Analysis of Evoked Potentials on the Surface of Primary Auditory Cortex Combining Ripples and ICA

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Synopsis

- EEG Recording made with 24 channels in 1mm^2 on AI surface

- Physiological Sources of Neural Activity seperated among channels using ICA (Independent Component Analysis).

- Pure tone stimuli: Separated sources reveal tonotopy

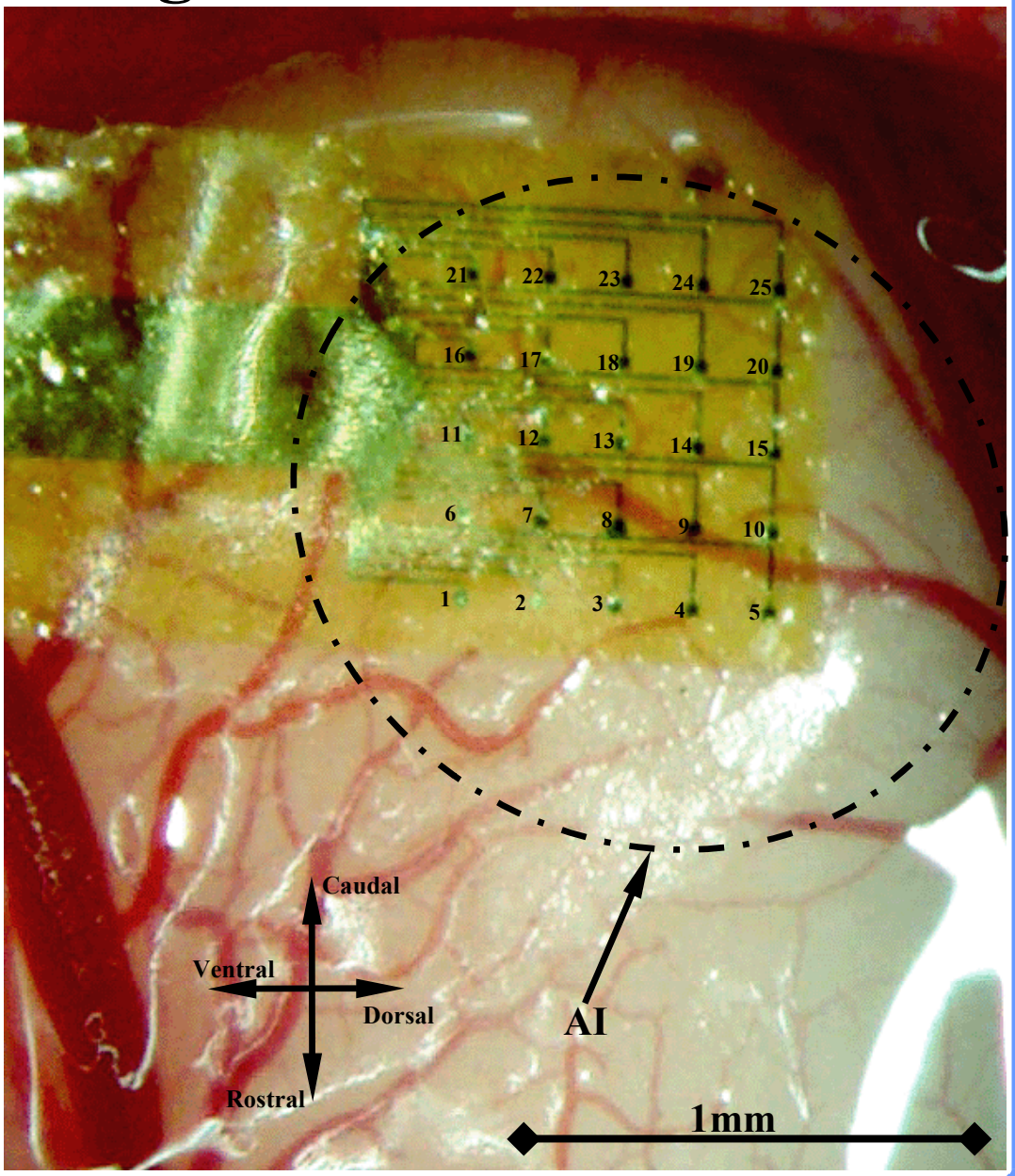
- Moving Ripple Stimuli: Separated sources reveal traveling waves with:

  - Direction given by tonotopy

  - Phase-locking to ripple speed

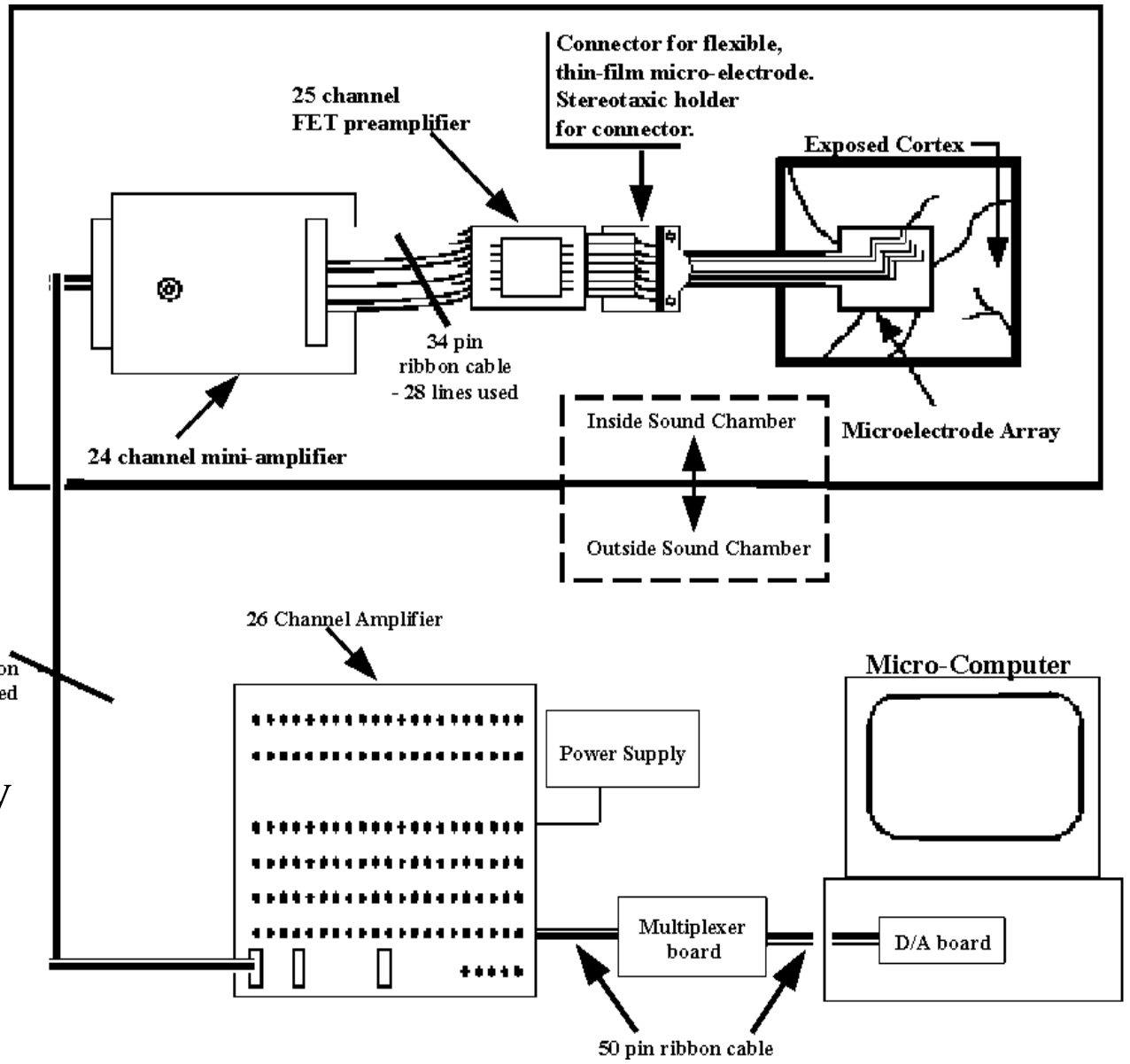
Recording Device

- Thin-film micro-electrode array, developed by Anthony Owens and Shihab Shamma recording Evoked Potentials (EPs).
- 24 gold electrodes ($40x40\mu m^2$) sandwiched between two layers of biocompatible polyimide.
- Rests directly on cortex surface
- Flexible enough to conform to the shape of the cortex
- Simultaneous recording, independent of the state of the animal and the level of anesthesia.



Experimental Setup

- 24 Channels
- EKG Measurement Gain-Normalization
- 3 Amplification Stages
- Optically-Coupled Isolation Main Stage Amplifier.
- 60Hz Suppression by Aluminum Shielding & Averaging



Stimuli

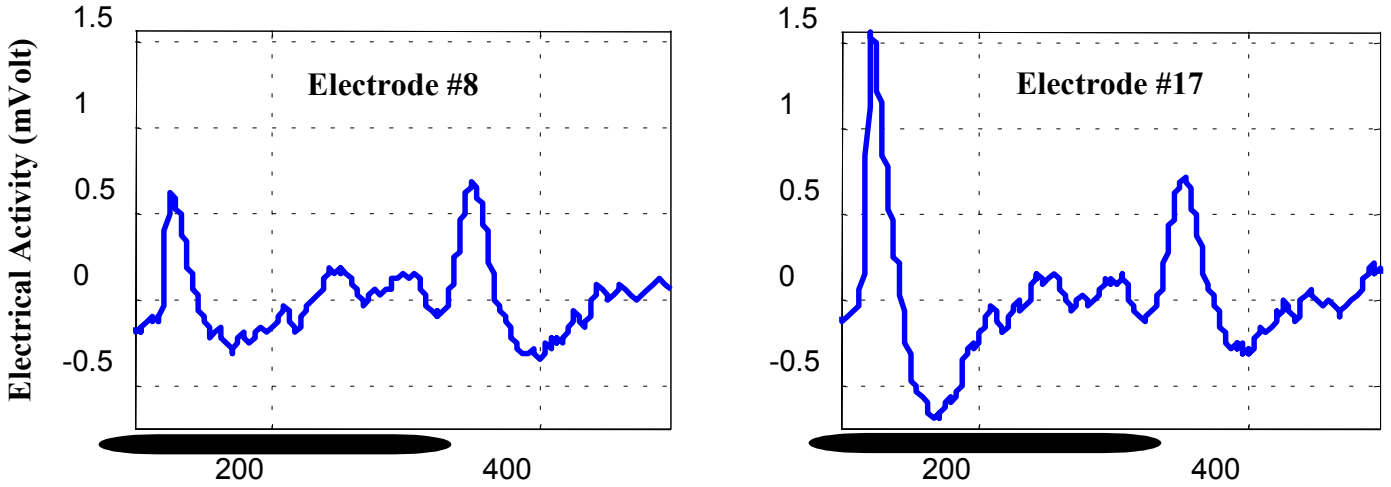
- Data were collected from a total of 7 **anesthetized** domestic Ferrets (*Mustela Putorius*), in response to monaurally presented acoustic stimuli.

- **Tone** stimuli were 200 ms in duration, with 10 ms rise/fall time, at various frequencies ranging from 2 to 11 kHz with intensity ranging from 65 to 85 dB.

- **Moving Ripples** were 1700ms in duration, with 8ms rise/fall time, repeating every 4.2 secs,with intensity ranging from 65 to 85 dB also. Ripples were chosen because they are dynamic and broadband as most natural sounds, with the ability to match the different cell Receptive Fields (elaborate description is given on Slide 13.)

Evoked Potentials

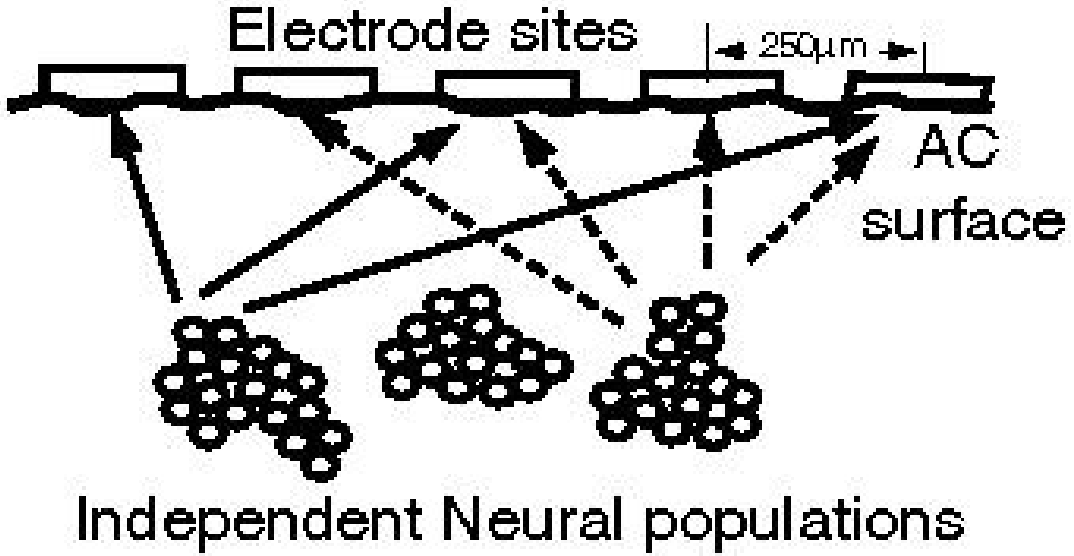
- Unlike unit activity, Evoked Potentials (EPs) consist primarily of synaptic activity. Peaks of the EPs appearing later than 10ms post-stimulus, are thought to reflect auditory processing by different neural centers/structures (neocortex and possibly subcortical structures).



Goal: to decompose the recorded EPs in the responses of separate / independent populations of neurons by using some criterion of separability that can be related to the neurophysiology.

Information Overlap

- The simultaneous multi-electrode, recording-from-the-surface approach, records overlapping signals from closely placed electrode sites.
- Each electrode receives signals not only from neurons directly underneath, but is a weighted sum (linear mixture) of the activity of various separate/independent distributed neurophysiological networks.
- We approximate the mixing process as simultaneous (un-filtered, un-delayed).



Linear ICA

- Independent Component Analysis (ICA), both
  - (1) unmixes the separate sources' activity, and
  - (2) reduces the information overlap between electrodes

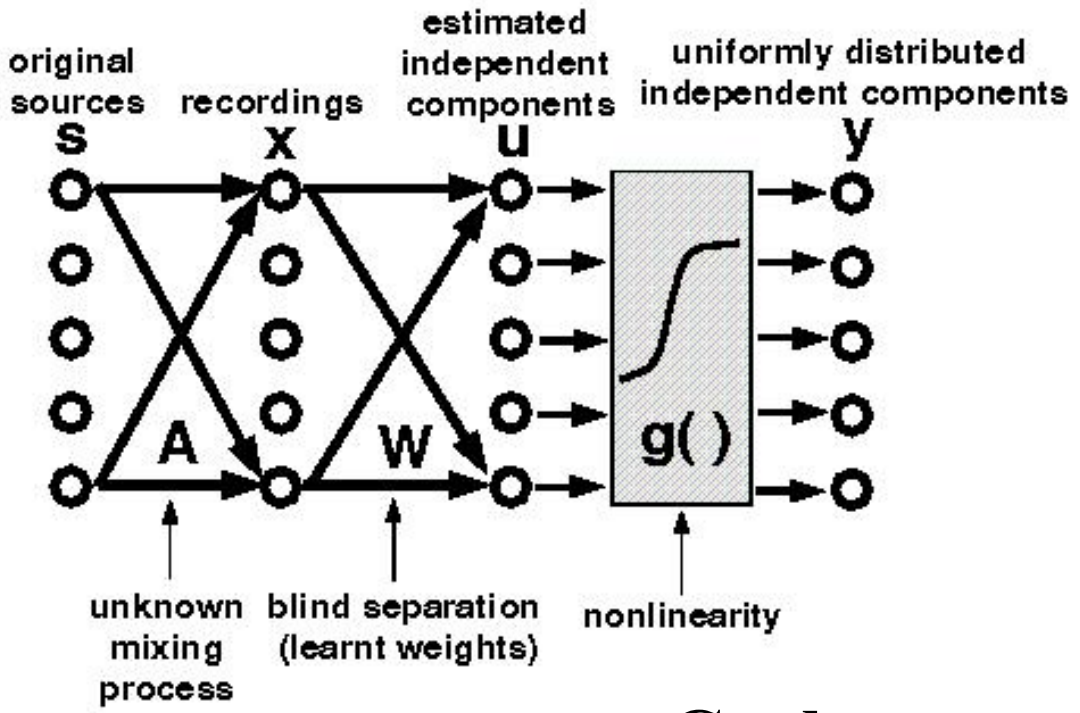
• Model:

Instantaneous Linear Mixing

$$X(t) = A*S(t)$$

$$A*W = P*D*I$$

P: Permutation Matrix
D: Diagonal Scaling Matrix
I: Identity Matrix



• Method:

Estimate weights so to maximize output entropy **H(y)** => minimize mutual information **I(y)**

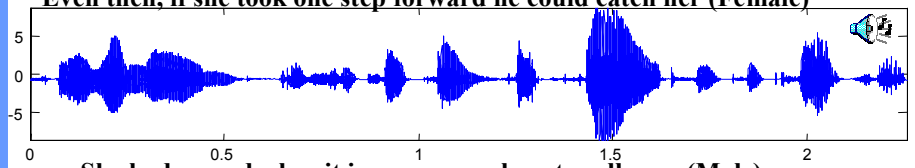
• Goal:

Learned weights approximate inverse of mixing matrix

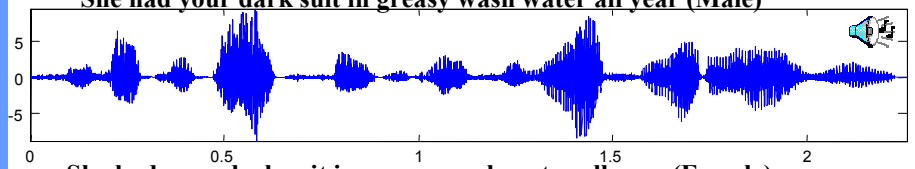
ICA Example on Speech

ORIGINAL SOURCES

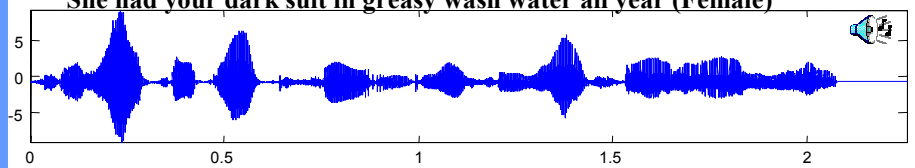
Even then, if she took one step forward he could catch her (Female)



She had your dark suit in greasy wash water all year (Male)



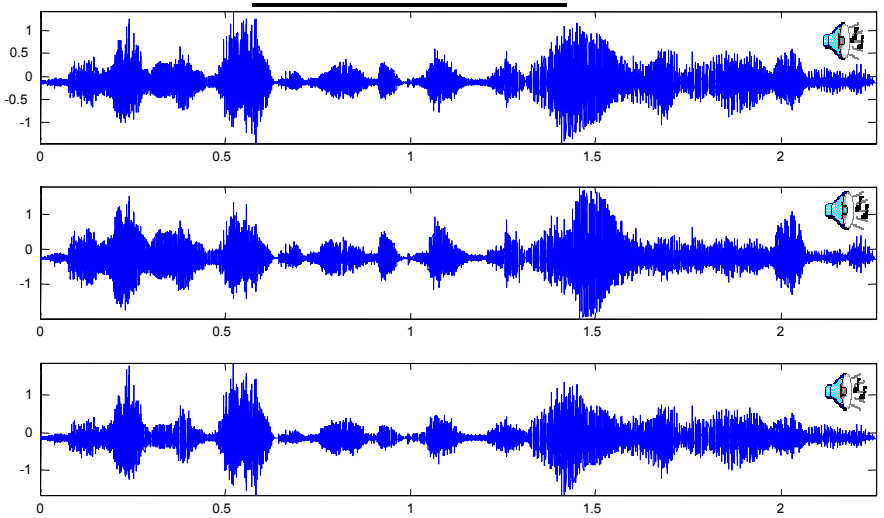
She had your dark suit in greasy wash water all year (Female)



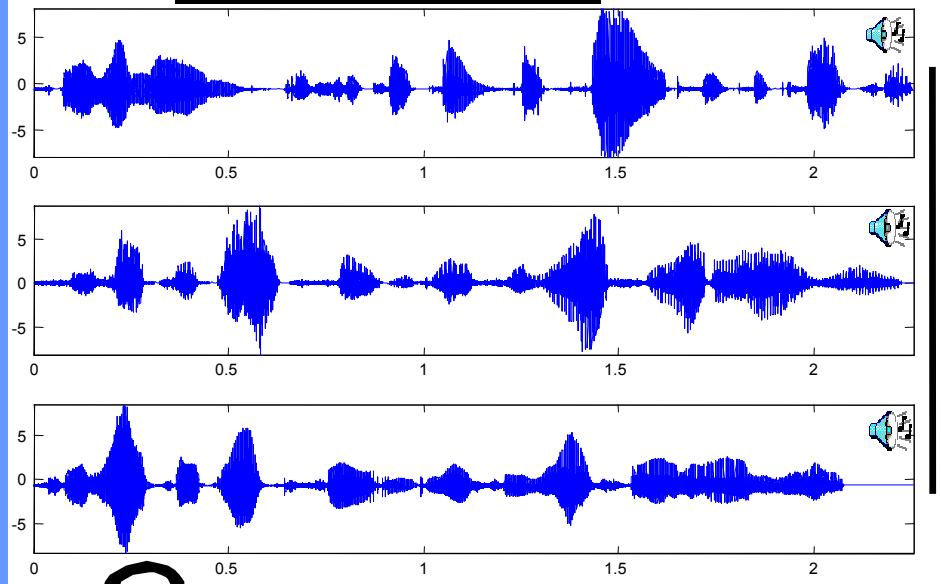
Linear Mixing Process

$$\begin{bmatrix} 1.0 & 1.4 & 0.6 \\ 1.8 & 1.0 & 1.2 \\ 0.8 & 1.6 & 1.0 \end{bmatrix}$$

MIXED SOURCES



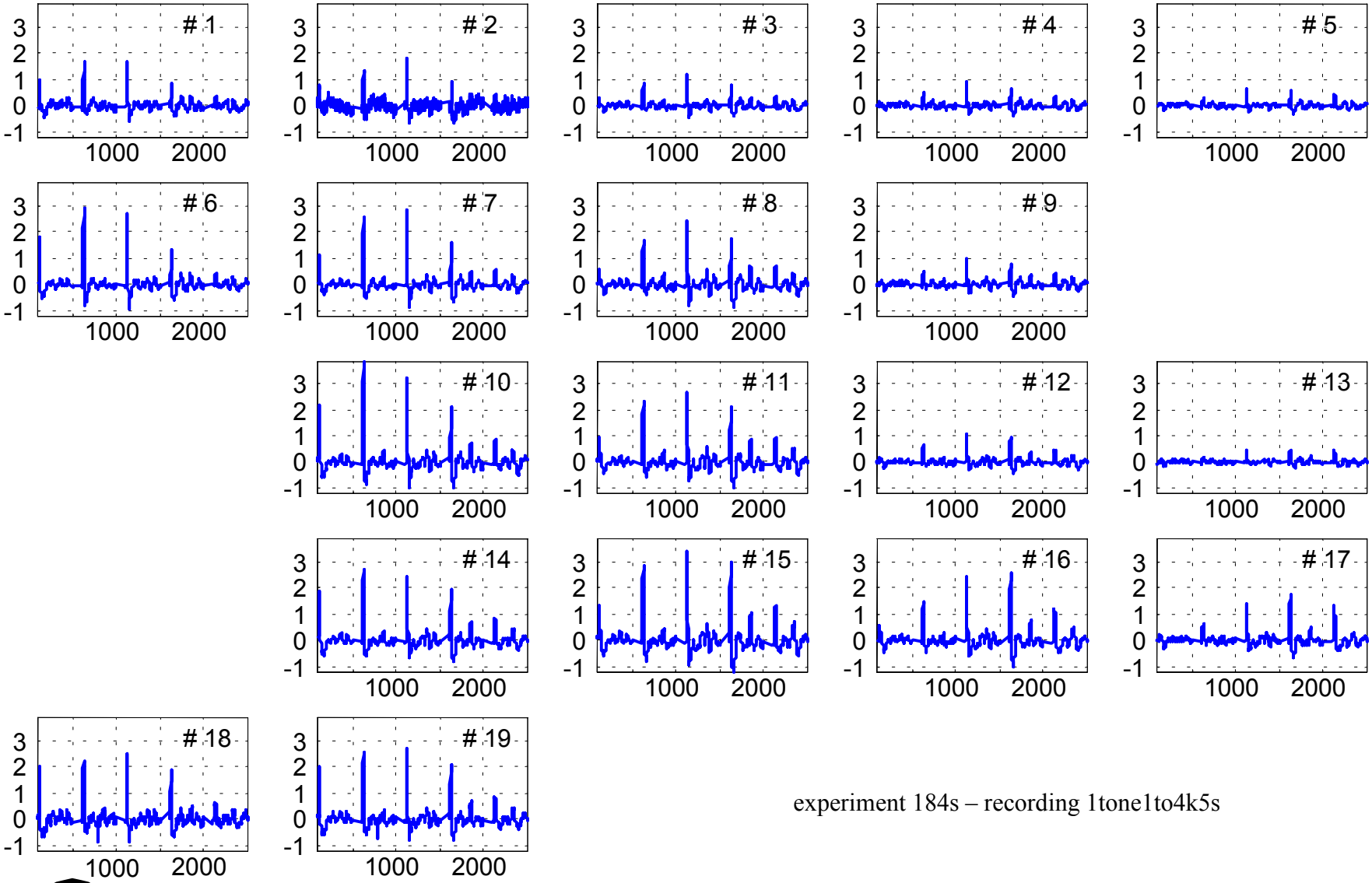
RECOVERED SOURCES



Linear ICA

Pure Tone Data I

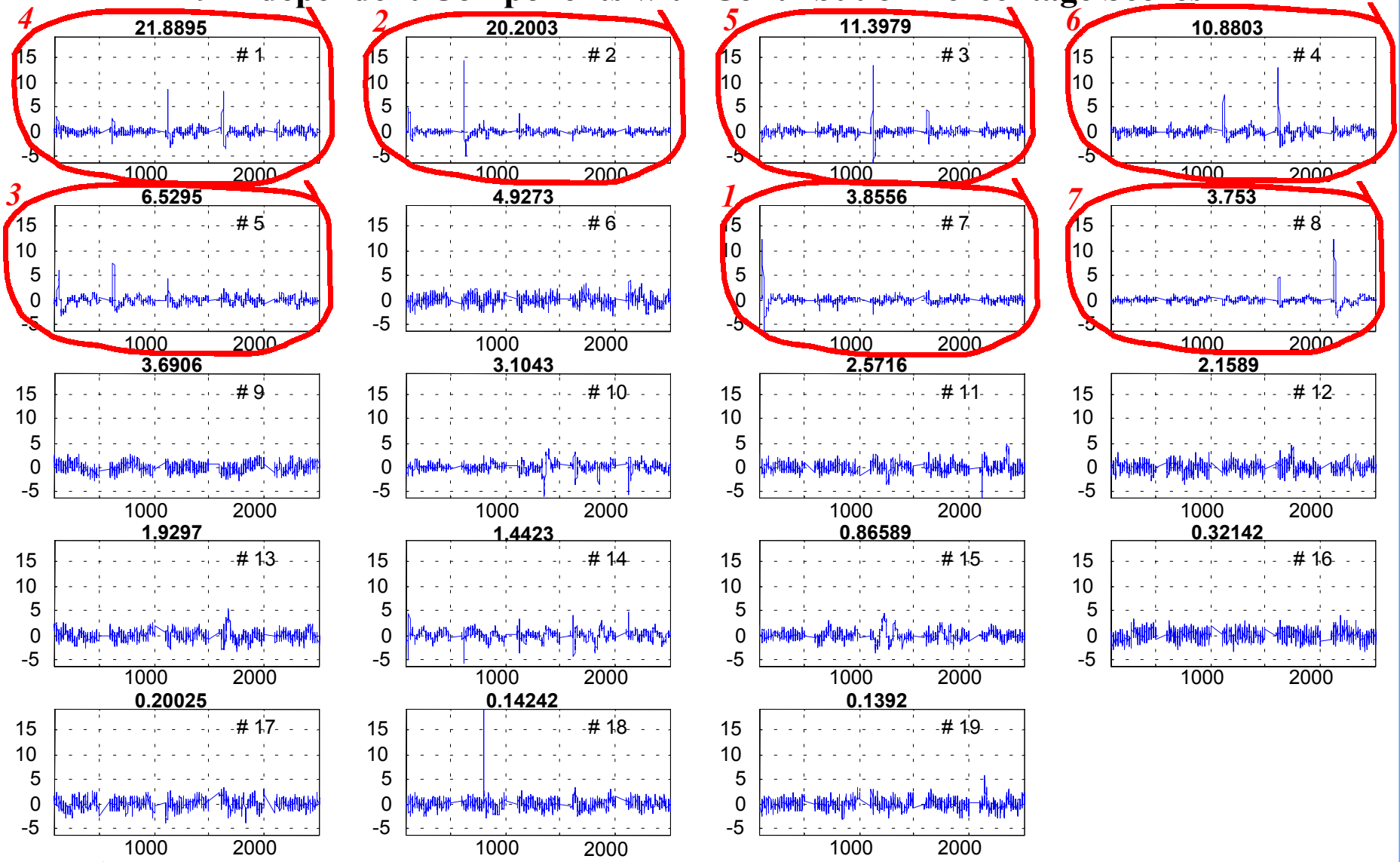
Single Tones 1.0KHz – 1.4KHz – 2.0KHz – 2.8KHz – 4.0KHz Concatenated



experiment 184s – recording 1tone1to4k5s

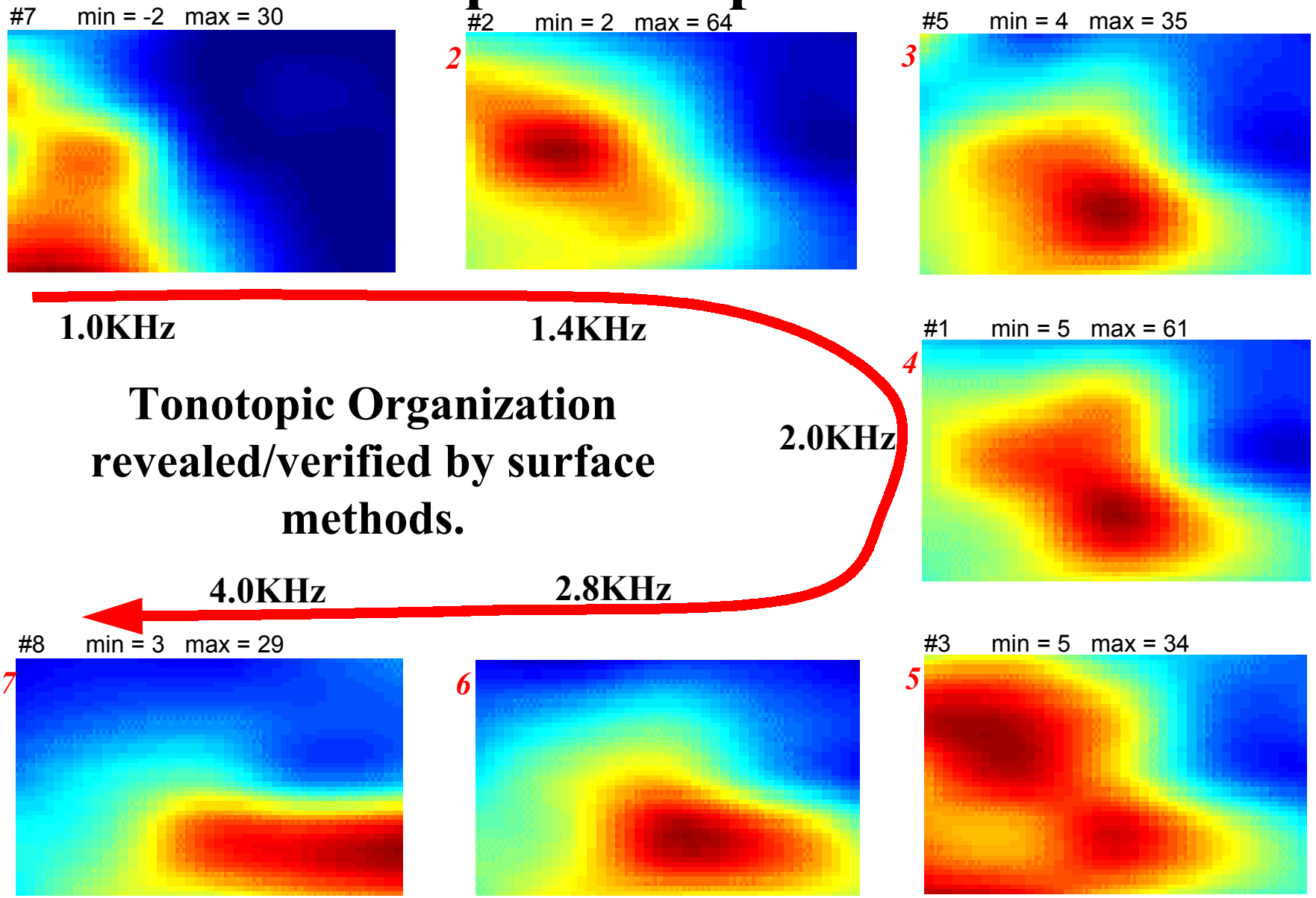
Pure Tone Analysis

19 Independent Components with Contribution Percentage Scores

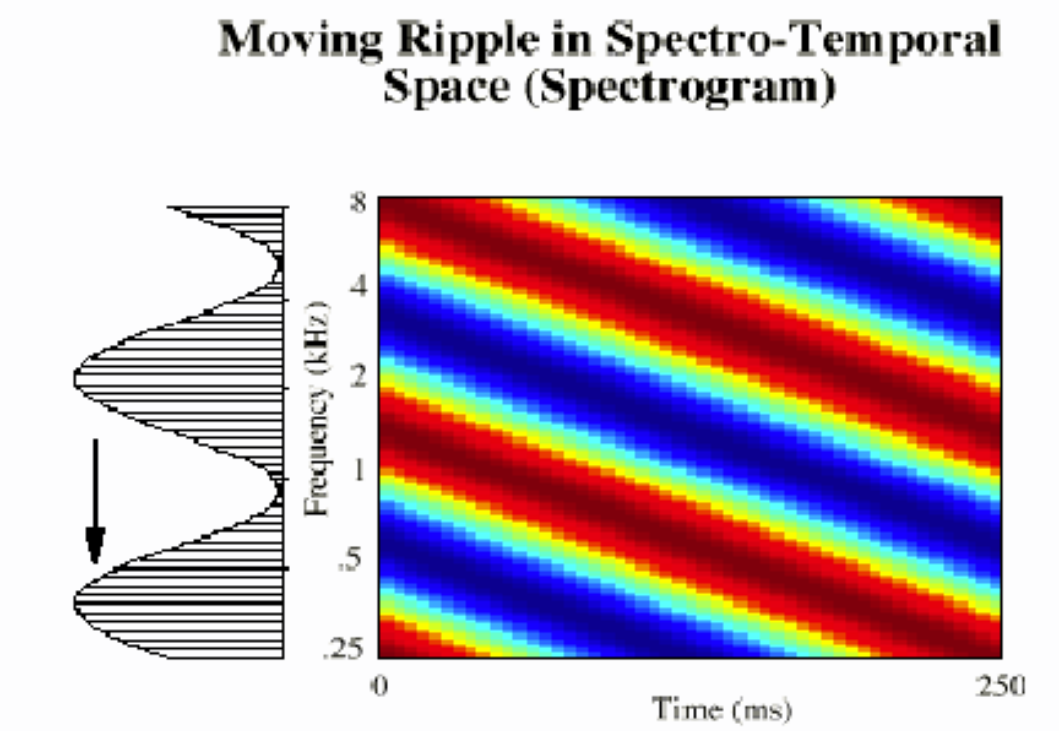


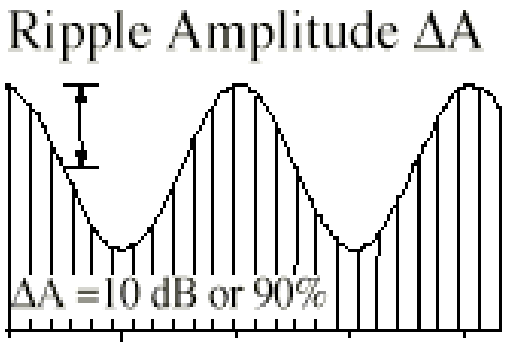
Center for Auditory and Acoustic Research

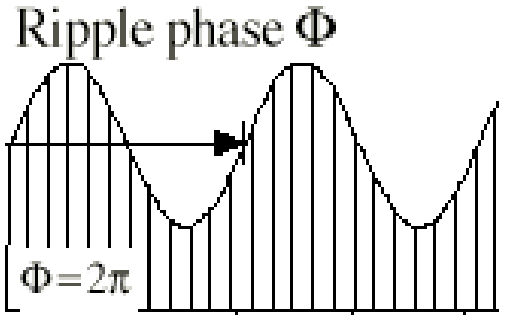
Spatial Maps I



Stimuli - Moving Ripples

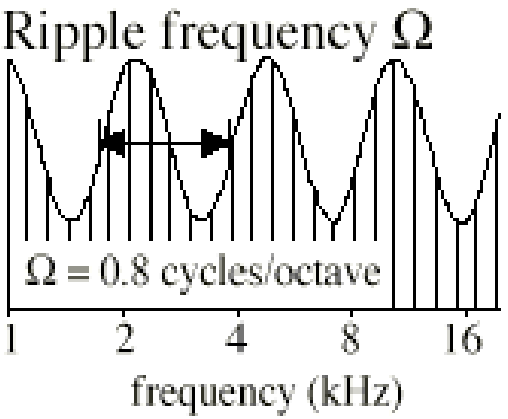






$$S(x,t) = 1 + \Delta A \cdot \sin\left[2\pi \cdot \left(w \cdot t + \Omega \cdot x\right) + \Phi\right]$$

where $x = \log_2\left(\frac{F}{F_0}\right)$

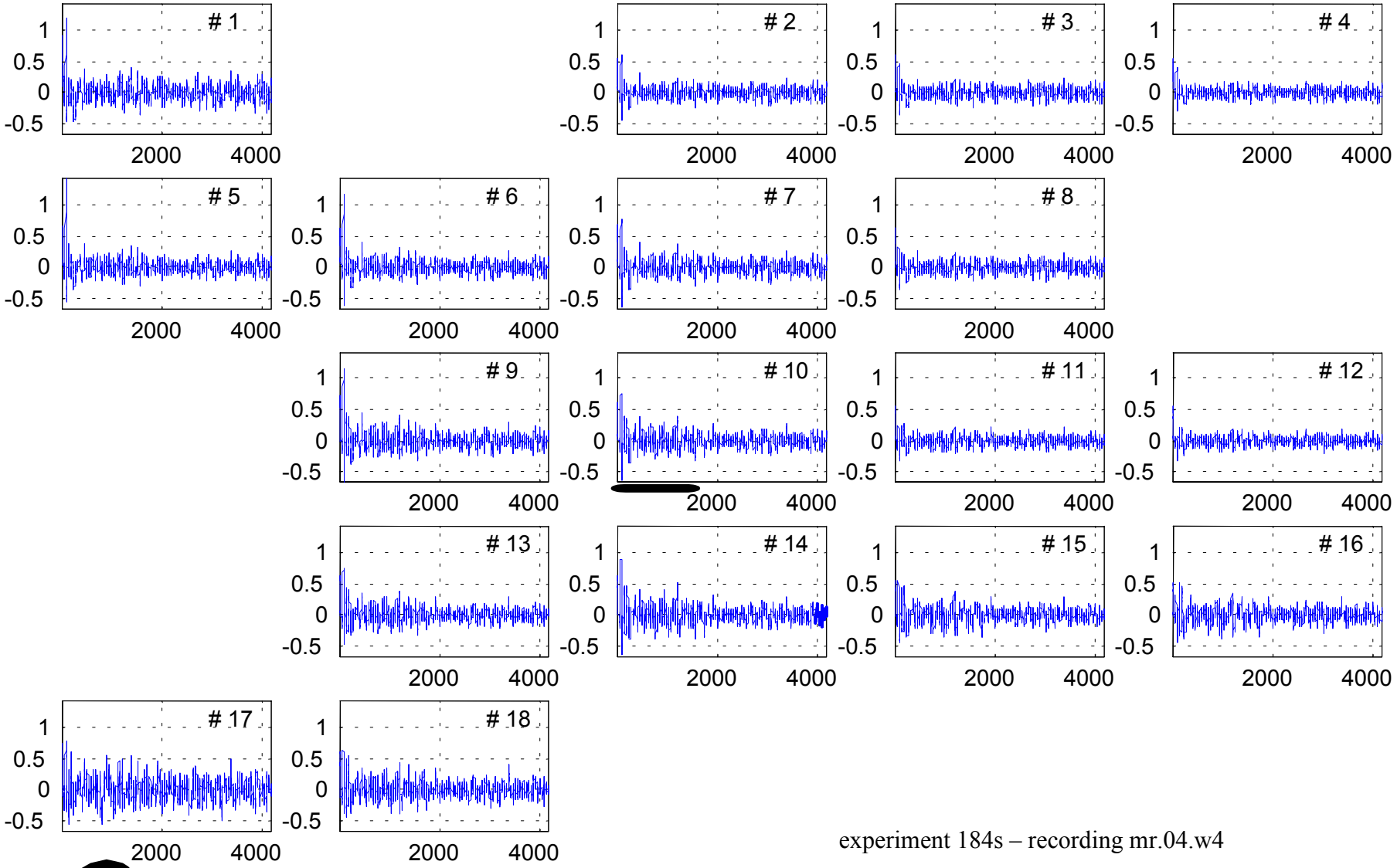


Parameters:

$w = \pm 4\text{Hz}$ and $\Omega = 0.4/0.8/1.6$ cyc/oct

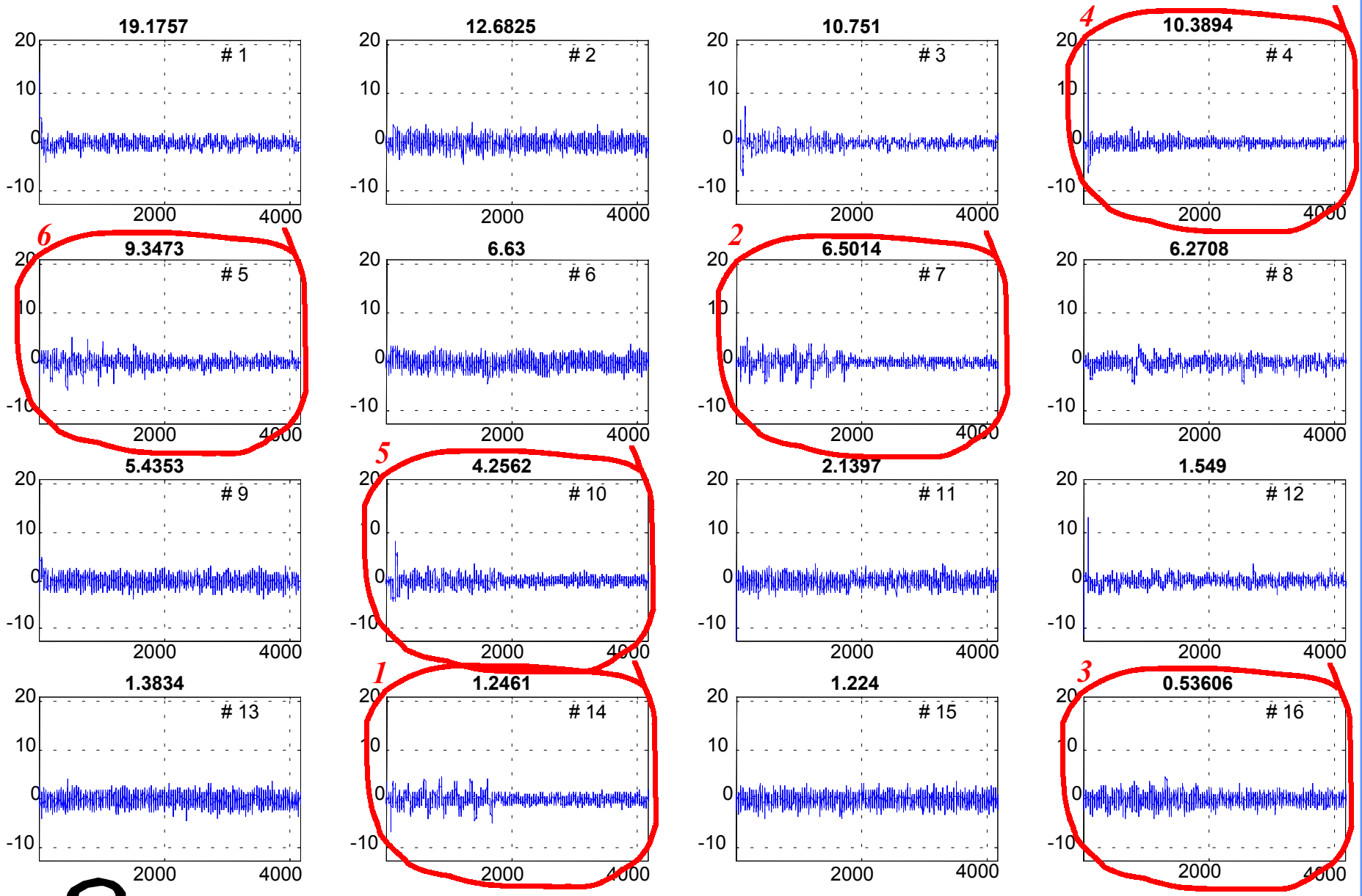
Moving Ripple Data

Moving Ripple: w = 4Hz, Ω = 0.4 cycles/octave

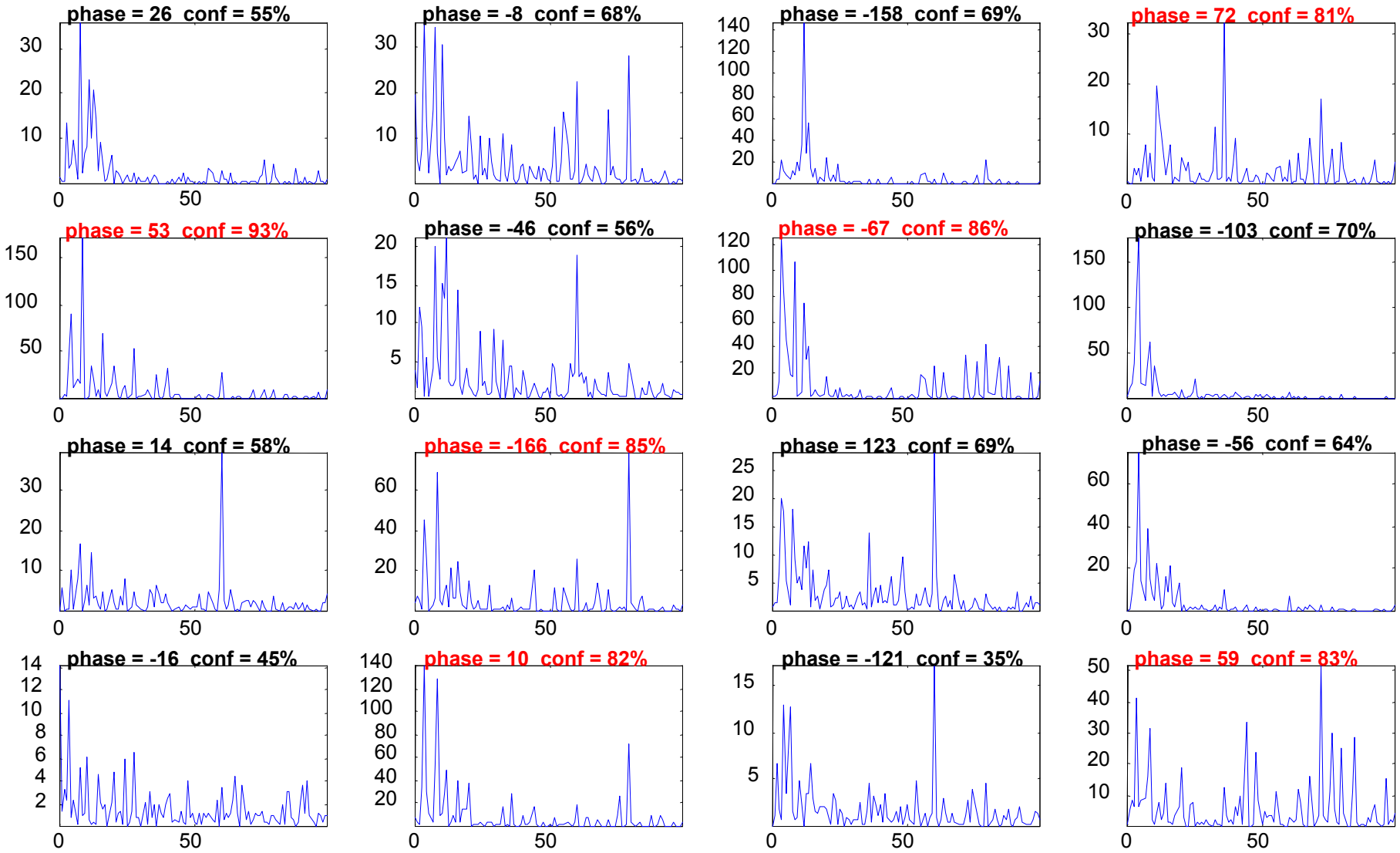


experiment 184s – recording mr.04.w4

Moving Ripple Analysis

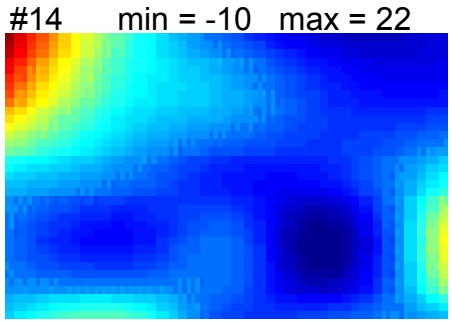


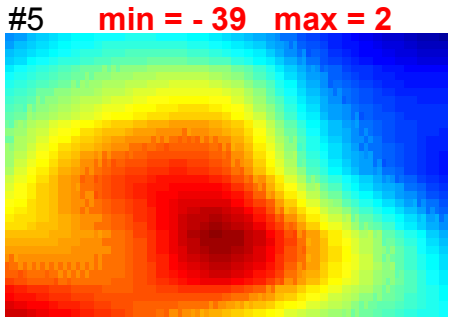
Spectral Analysis

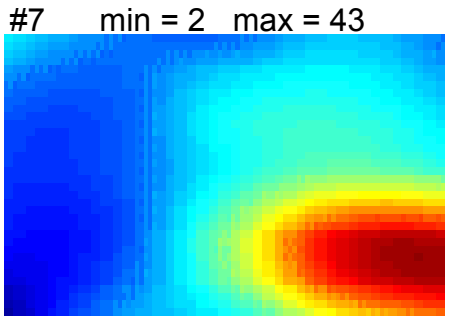


$$\text{Confidence} = \frac{\text{power in 4Hz harmonic set}}{\text{total power}}, \text{ Criterion for RED: conf} > 80\%$$

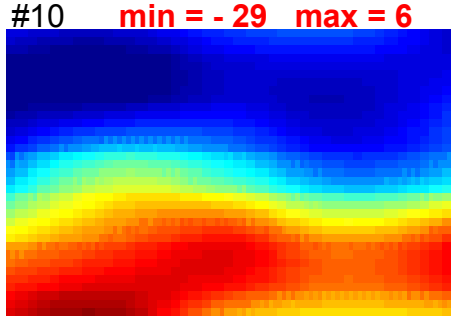
Spatial Maps II

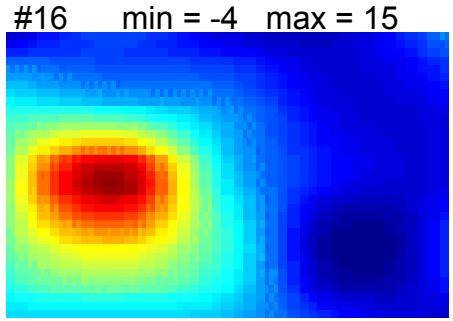


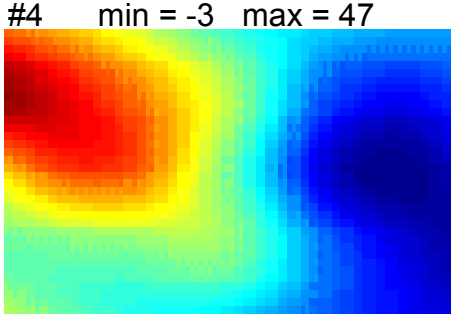




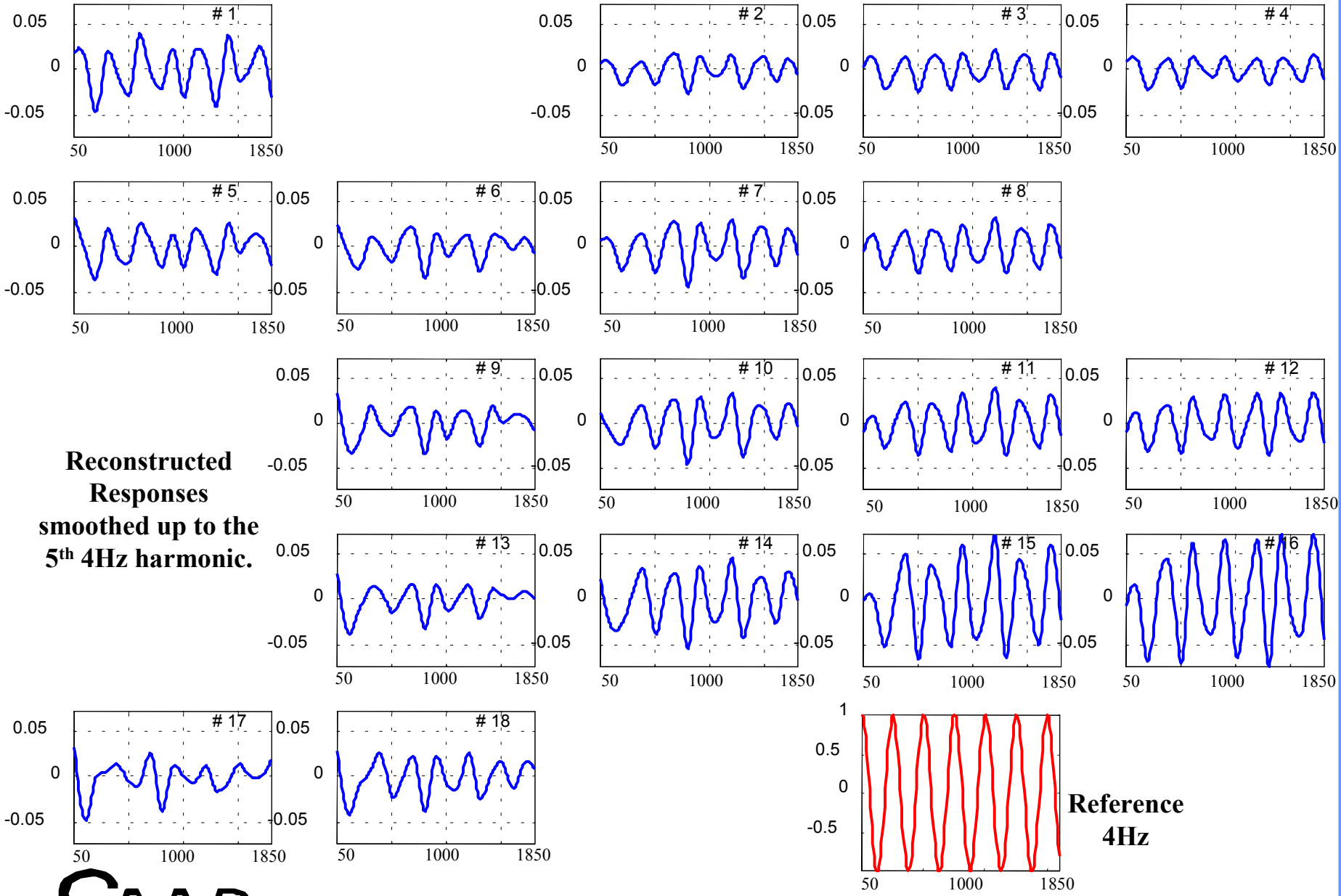
Traveling wave succession







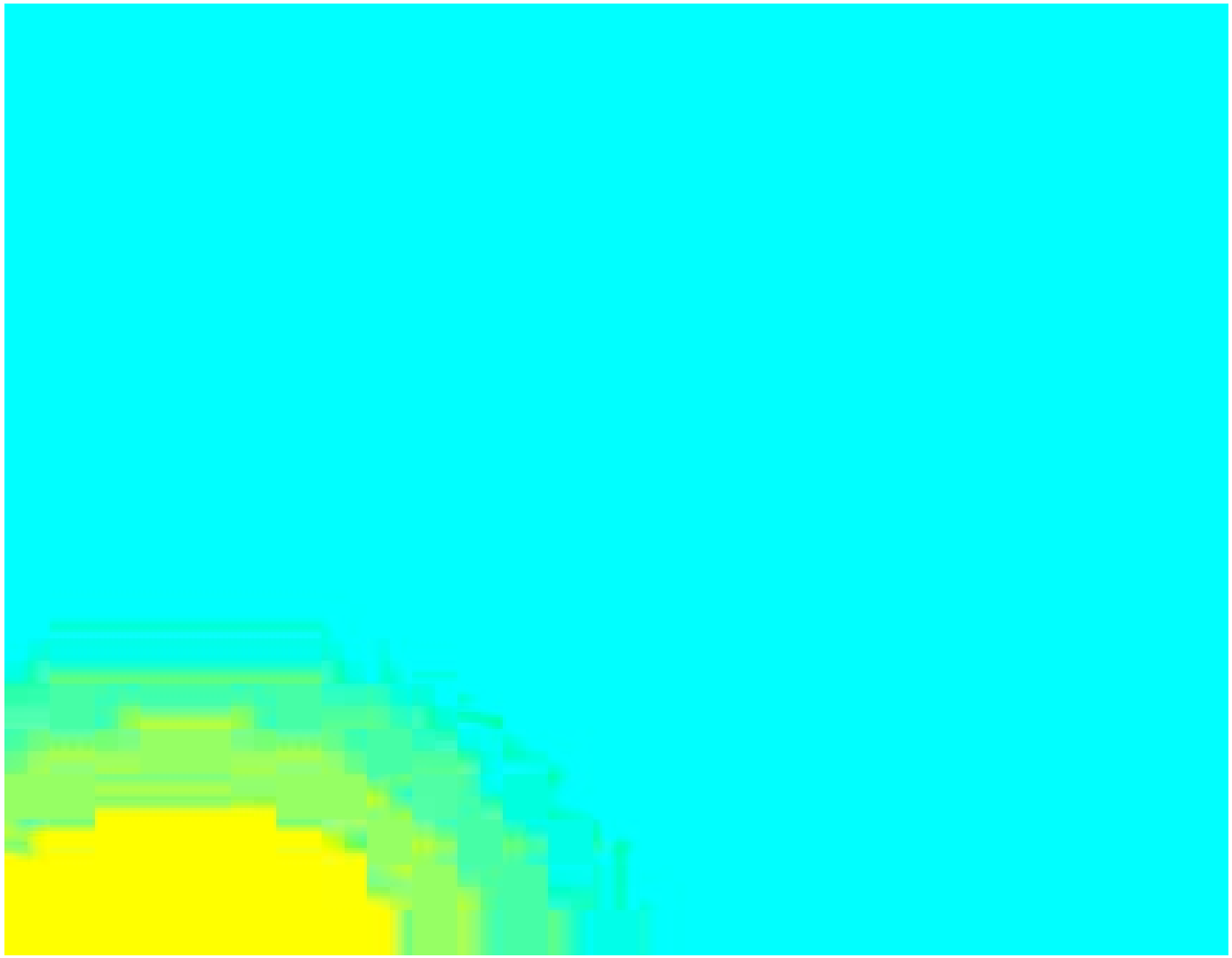
Reconstructed Responses



Reconstructed Responses smoothed up to the 5th 4Hz harmonic.

Reference 4Hz

Moving Wave Movie



Discussion

- Tonotopic organization revealed from the surface of the cortex, as documented to be the case (Shamma et. al. 1993) with single unit recordings, from sub-cortical layers.

- ICA identified components of physiological importance, unlike the orthogonal componets extracted by PCA used in previous studies (Barth & Di, 1990).

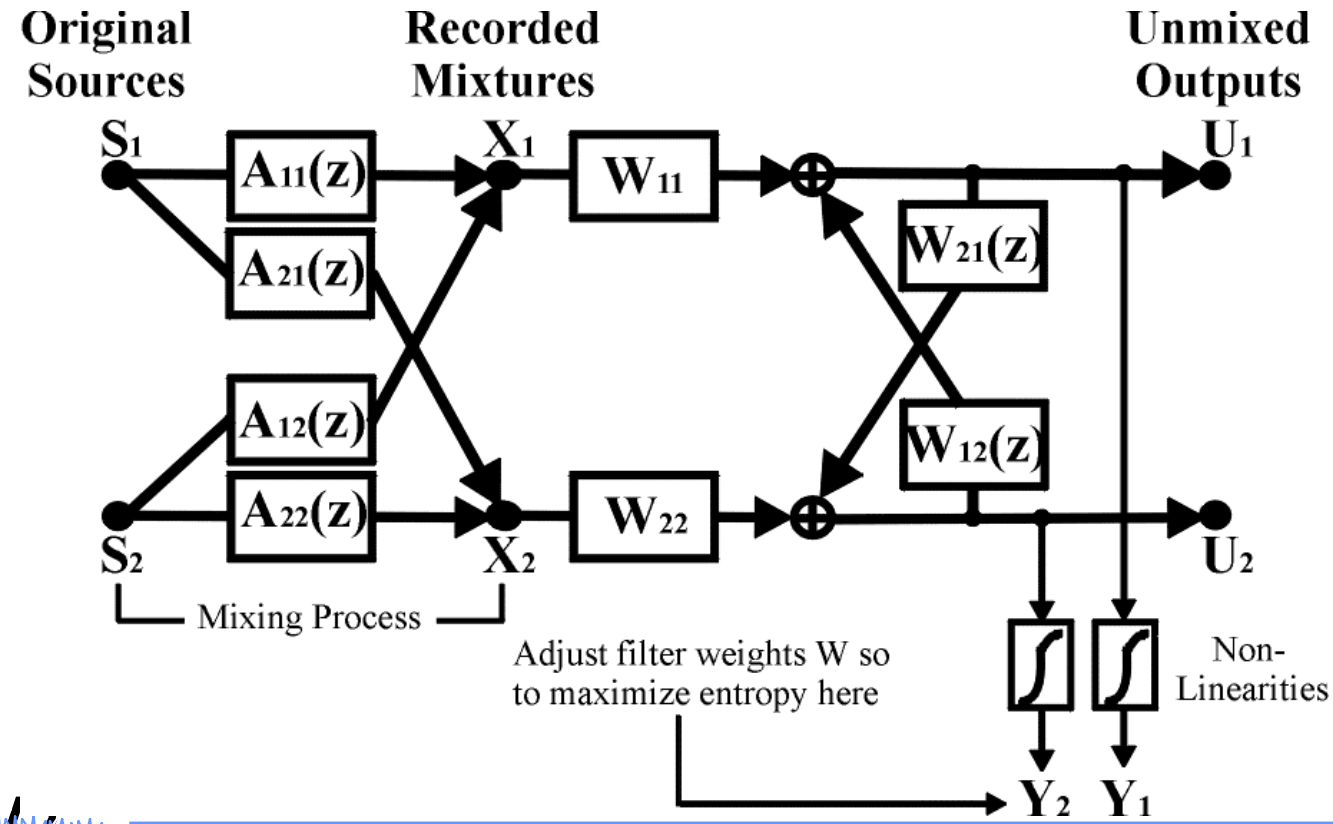
- ICA performed on moving-ripple responses, revealed components with phase-locking to the ripple speed.

- Response reconstruction using phase-locked components is done in a coherent way, so that traveling wave on AI was revealed.

- ICA in this case, can considered as another way of "filtering", helping remove noisy sources

Future Considerations

- Systematic recordings of moving ripples, so that surface SpectroTemporal Responsive Fields (STRF) can be constructed as for single-neuron STRFs.
- Application of **convolutive-ICA** that compensates for **delays & filtering** in the mixing process



Selected References

Micro-Electrode Array

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Auditory Cortex and Rippled Spectra Stimuli

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