6T2: Fundamental frequency detection

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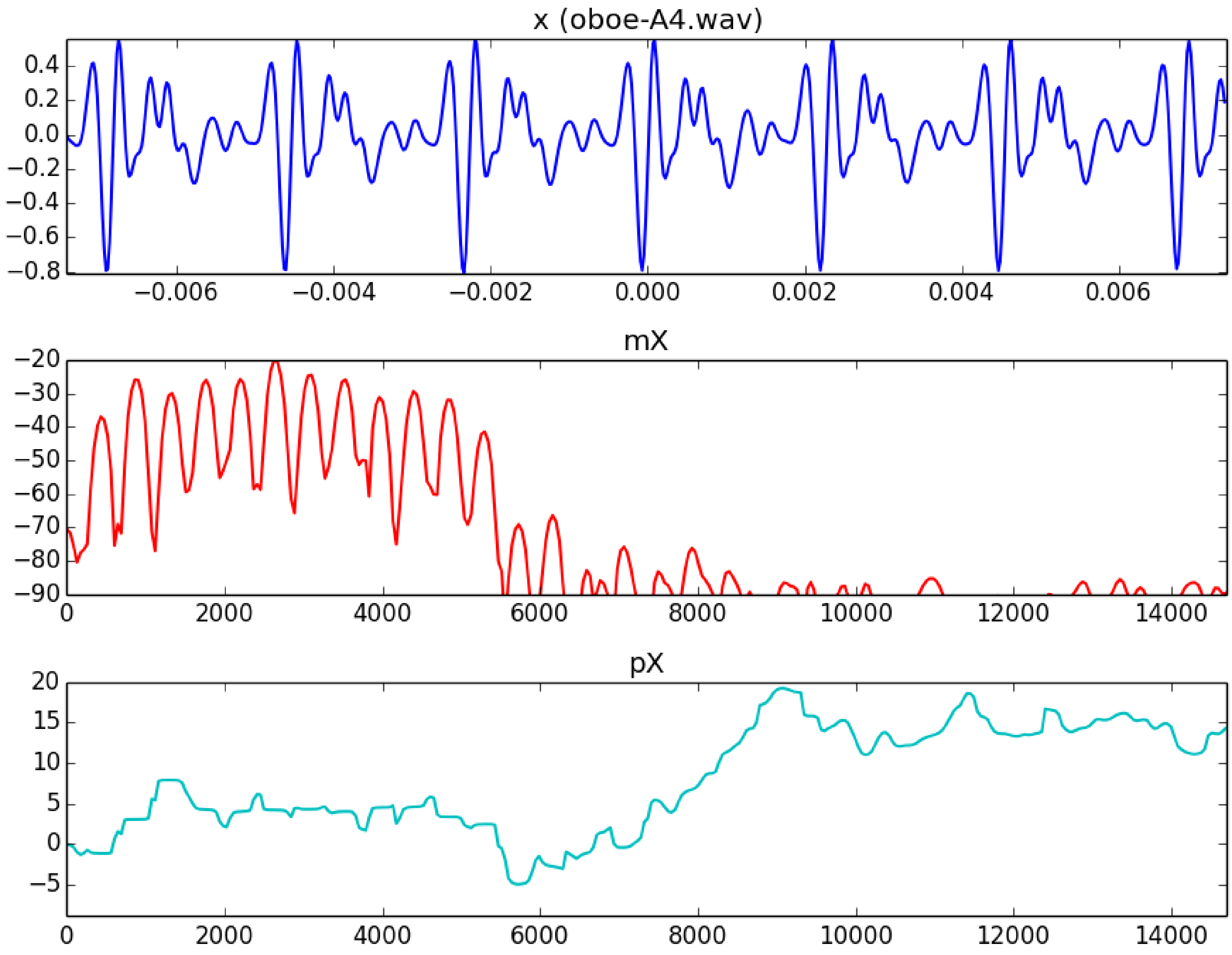
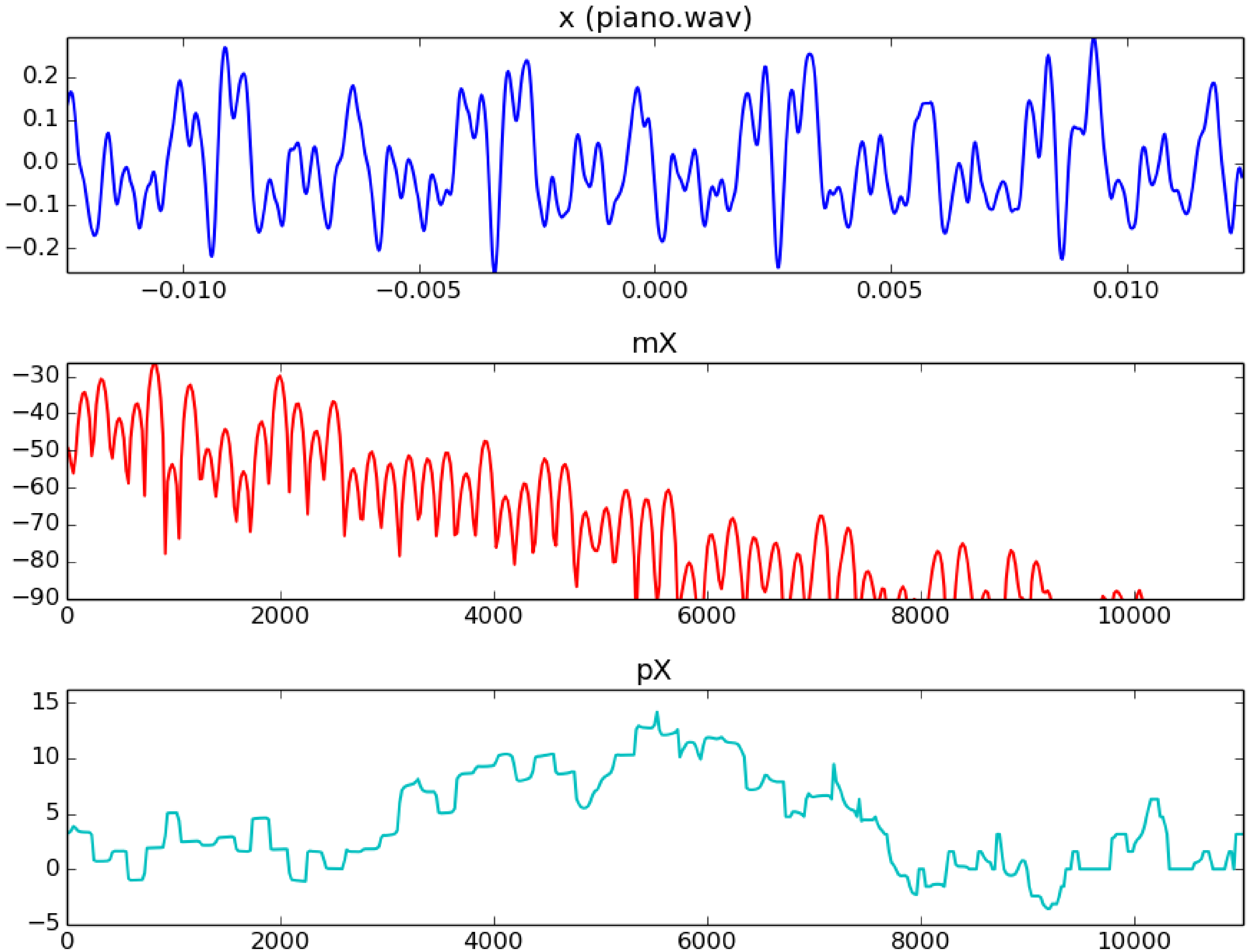
Index

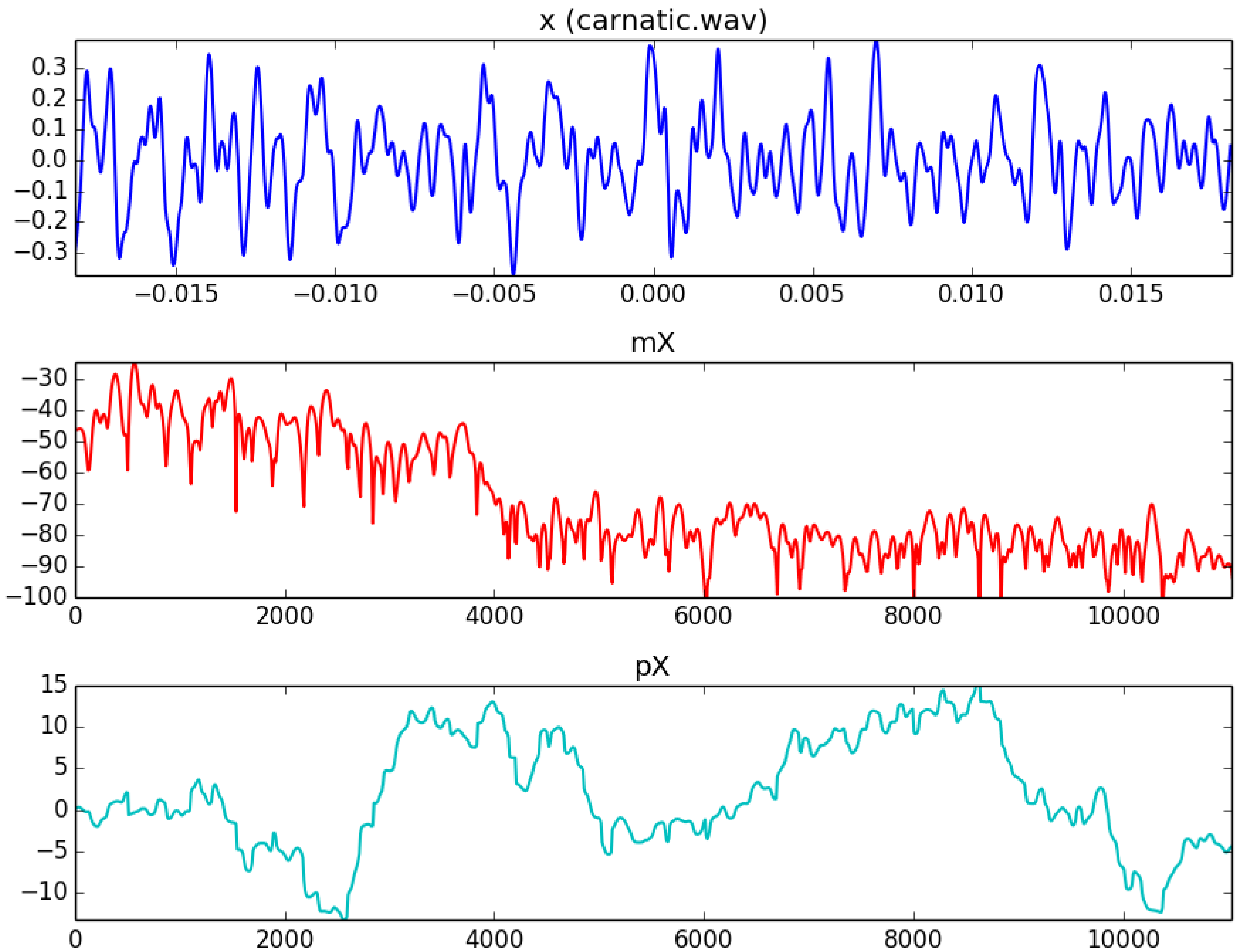
- F0 detection in time domain
  - monophonic signals
- F0 detection in frequency domain
  - monophonic and polyphonic signals



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 (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
15
10
5
0
−5
0
2000
4000
6000
8000
10000



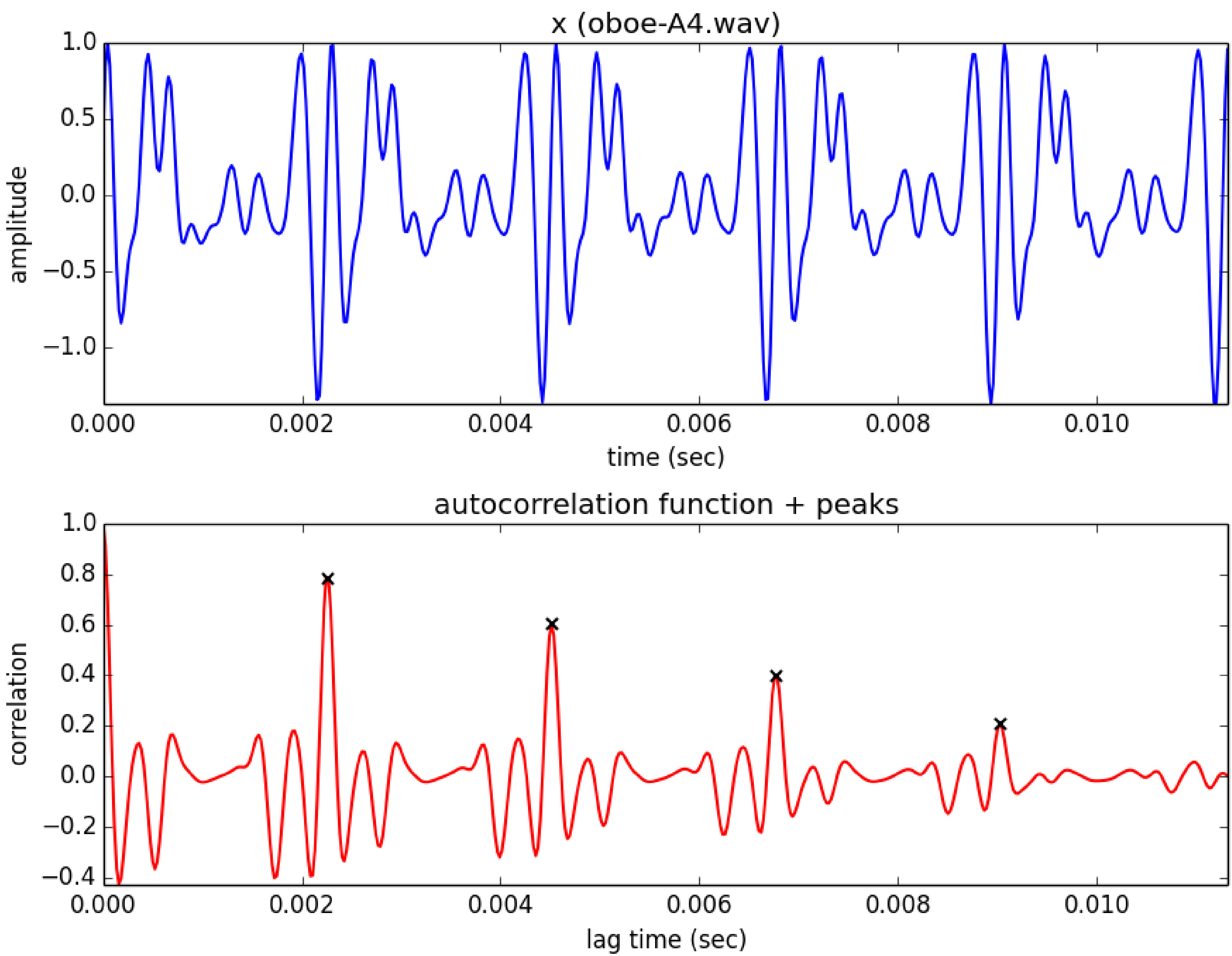
x (carnatic.wav)
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
−0.015
−0.010
−0.005
0.000
0.005
0.010
0.015
mX
−30
−40
−50
−60
−70
−80
−90
−100
0
2000
4000
6000
8000
10000
pX
15
10
5
0
−5
−10
0
2000
4000
6000
8000
10000

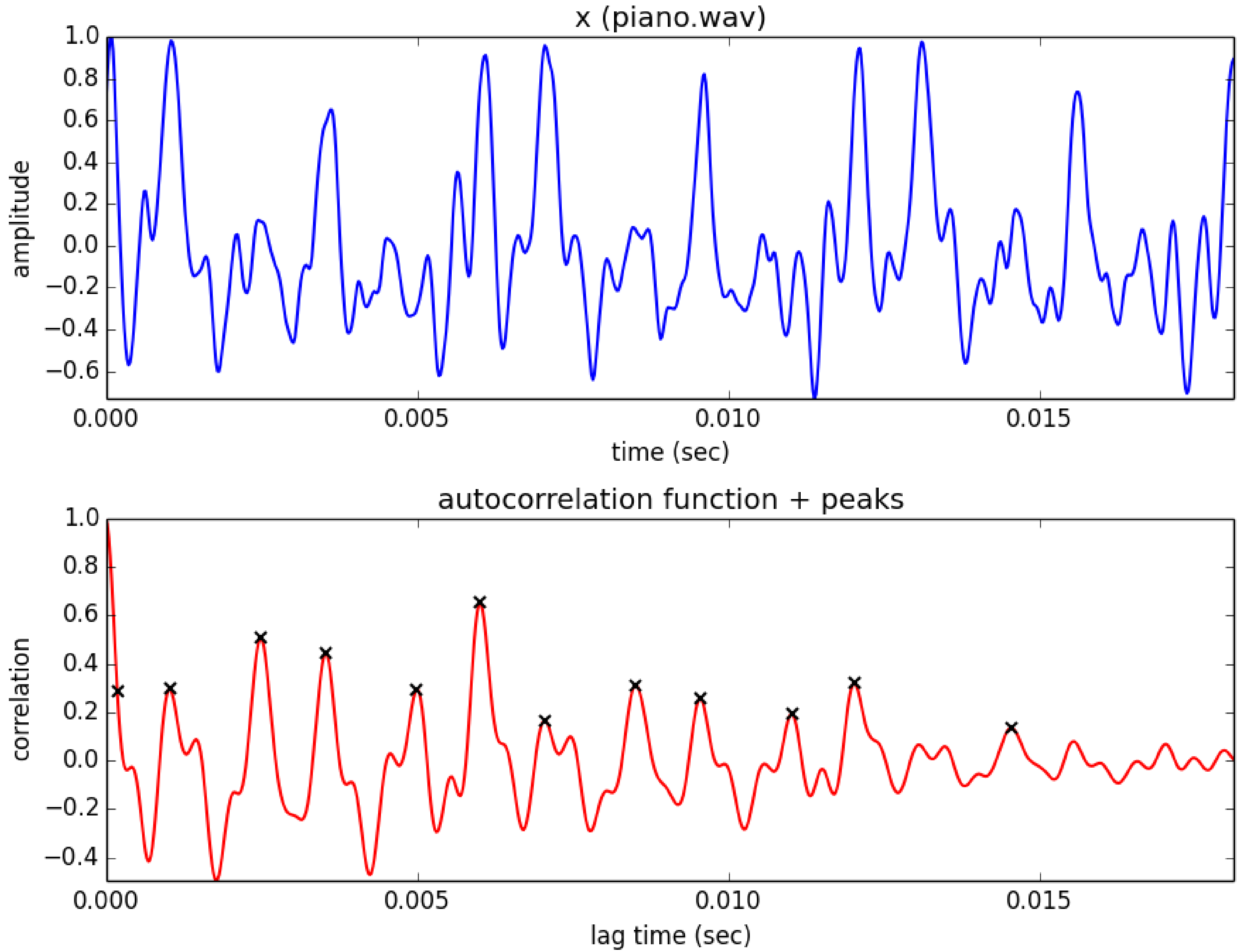
F0 detection in time domain

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)

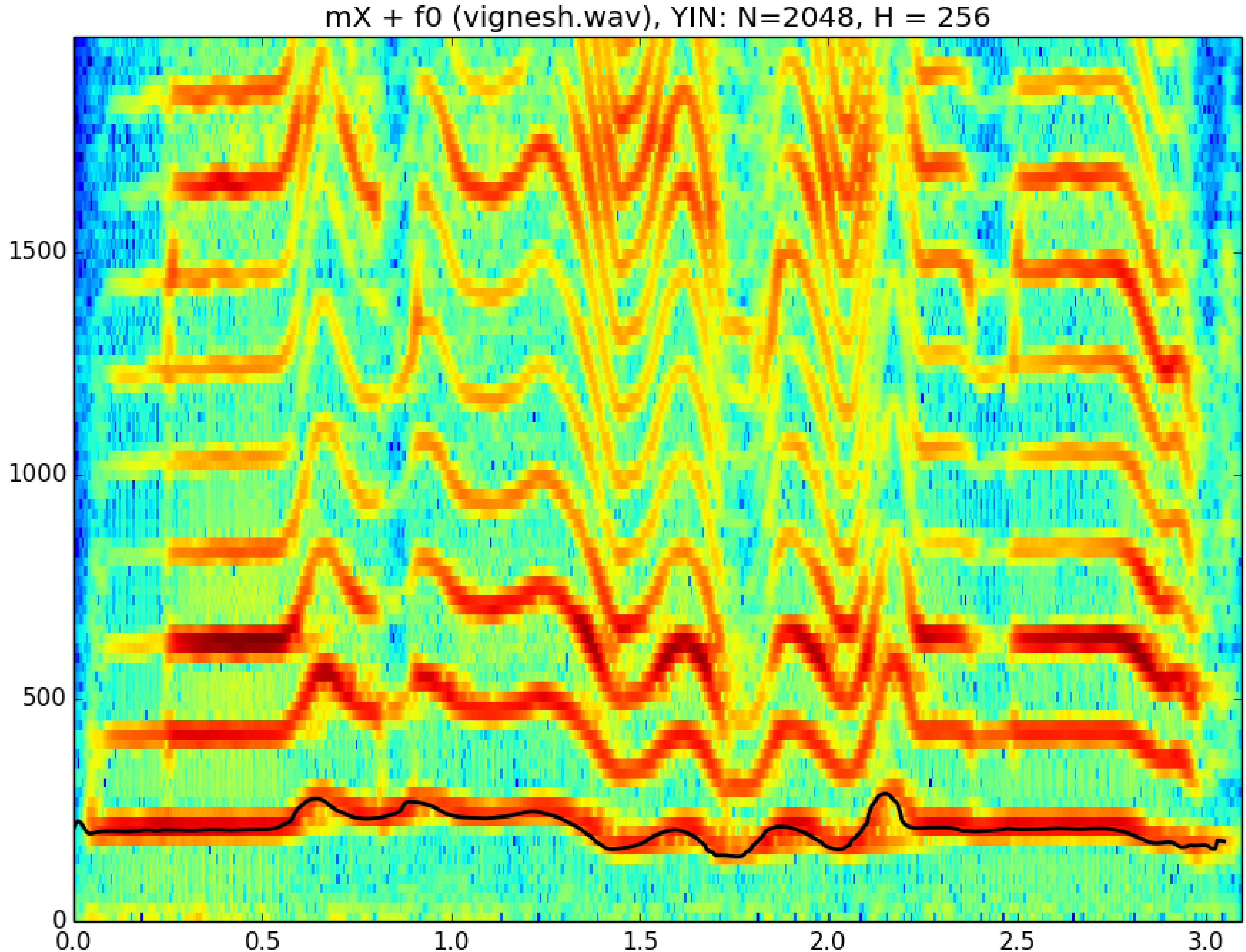


x (piano.wav)
amplitude
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
0.000
0.005
0.010
0.015
time (sec)
autocorrelation function + peaks
correlation
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
0.000
0.005
0.010
0.015
lag time (sec)

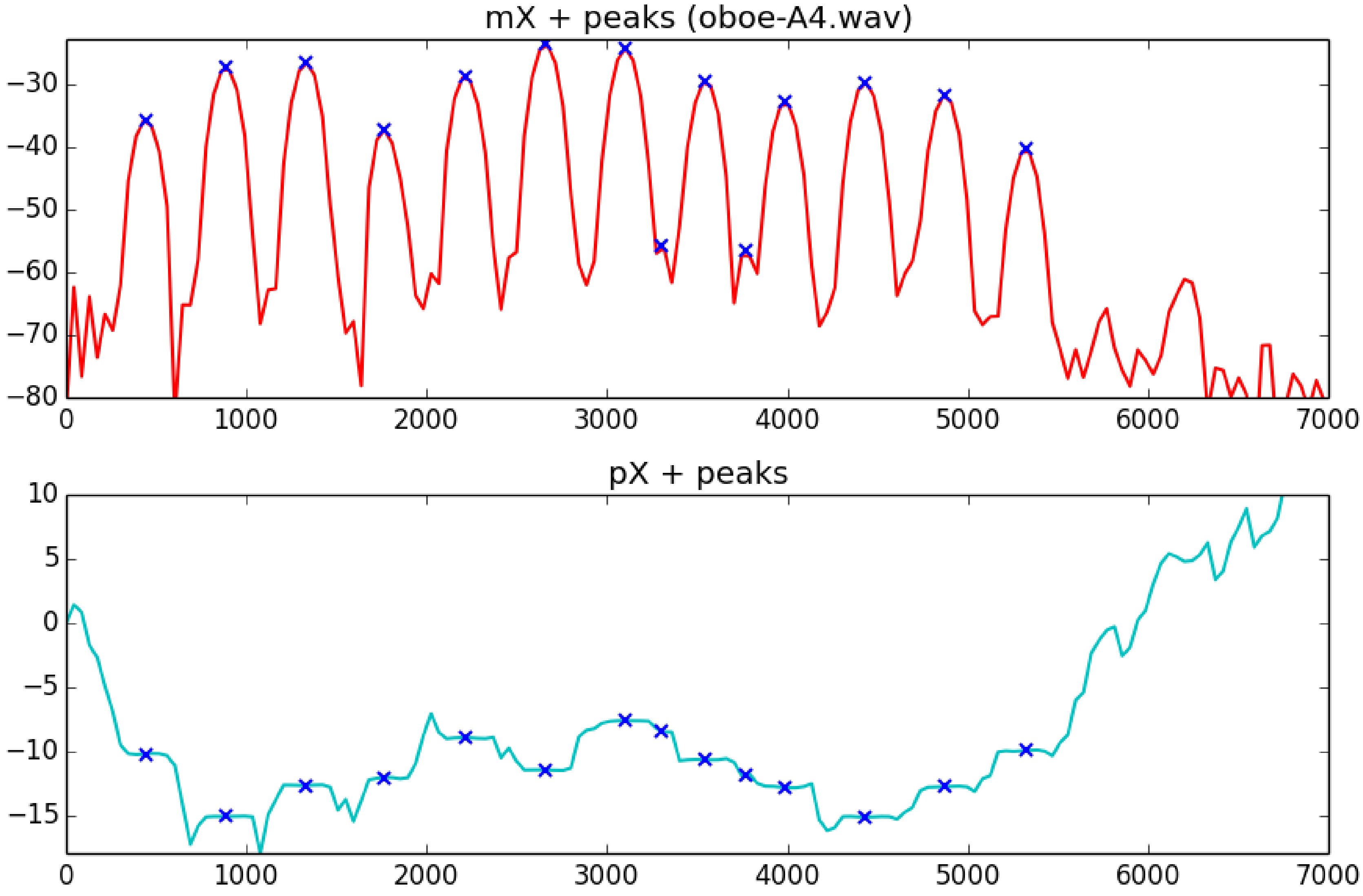
YIN Algorithm (Cheveigné and Kawahara, 2002)

- Based on the difference function

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

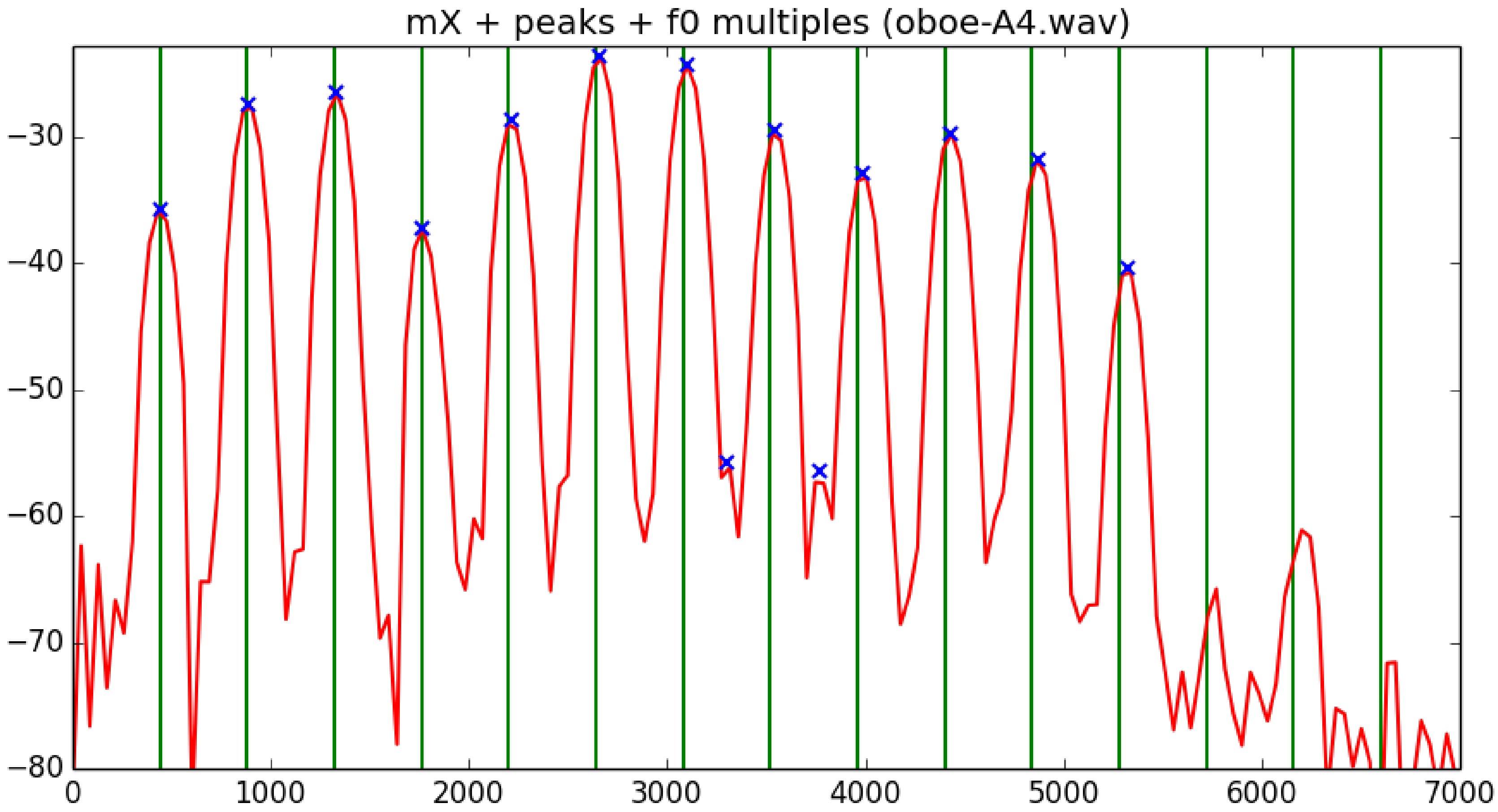

mX + f0 (vignesh.wav), YIN: N=2048, H = 256
0
500
1000
1500
0.0
0.5
1.0
1.5
2.0
2.5
3.0

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

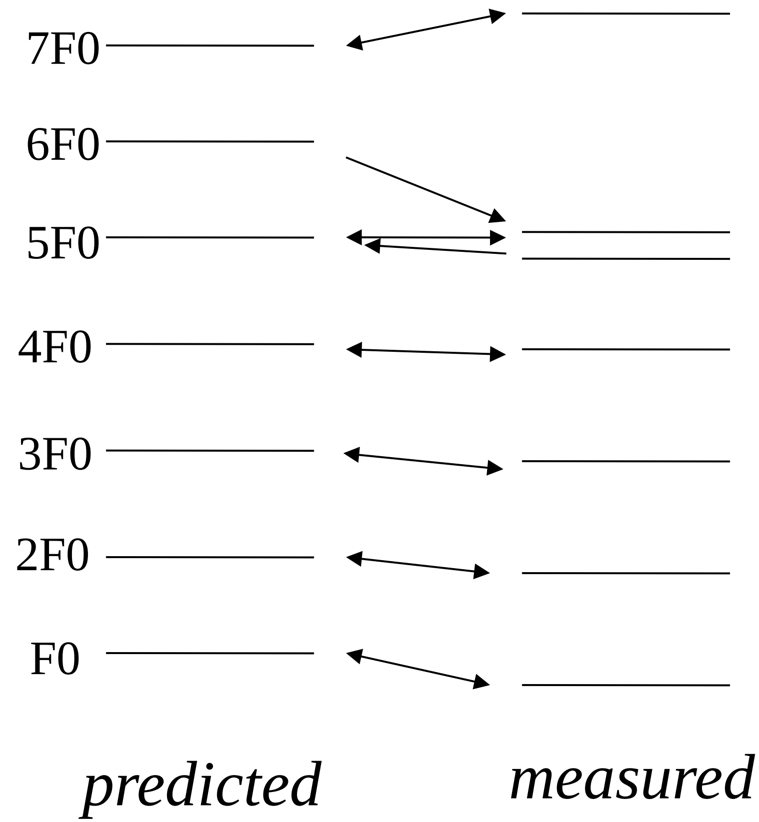
Two-way mismatch algorithm (Maher and Beauchamp, 1994)

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

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



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

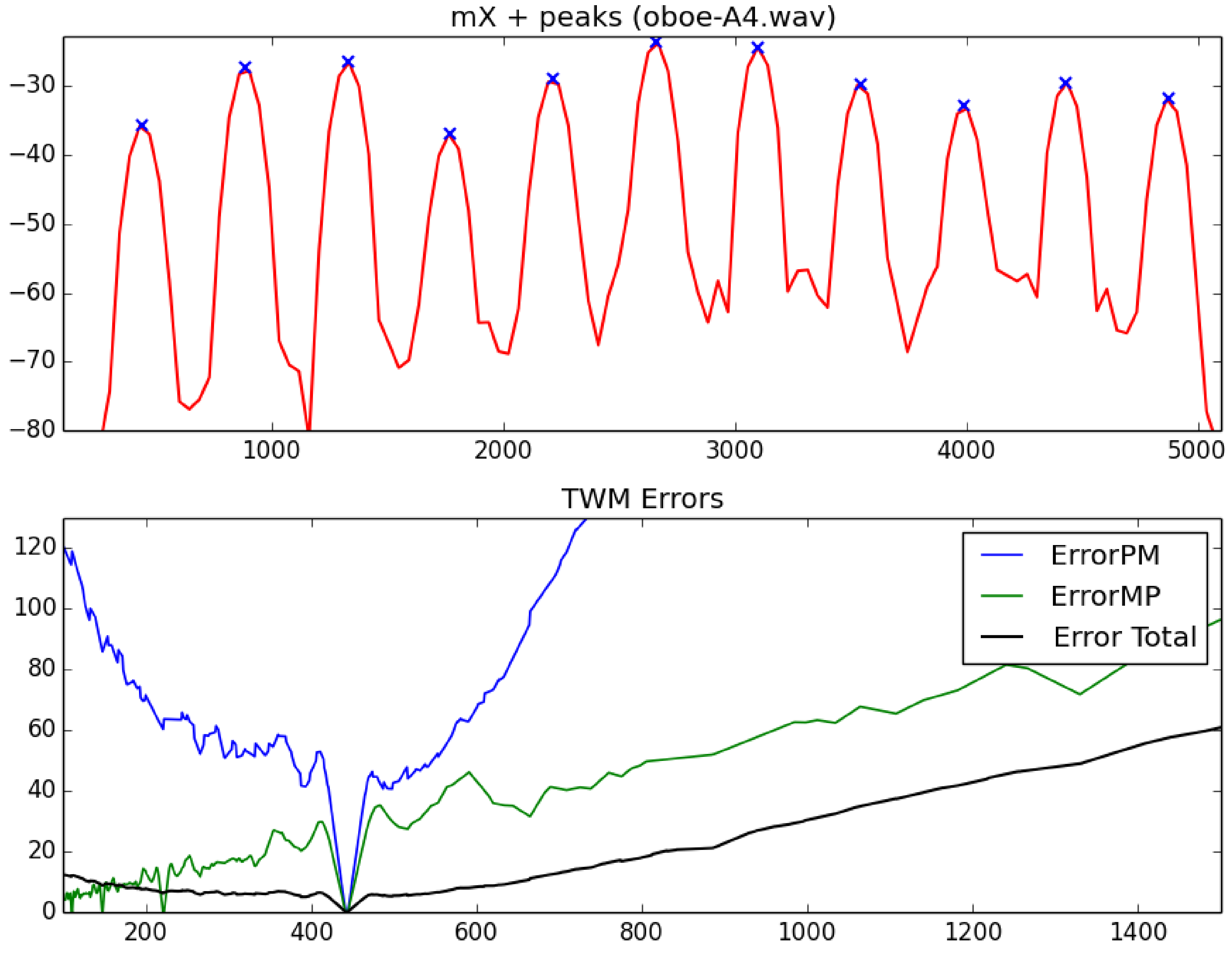
Δf_k: diff. between predicted and its closest measured peaks
f_k, a_k: frequency and magnitude of predicted peaks
$A_{\max}$: maximum peak magnitude

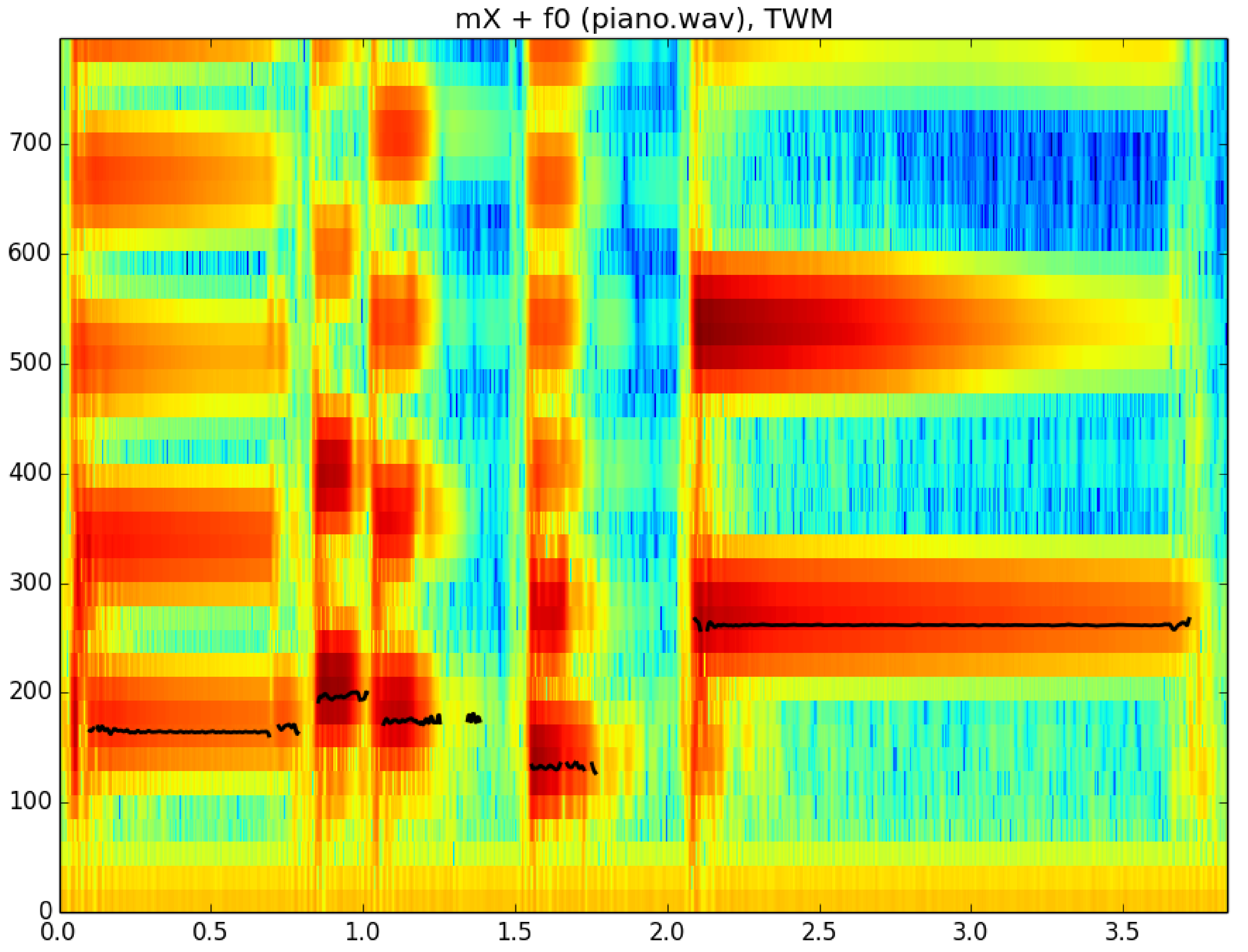
Total error: $\mathrm{Err}_{\mathrm{total}} = \mathrm{Err}_{p \to m} / N \; + \; \rho\, \mathrm{Err}_{m \to p} / K$

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

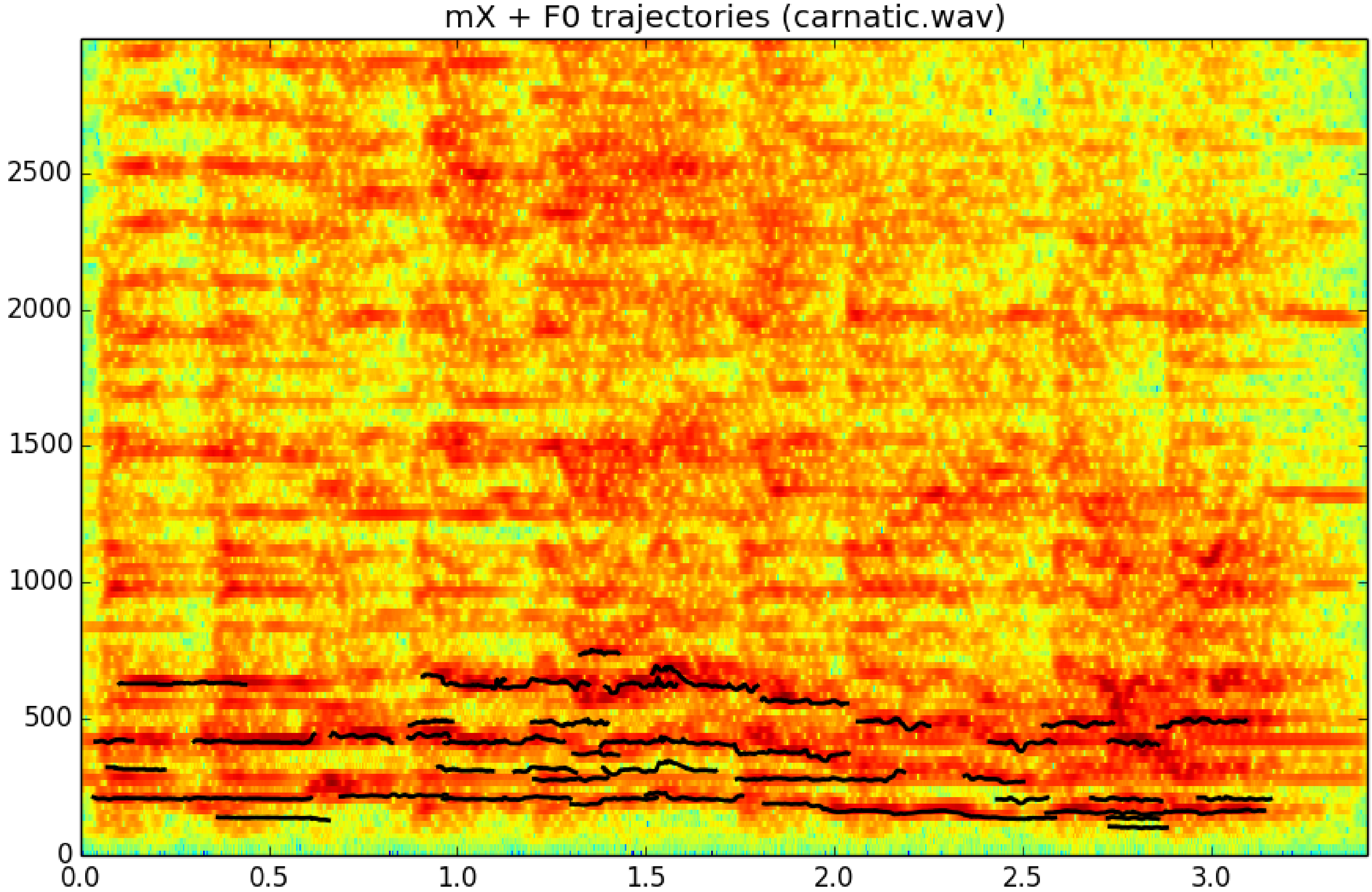
	$Err_{p->m}$	$Err_{m->p}$	Err_{total}
50Hz	122.58	-3.0	7.49
100Hz	32.0	-3.0	3.83
200Hz	10.0	30.66	4.2

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

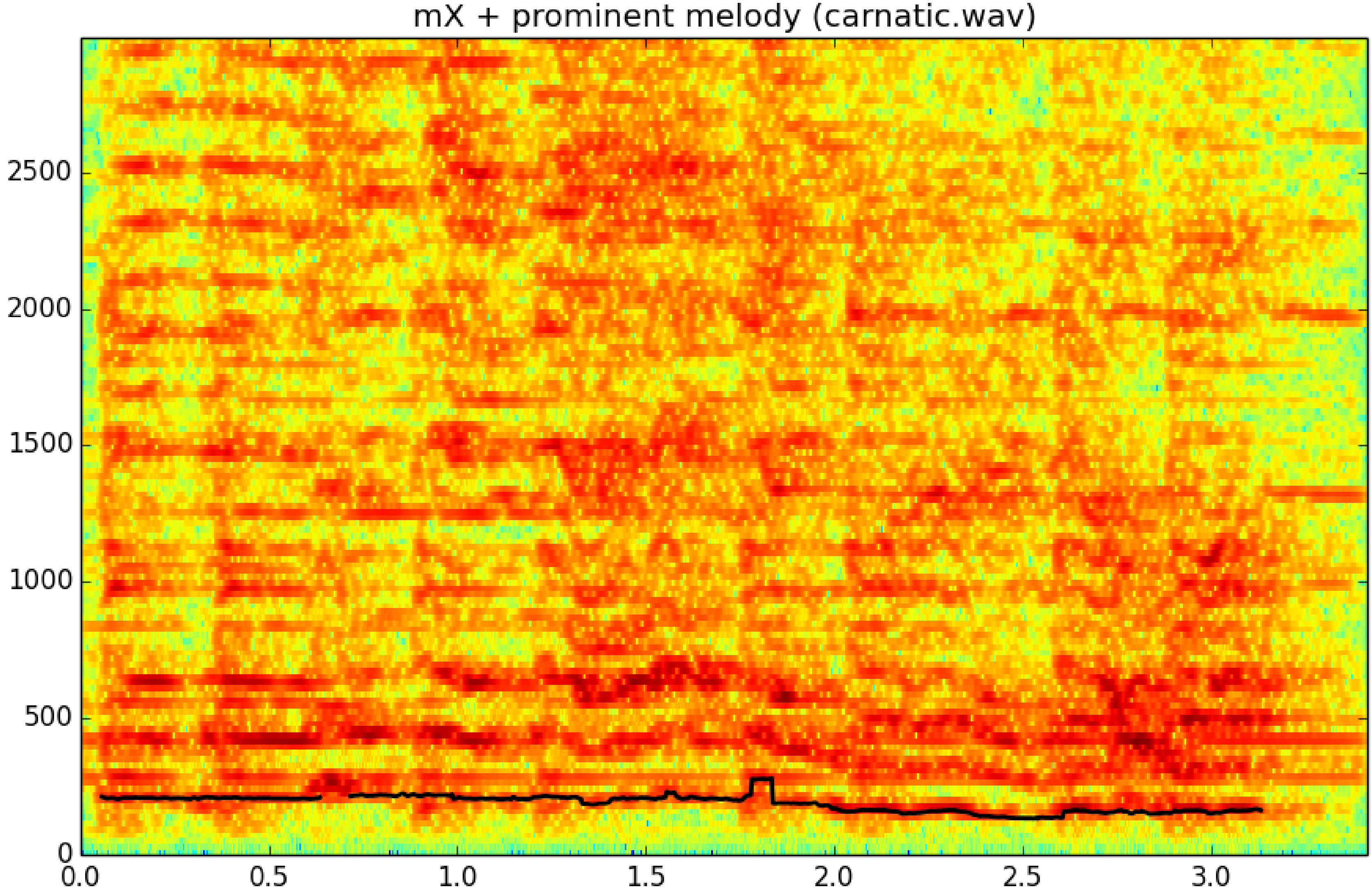

mX + peaks (oboe-A4.wav)
−30
−40
−50
−60
−70
−80
1000
2000
3000
4000
5000
TWM Errors
ErrorPM
ErrorMP
Error Total
120
100
80
60
40
20
0
200
400
600
800
1000
1200
1400


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

F0 in polyphonic signals



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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