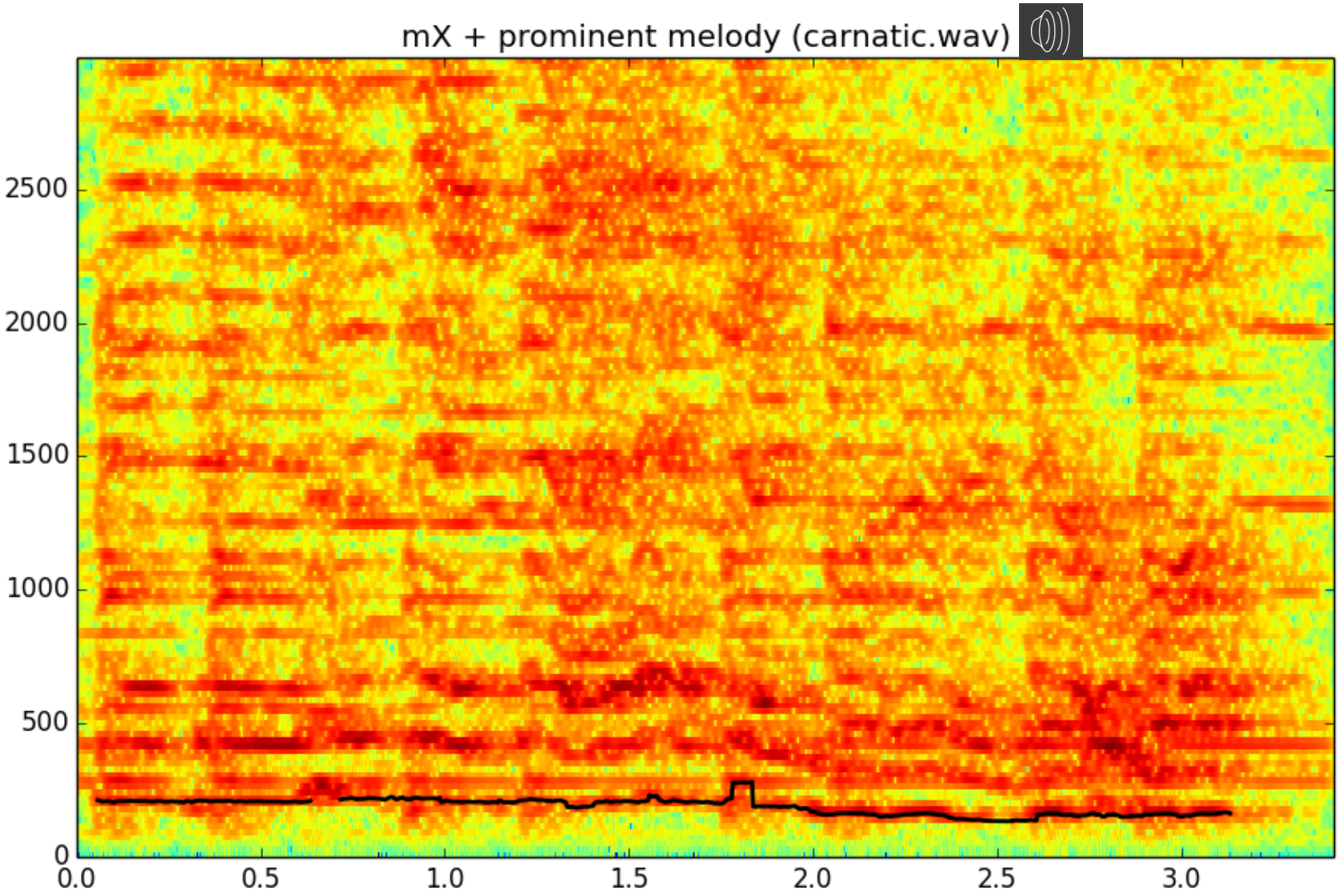
Prominent pitch in polyphonic signals

(Salamon and Gómez, 2012)



Prominent pitch in polyphonic signals

(Salamon and Gómez, 2012)



References and credits

- More information in:
  - http://en.wikipedia.org/wiki/Fundamental_frequency
  - http://en.wikipedia.org/wiki/Pitch_detection_algorithm
  - http://en.wikipedia.org/wiki/Autocorrelation
- F0 detection algorithms:
  - A. de Cheveigné and H. Kawahara. “YIN, a fundamental frequency estimator for speech and music,” J. Acoust. Soc. Am. 111, 1917 (2002).
  - R. C. Maher and J. W. Beauchamp, “Fundamental frequency estimation of musical signals using a Two-Way Mismatch procedure,” J. Acoust. Soc. Am., vol. 95., no. 4, pp. 2254-2263 (1994).
  - J. Salamon and E. Gómez, "Melody extraction from polyphonic music signals using pitch contour characteristics," IEEE Transactions on Audio, Speech, and Language Processing, vol. 20, no. 6, pp. 1759–1770 (2012).
- Sounds from: http://www.freesound.org/people/xserra/packs/13038/
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