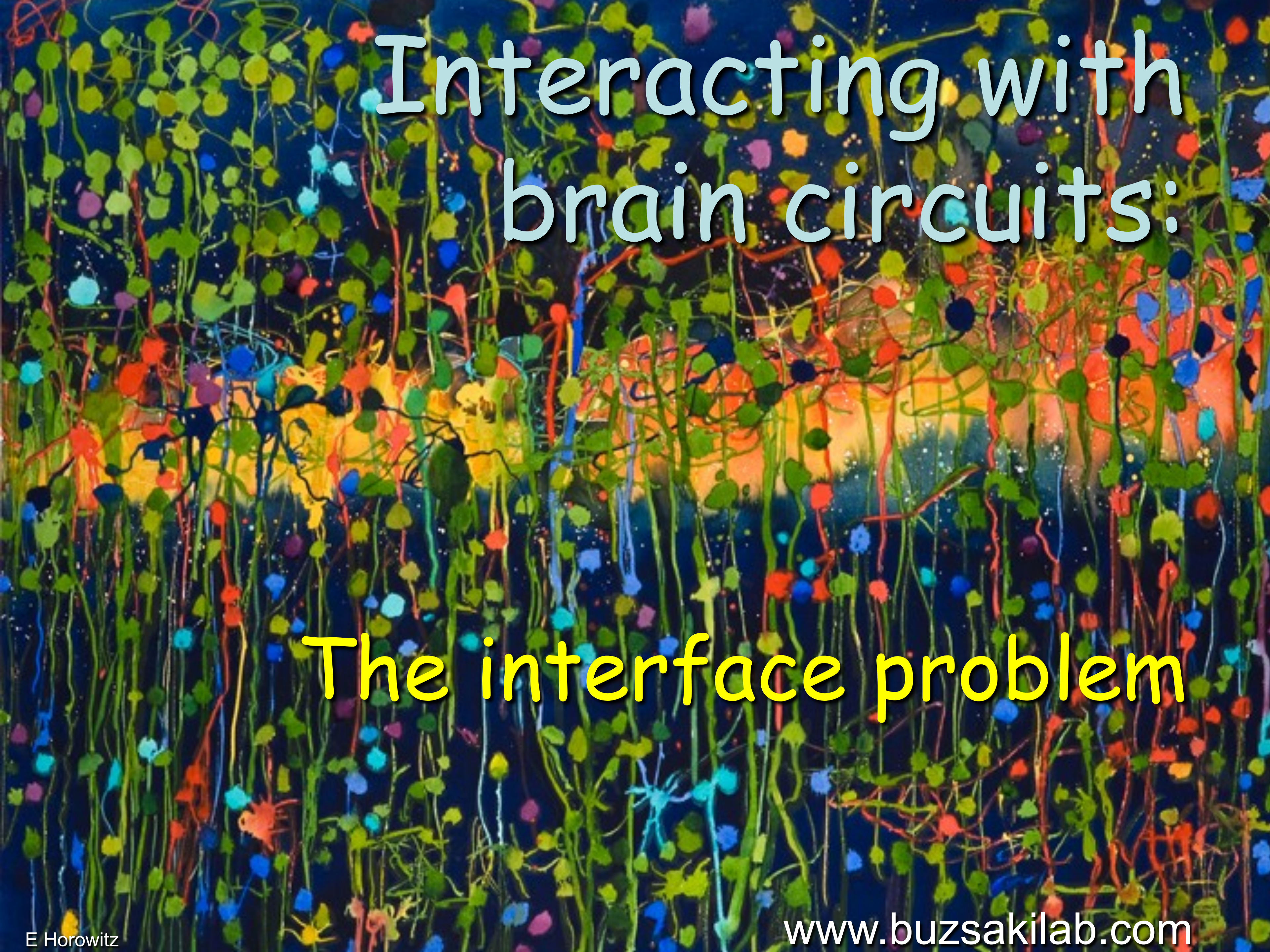
Interacting with brain circuits:

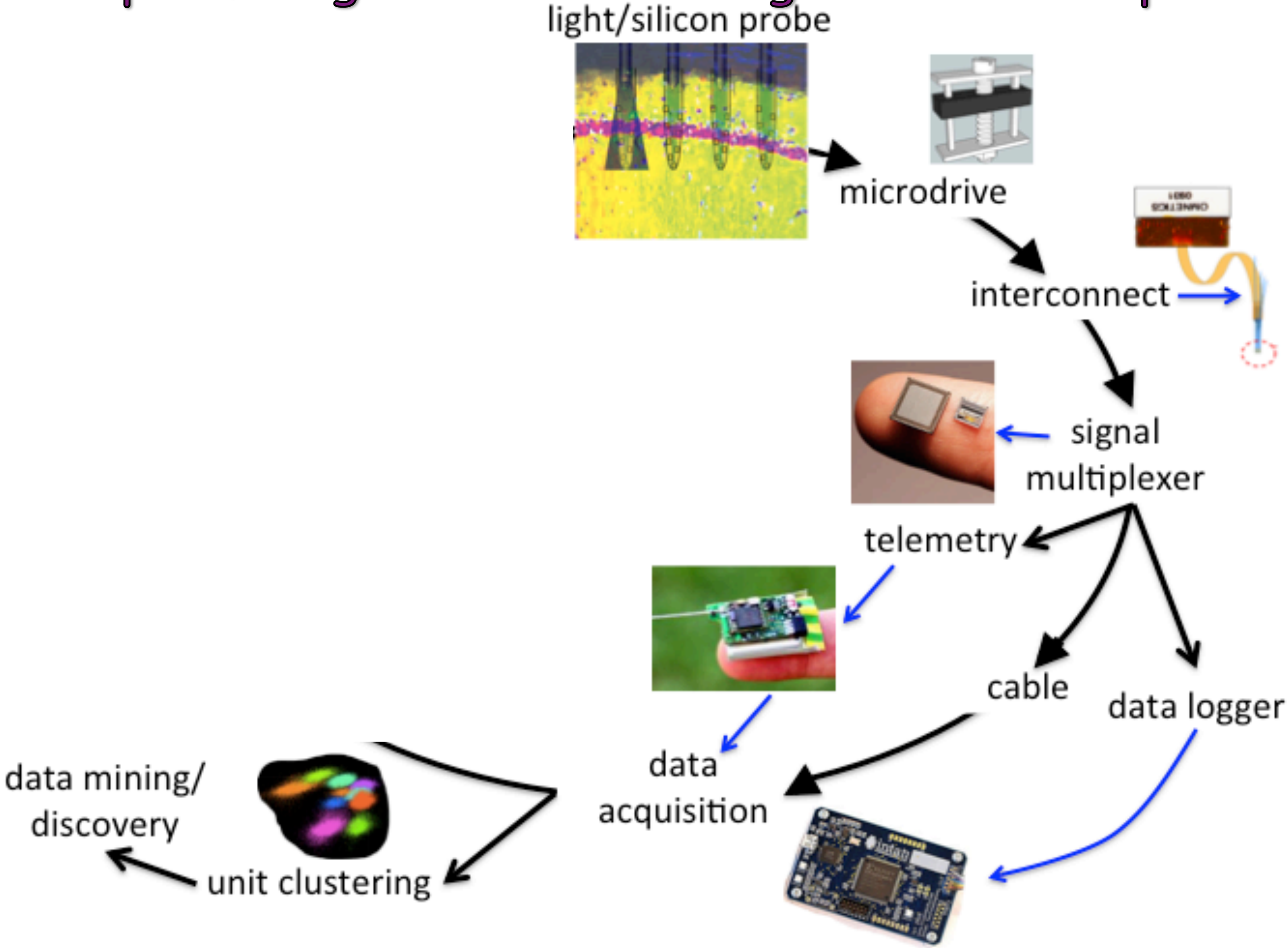
The interface problem



E Horowitz

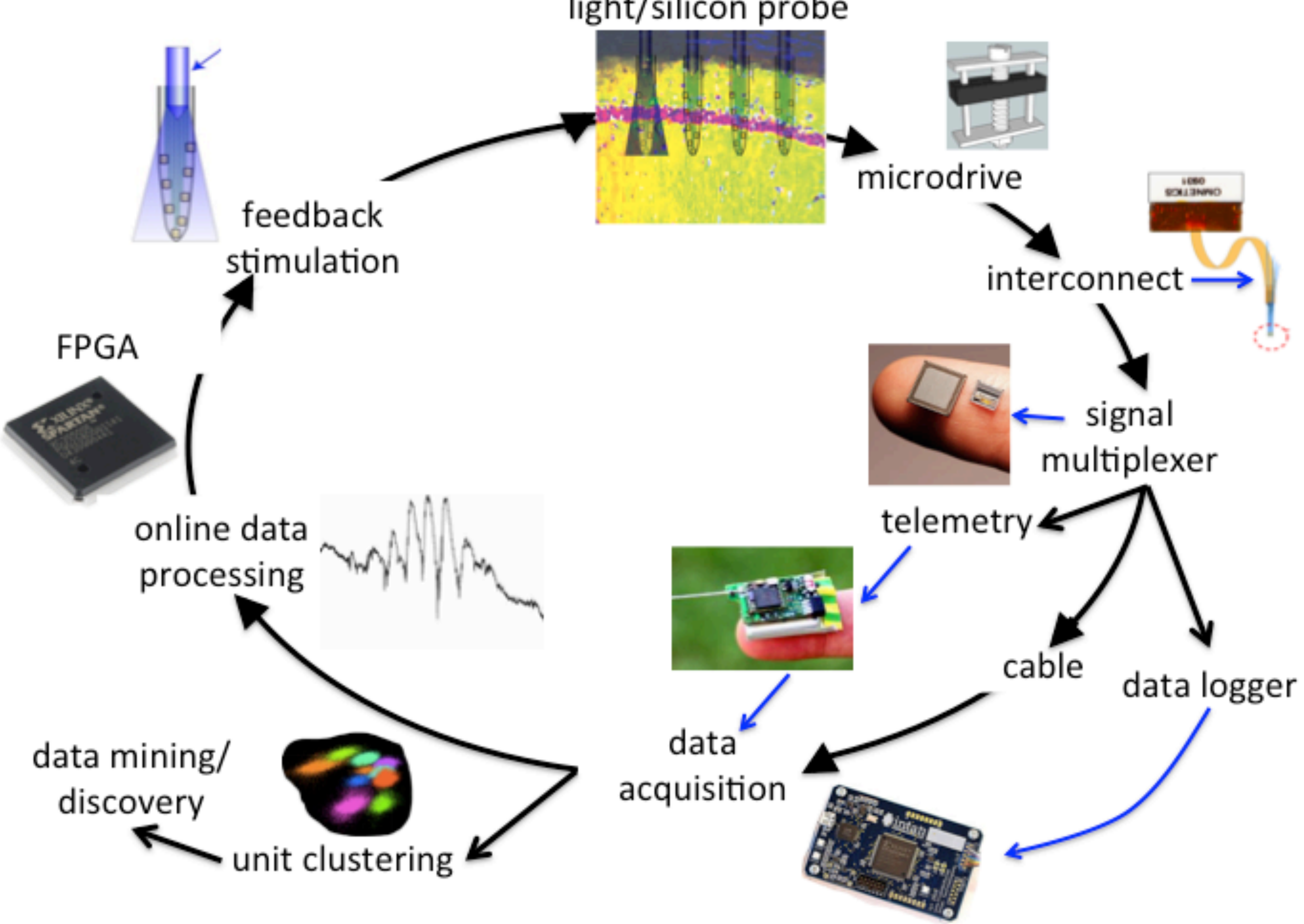
www.buzsakilab.com

Steps of large-scale recordings with silicon probes



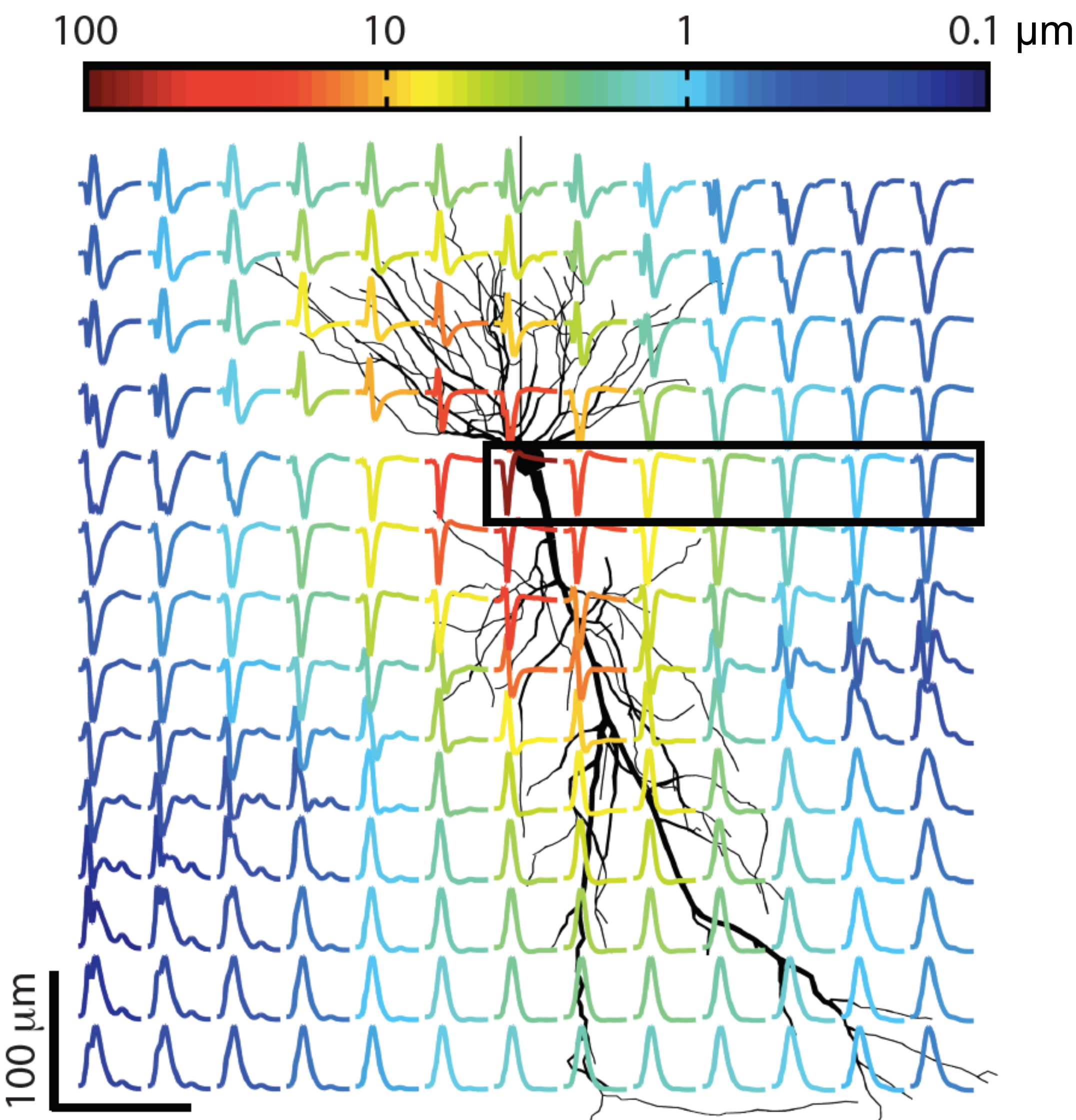
Buzsaki, Stark, Berenyi, Khodagholy, Kipke, Yoon, Wise **Neuron** (2015)

Steps of large-scale recordings with silicon probes

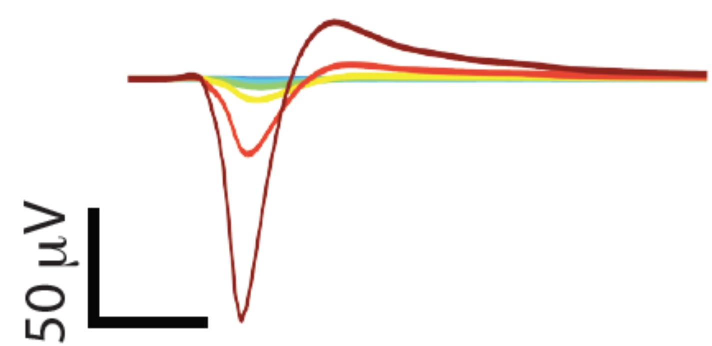


Buzsaki, Stark, Berenyi, Khodagholy, Kipke, Yoon, Wise **Neuron** (2015)

Pyramidal cells generate elongated open fields



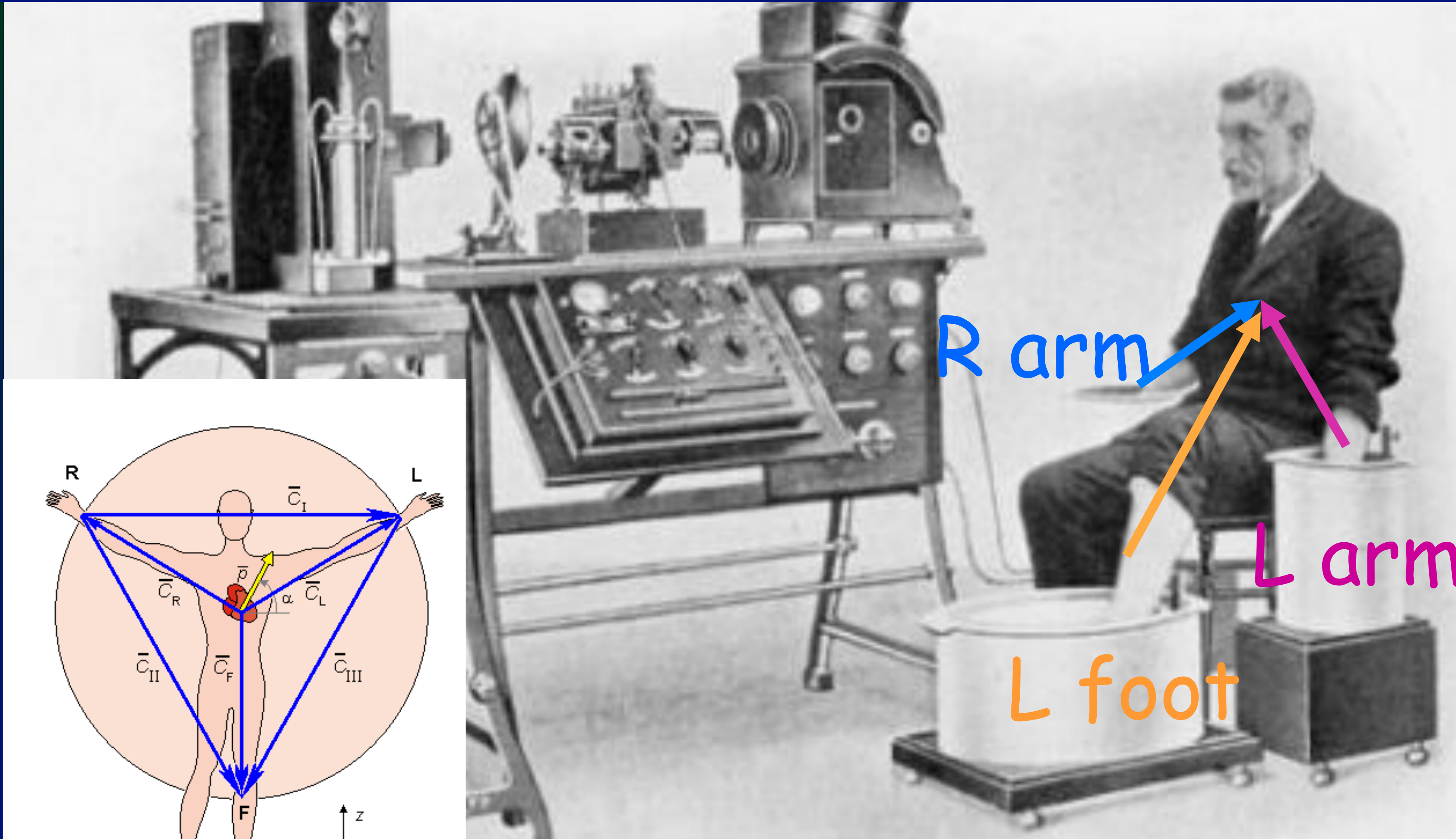
Amplitude drops rapidly with distance (~ 1 V/m)



Buzsaki, Anastassiou, Koch, **Nature Rev Neurosci** 2012

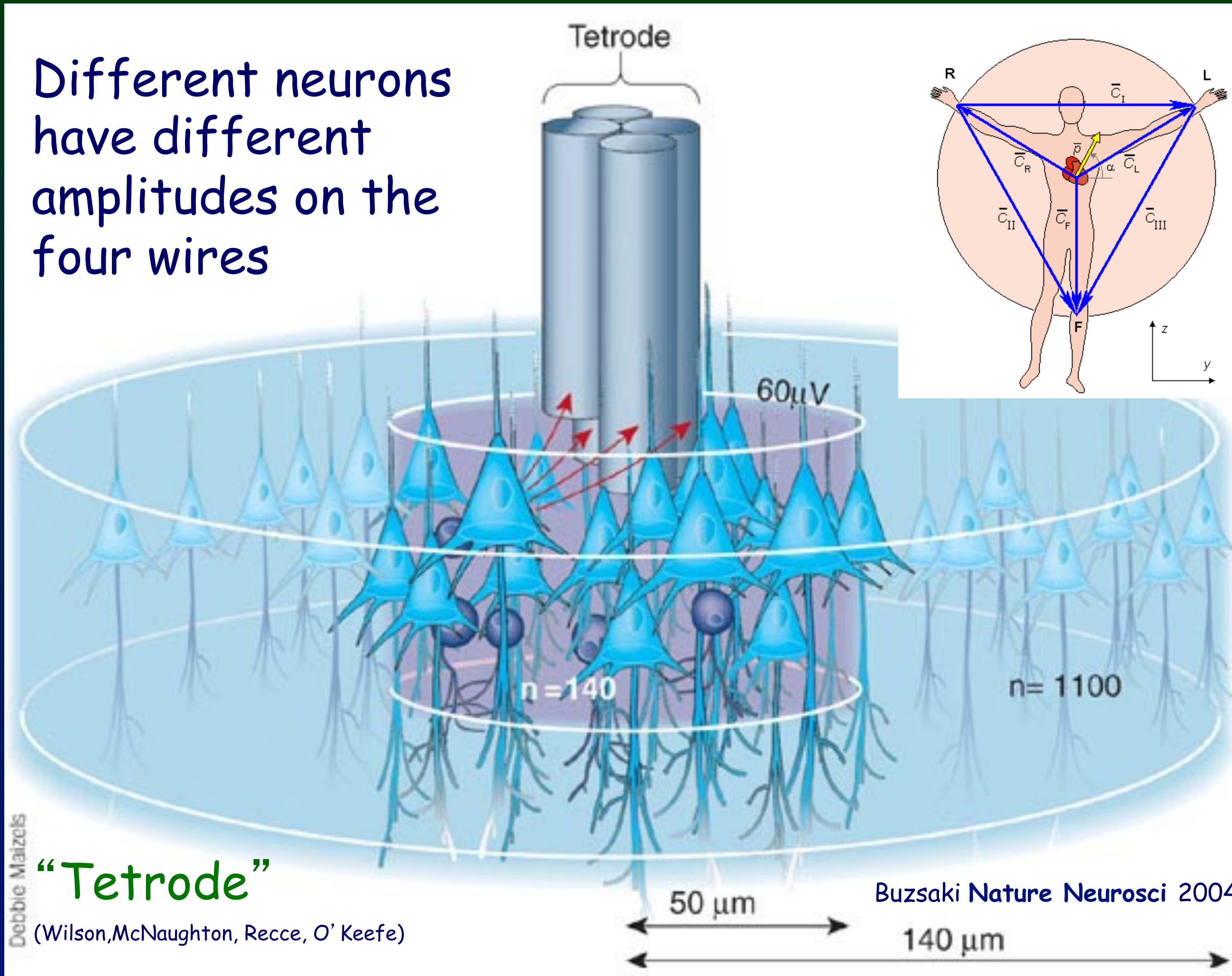
Einthoven:

triangulation of voltage signals



Separation of neurons by triangulation of electric sources

Different neurons have different amplitudes on the four wires



"Tetrode"

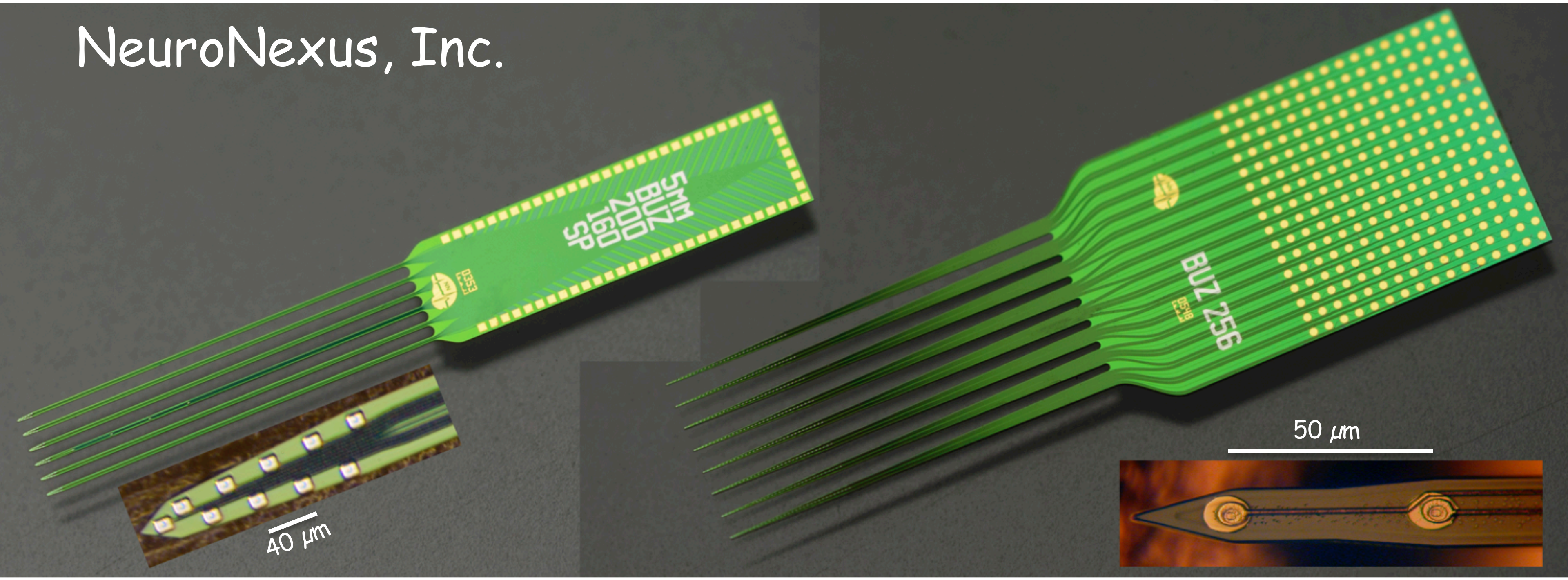
(Wilson,McNaughton, Recce, O' Keefe)

Buzsaki **Nature Neurosci** 2004

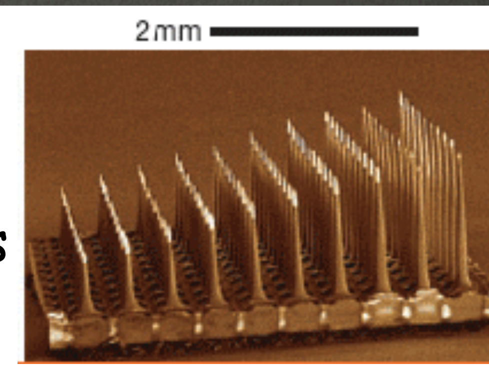
State of the art (to date)

Six-shank 'docatrode'

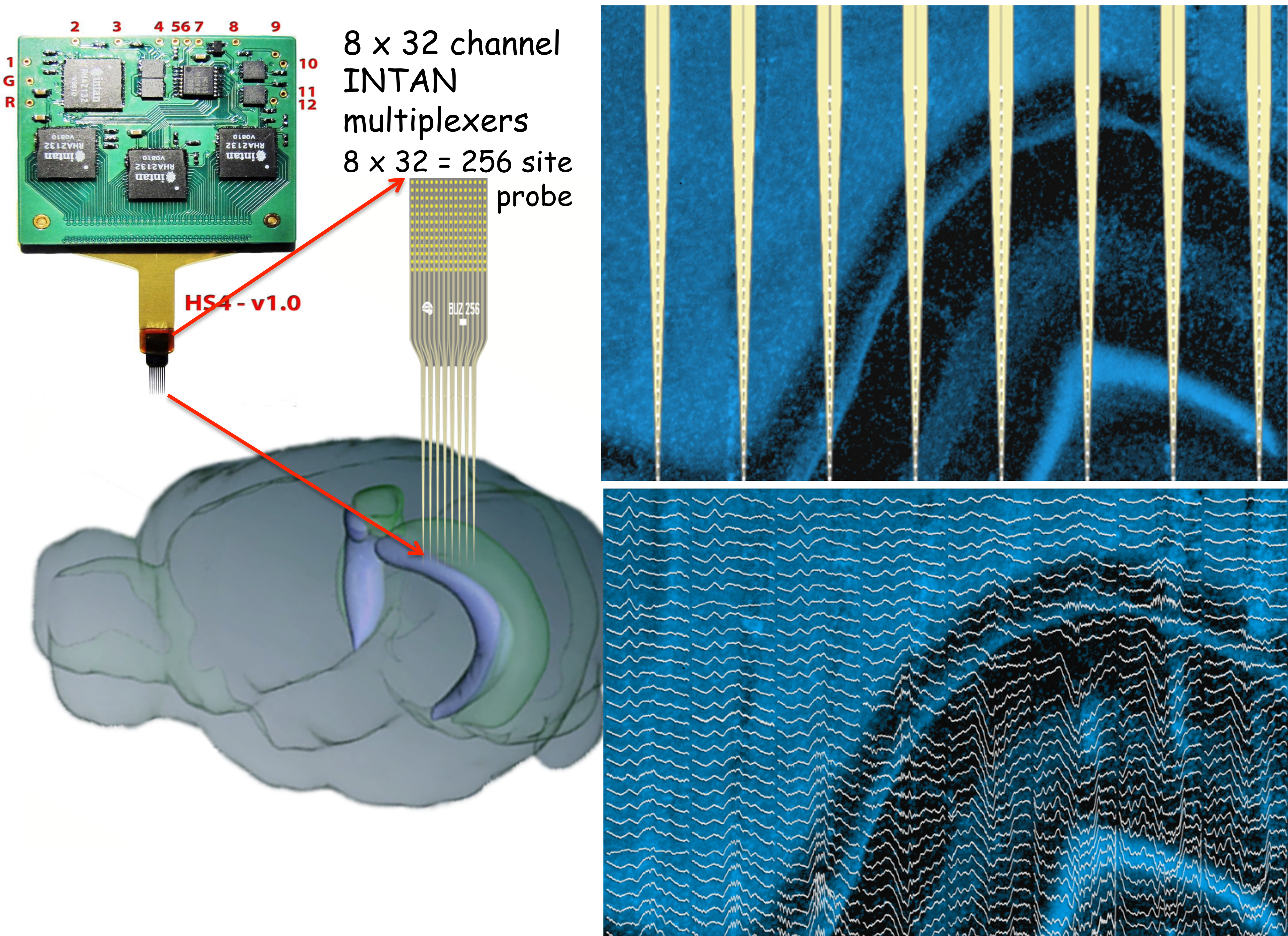
Eight-shank x 32 = 256-site probe



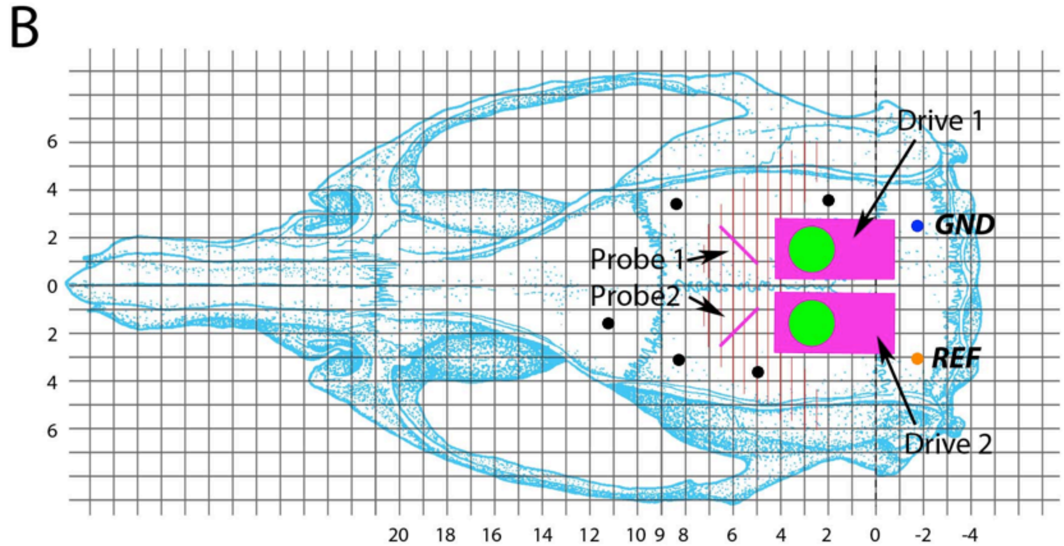
Blackrock Microsystems

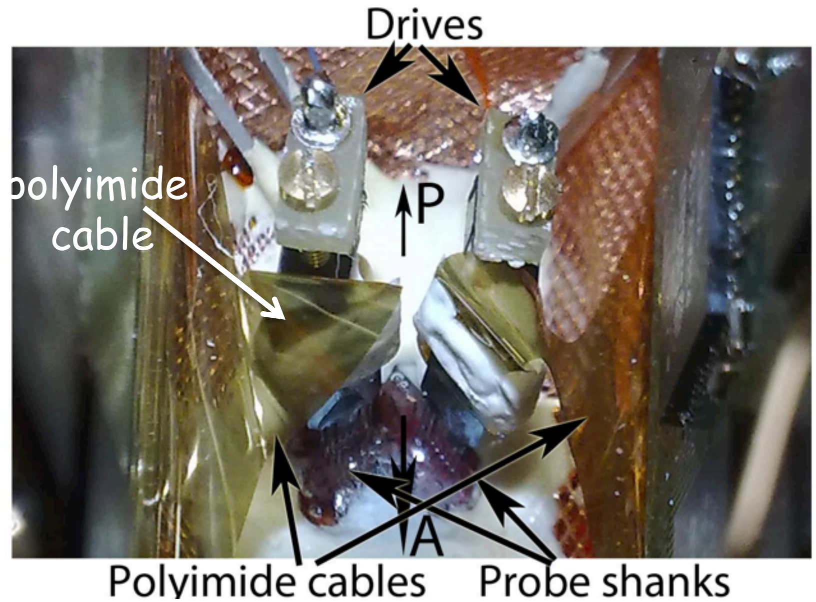


Buzsaki, Stark, Berenyi, Khodagholy, Kipke, Yoon, Wise **Neuron** (2015)

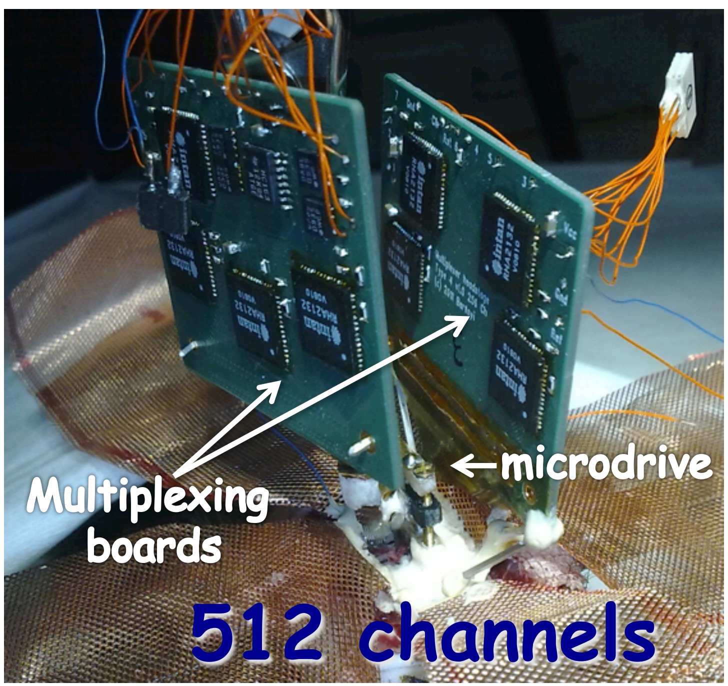


Berenyi, Stark, Roux, Harris, Leonardo, Buzsaki **J Neurophysiol** 2013

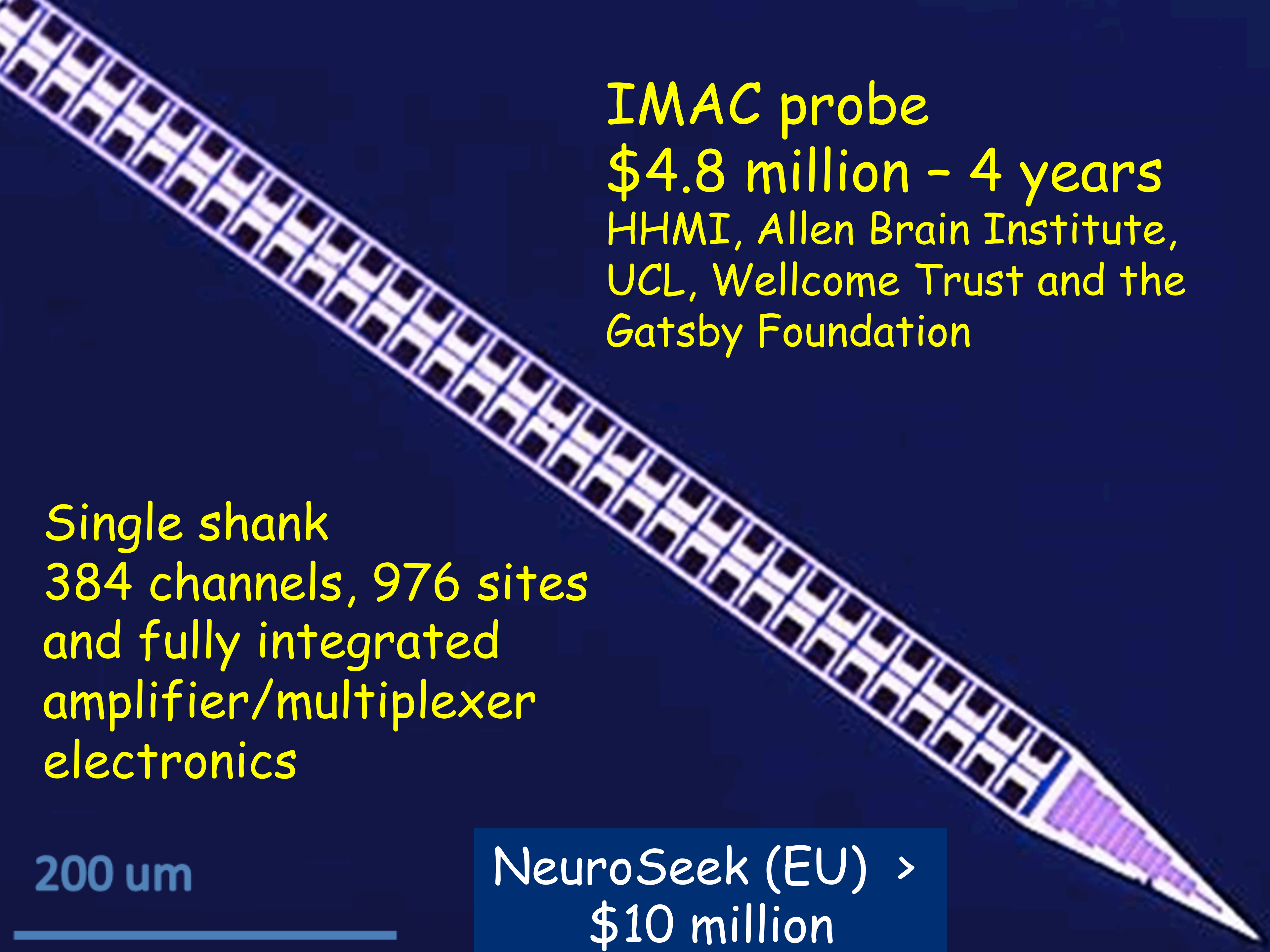




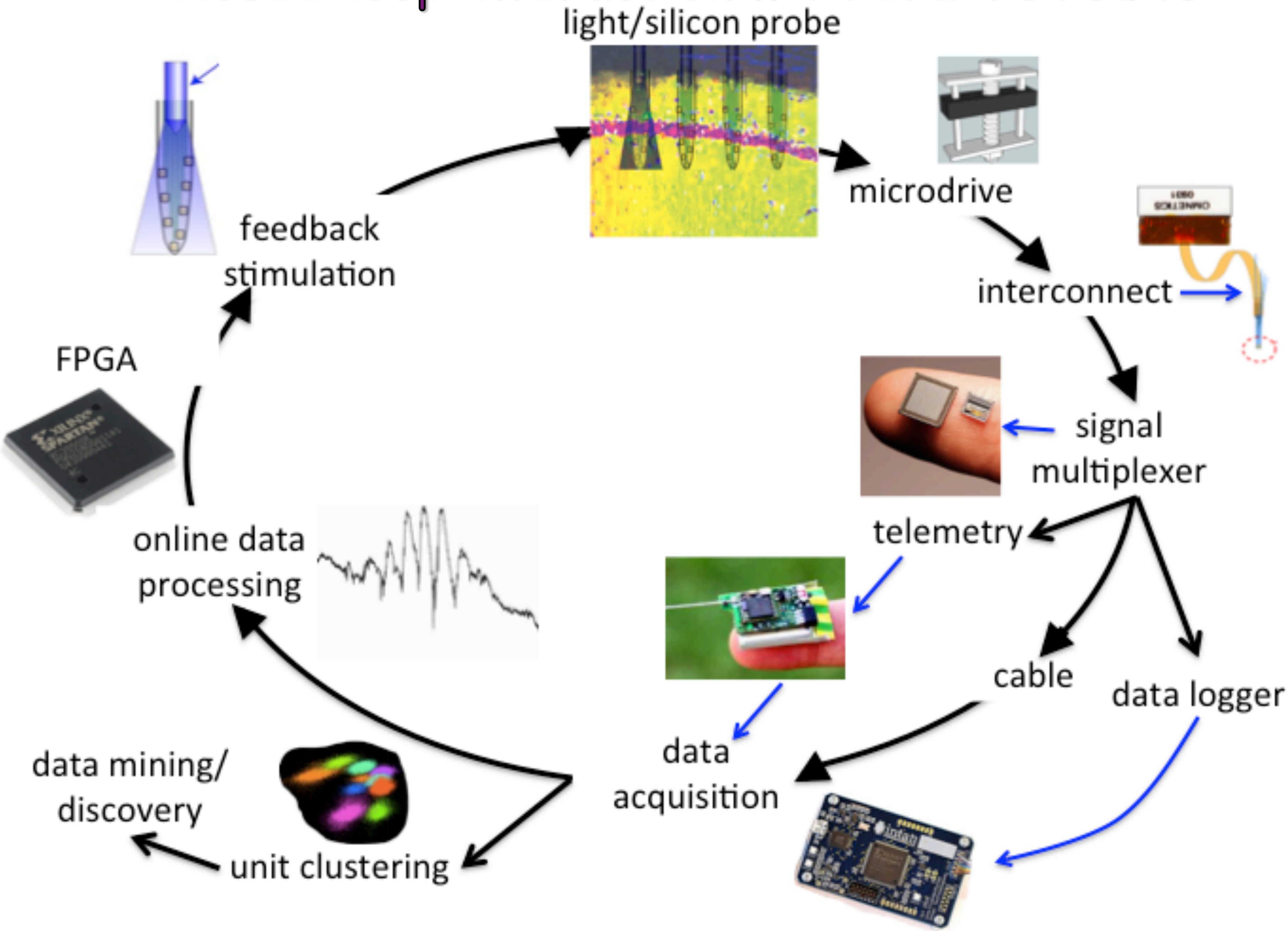
External electronics



Berenyi, Stark, Roux, Harris, Leonardo, Buzsaki **J Neurophysiol** 2013

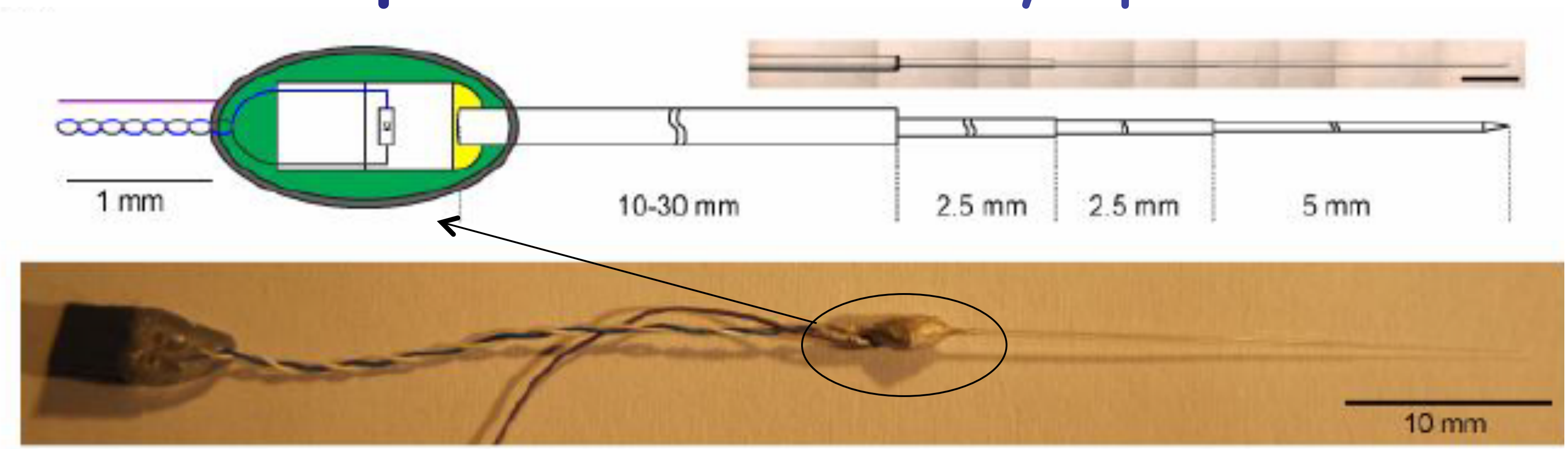

IMAC probe
$4.8 million – 4 years
HHMI, Allen Brain Institute, UCL, Wellcome Trust and the Gatsby Foundation
Single shank
384 channels, 976 sites and fully integrated amplifier/multiplexer electronics
200 um
NeuroSeek (EU) > $10 million

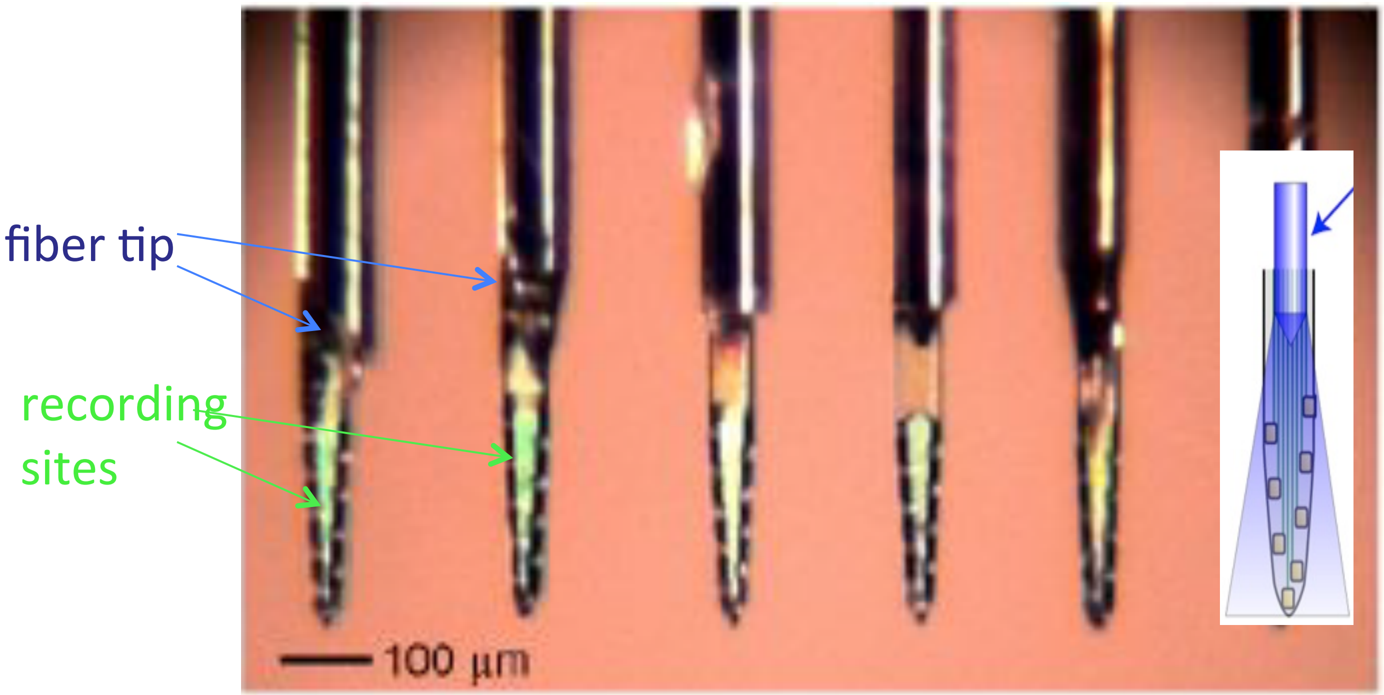
Closed-loop interaction with brain circuits

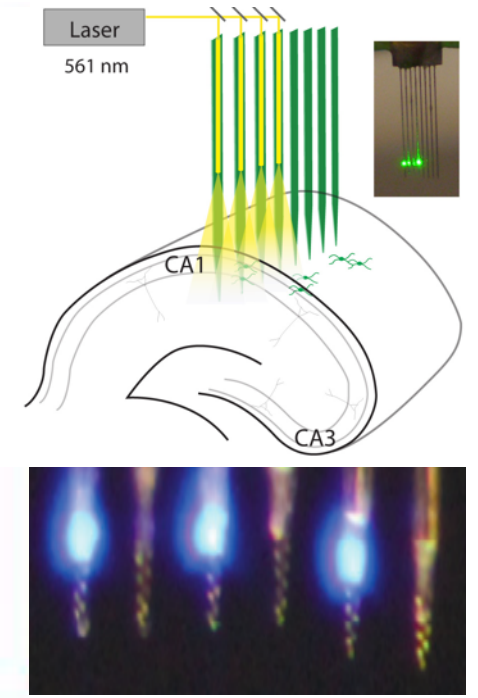


Buzsaki, Stark, Berenyi, Khodagholy, Kipke, Yoon, Wise **Neuron** (2015)

Diode-probe – 3 to 5 days postdoc cost

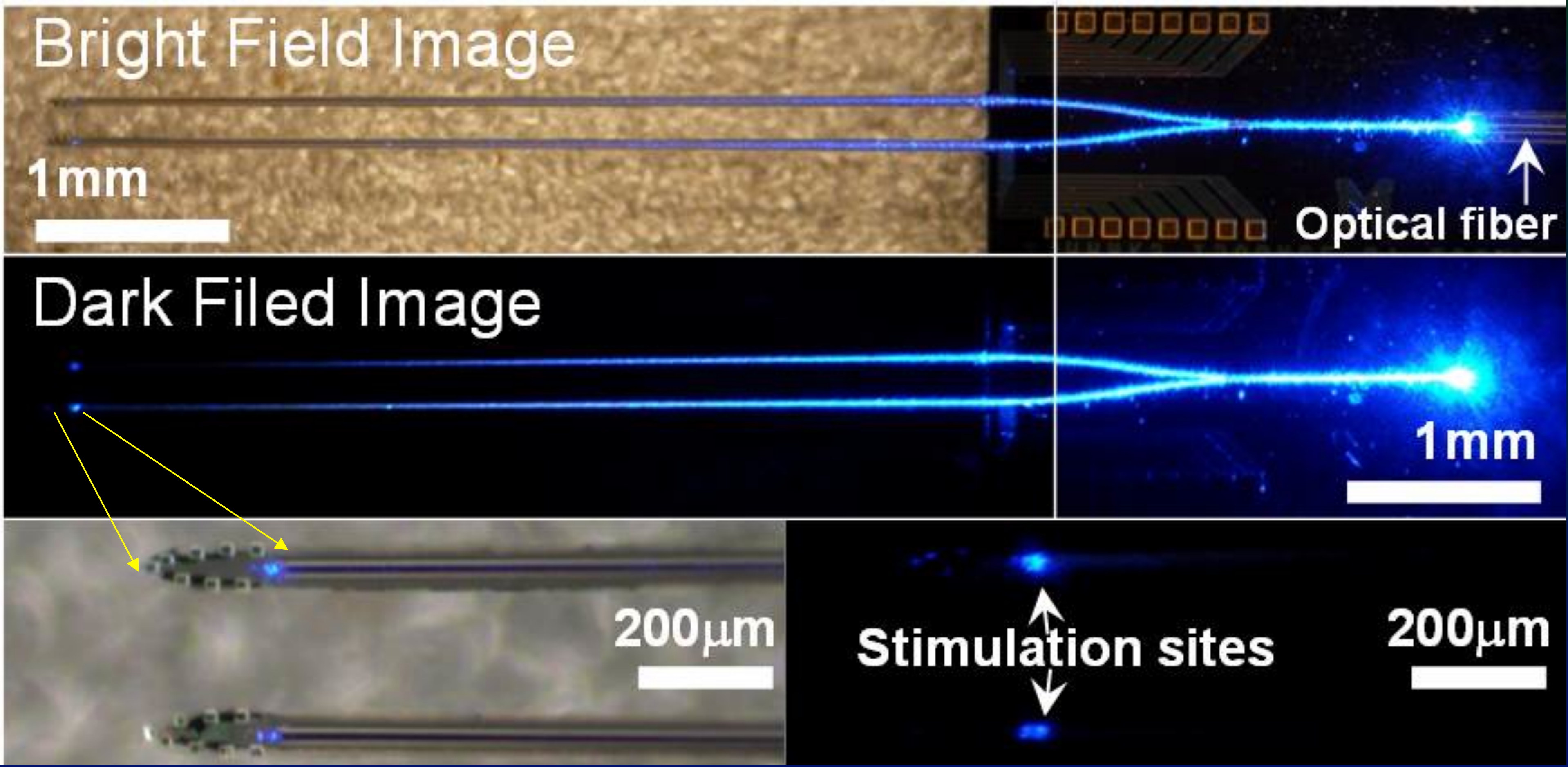






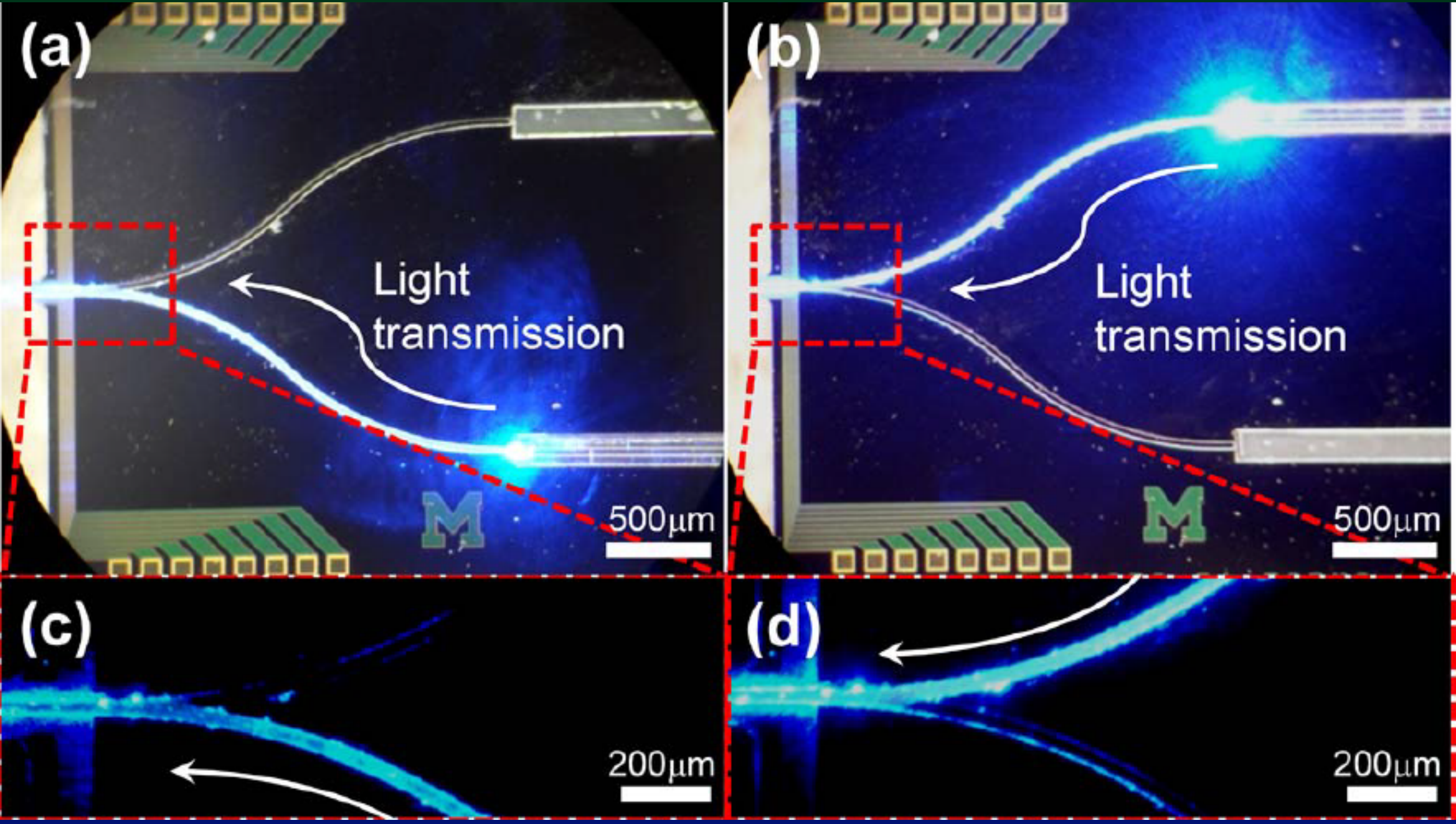
Stark, Koos & Buzsaki, **J Neurophysiol** 2012

Optical splitter



Wu, Stark, Im, Cho, Yoon, Buzsáki, Wise, Yoon **J Neural** Eng 2013

Optical mixer

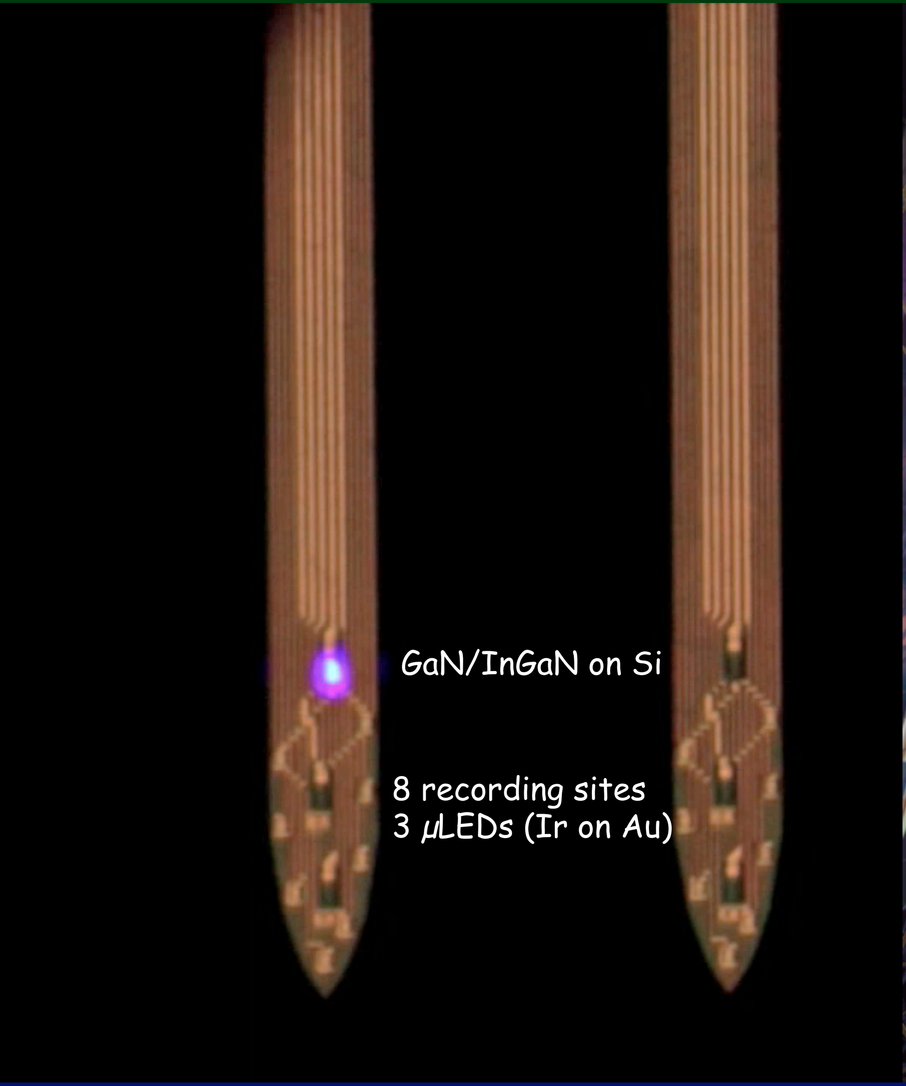


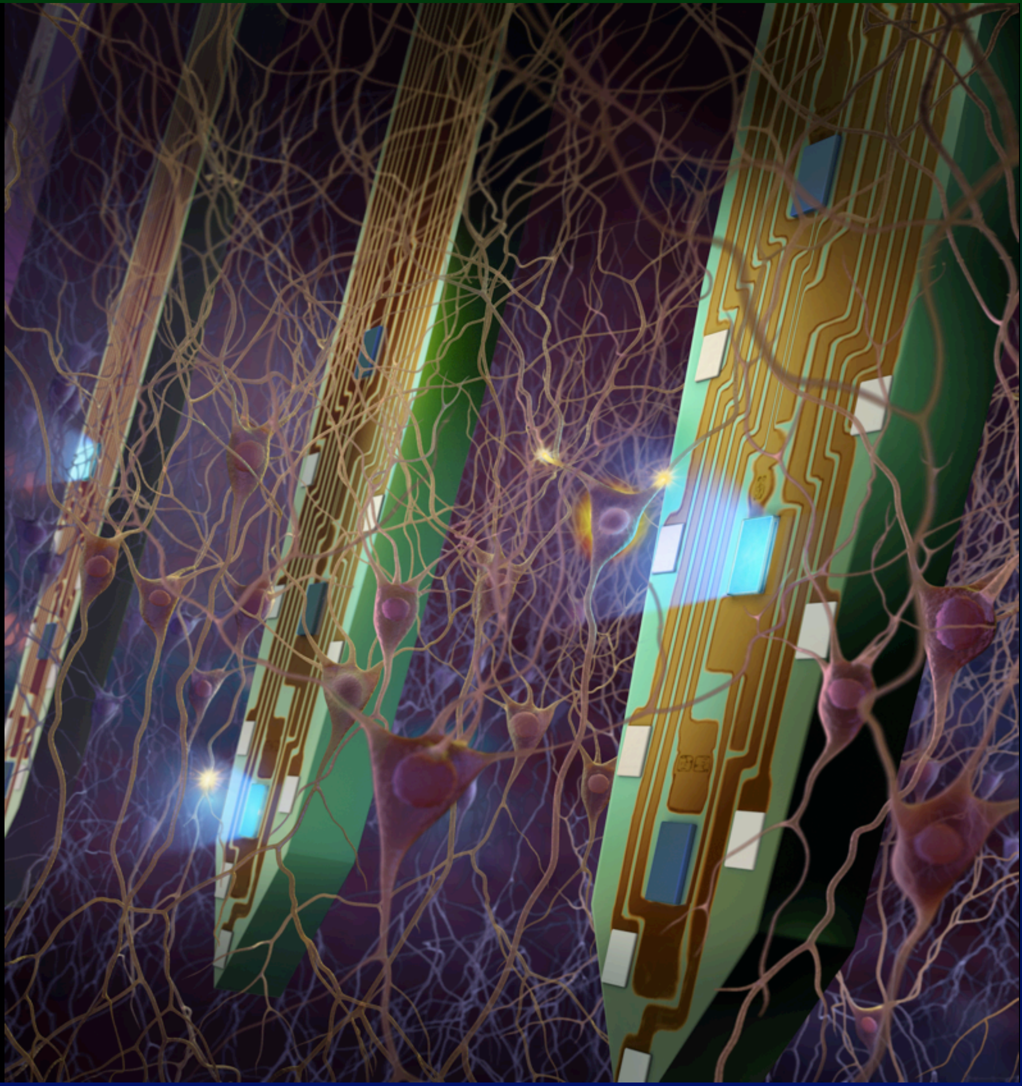
Wu, Stark, Im, Cho, Yoon, Buzsáki, Wise, Yoon **J Neural** Eng 2013

μLED-probe – simultaneous recording and stimulation

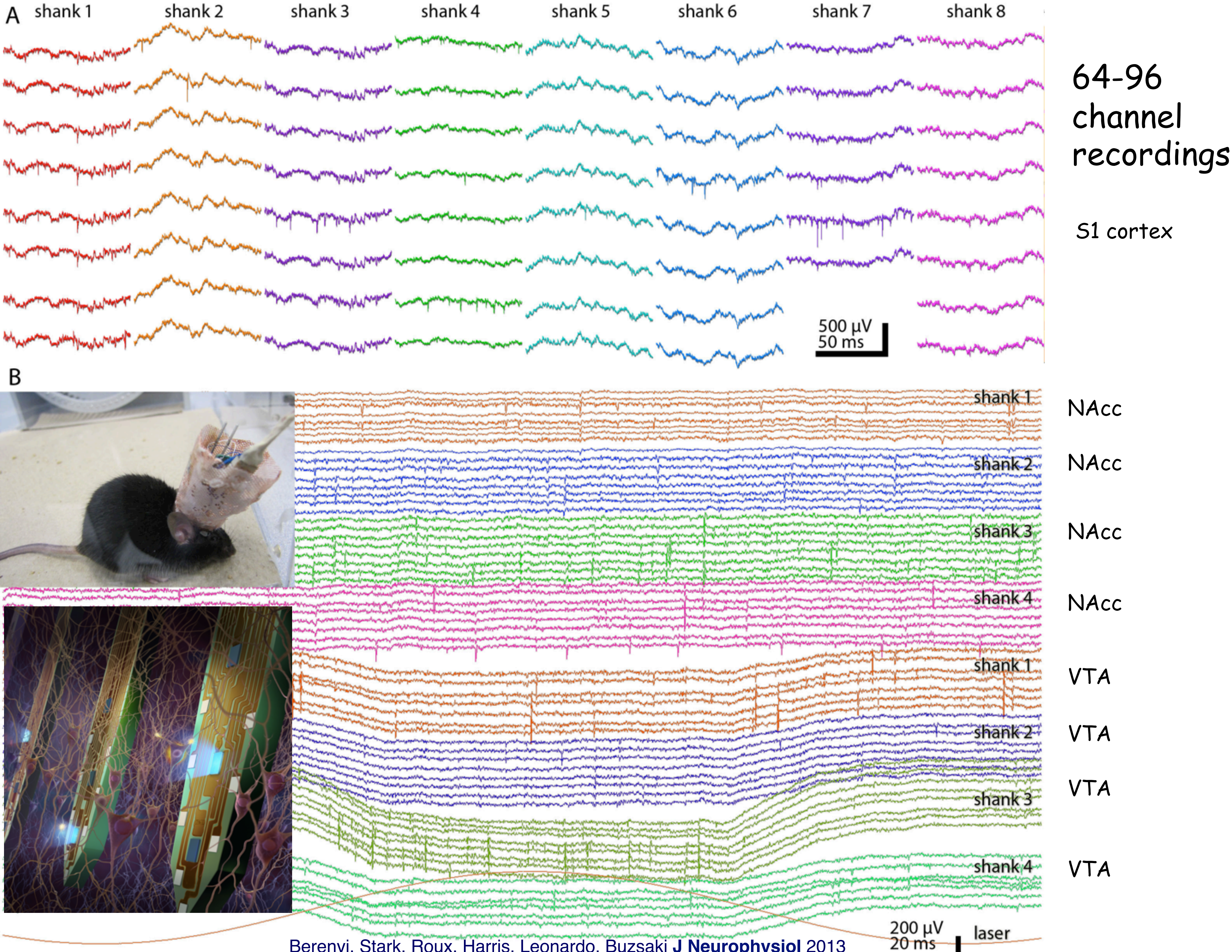
Wu , Stark , Ku , Wise, Buzsáki, Yoon **Neuron** 2015

μLED-probe – simultaneous recording and stimulation



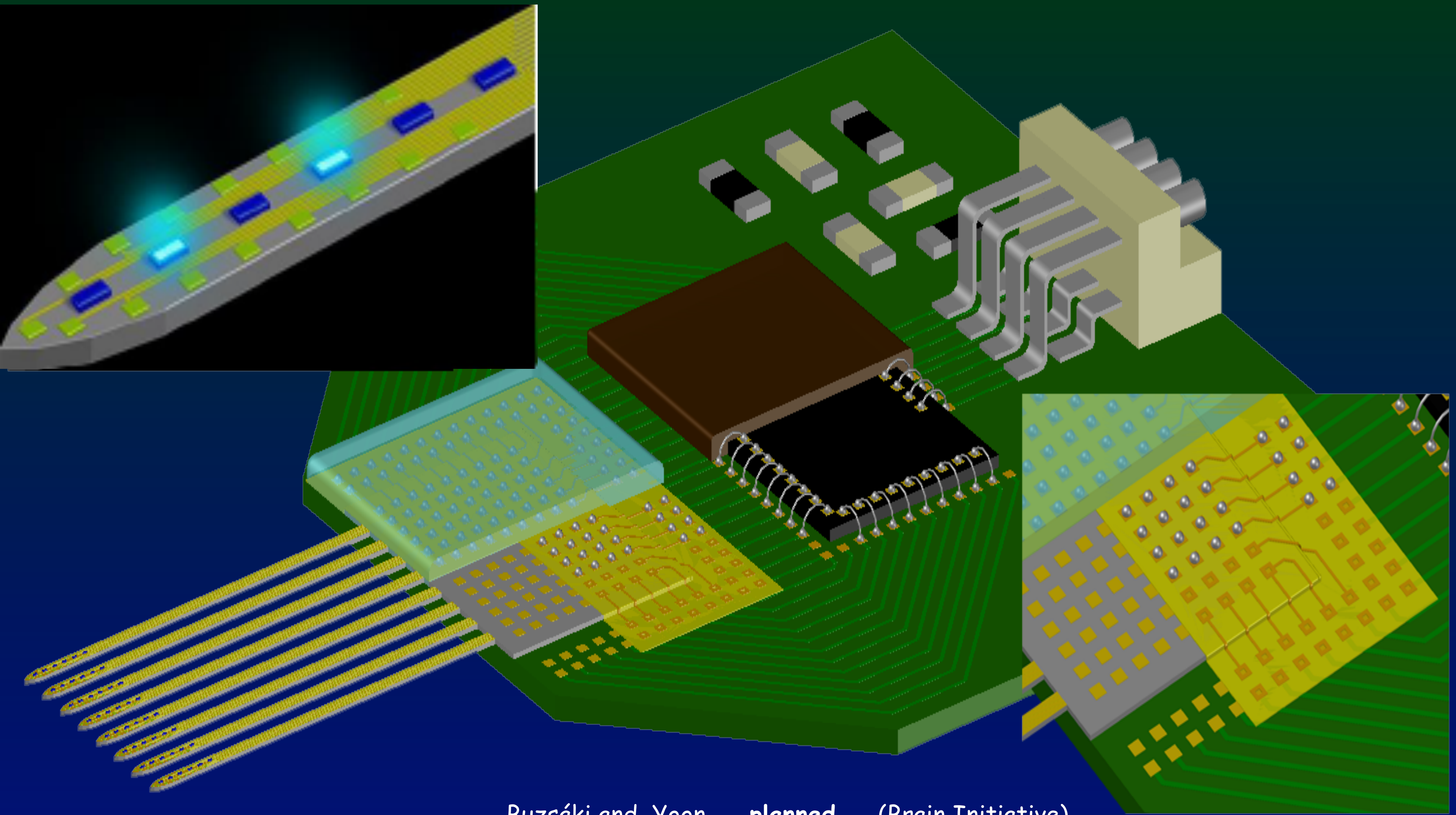


Wu , Stark , Ku , Wise, Buzsáki, Yoon **Neuron** 2015

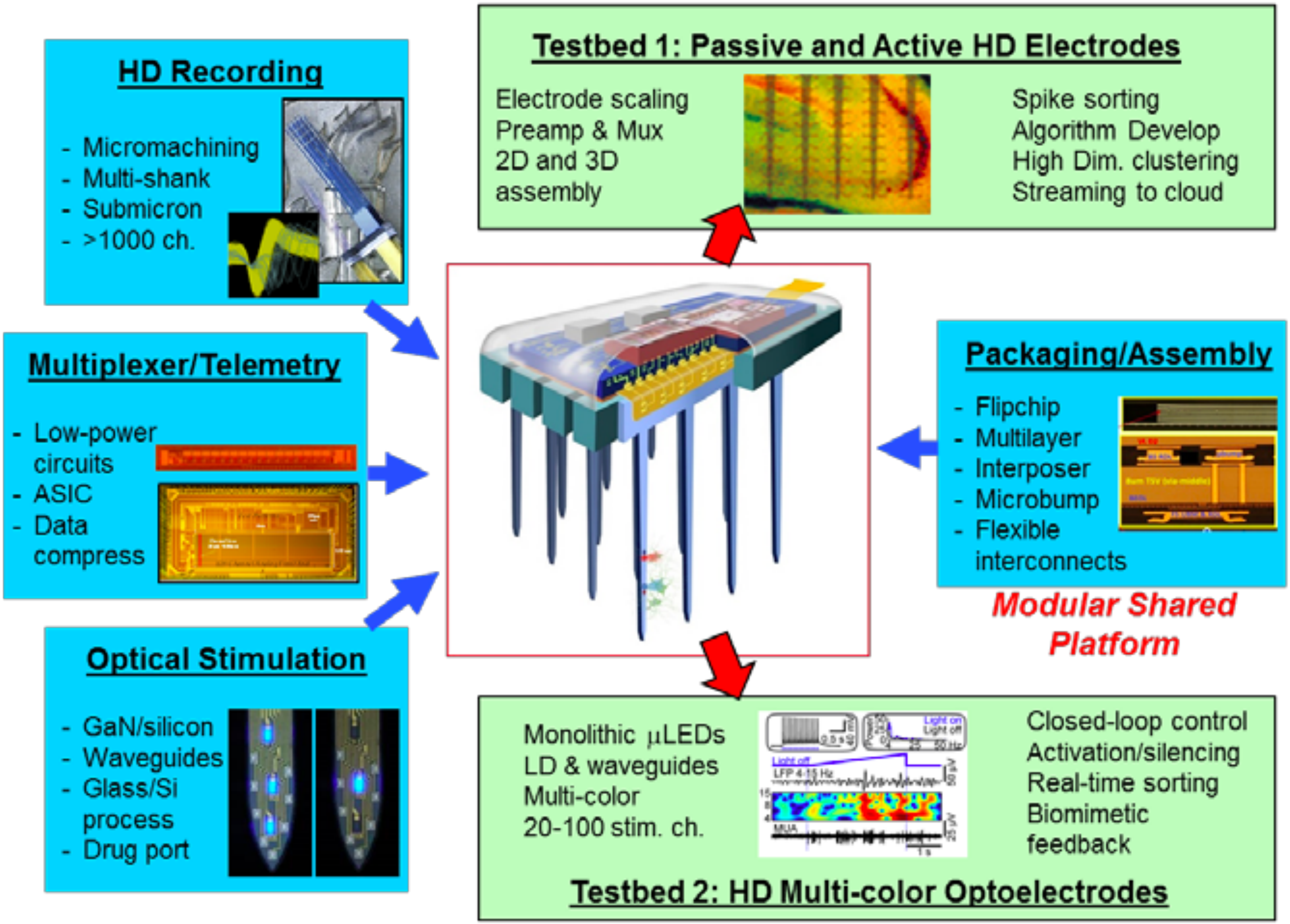


Berenyi, Stark, Roux, Harris, Leonardo, Buzsaki **J Neurophysiol** 2013

Advanced μLED-probe – back-end electronics

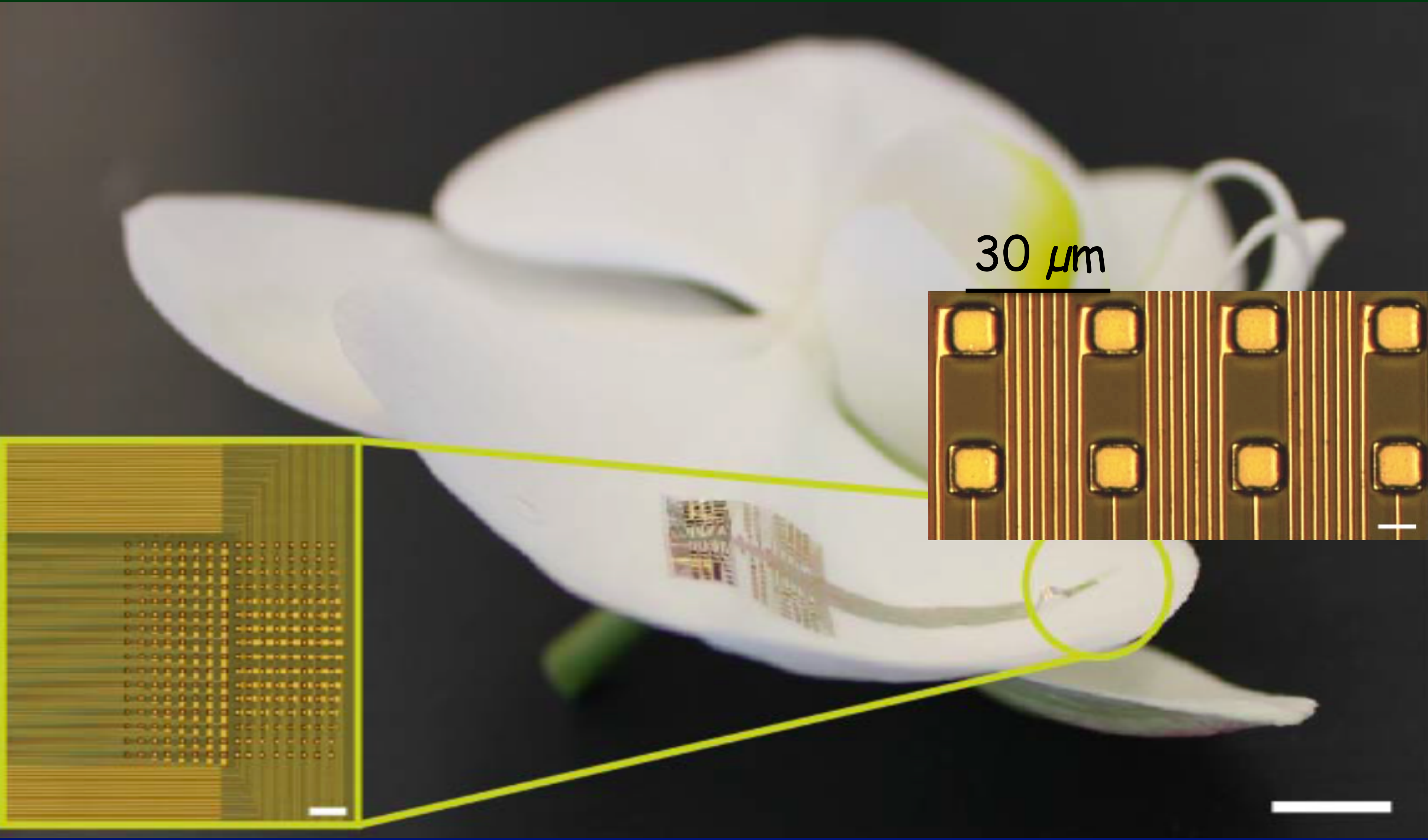


Buzsáki and Yoon **planned** (Brain Initiative)



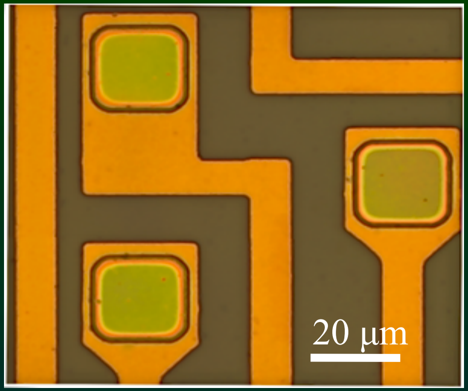
Yoon and Buzsáki **planned**

NeuroGrid - spikes from the brain surface



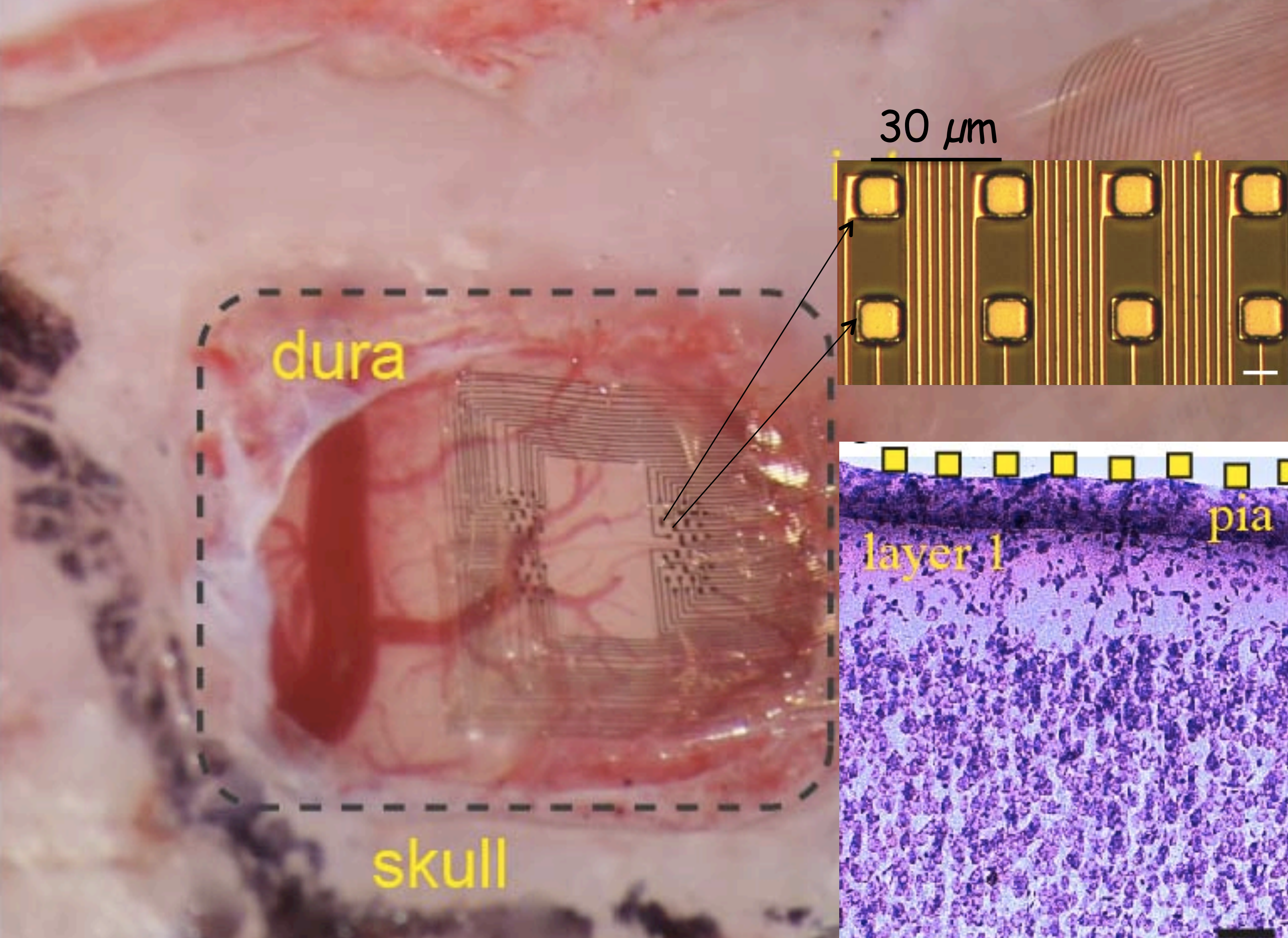
Khodagholy, Gelinas, Thesen, Doyle, Devinsky, Malliaras, Buzsáki, **Nature Neurosci** (2014)

NeuroGrid



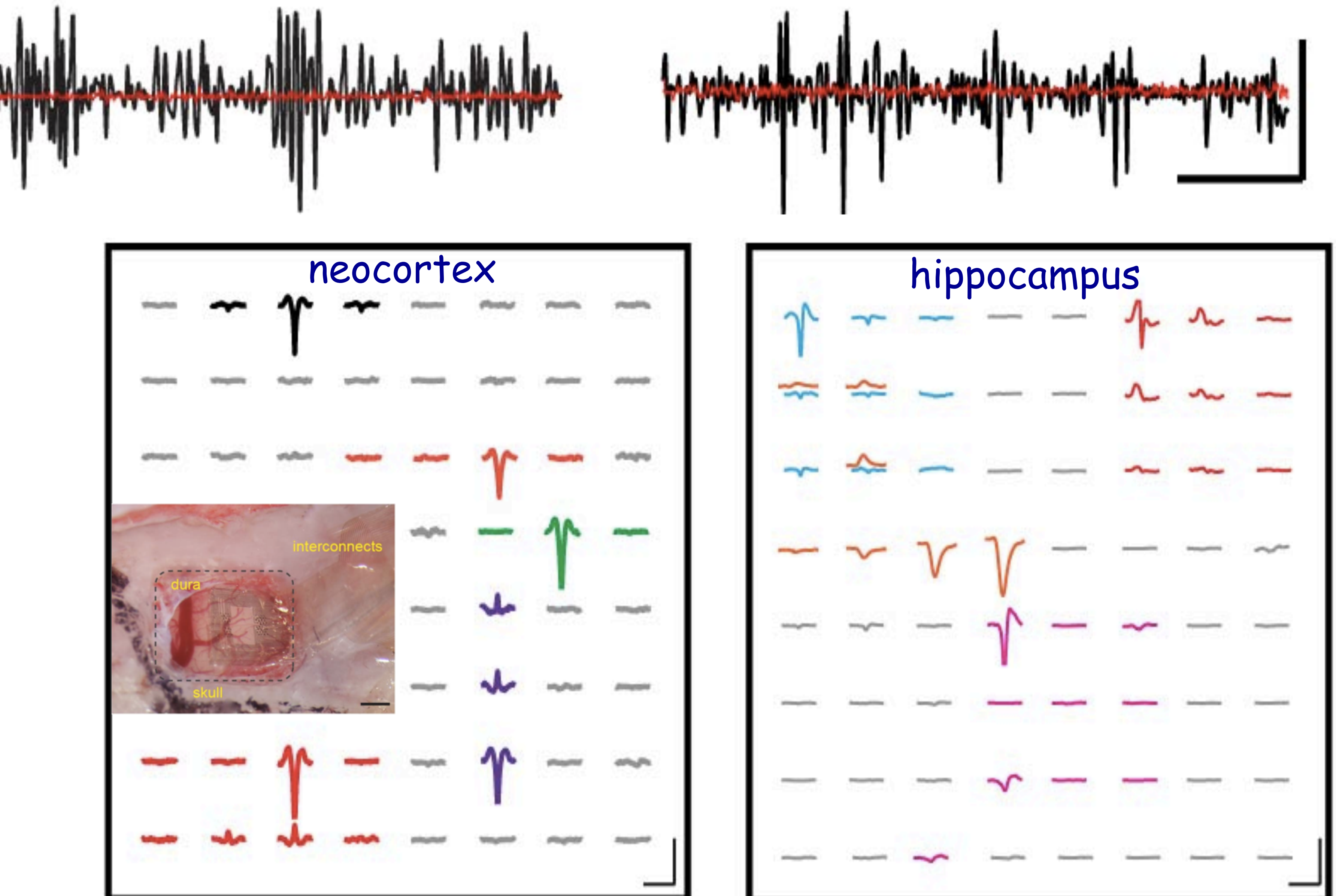
- organic material-based,
- ultraconformable (4 μm thick)
- biocompatible (PEDOT:PSS; parylene C encapsulated)
- scalable neural interface array with
- neuron-sized-density electrodes
- record both local field potentials (LFPs) and action potentials from superficial cortical neurons without penetrating the brain surface

Khodagholy, Gelinas, Thesen, Doyle, Devinsky, Malliaras, Buzsáki, **Nature Neurosci** (2014)

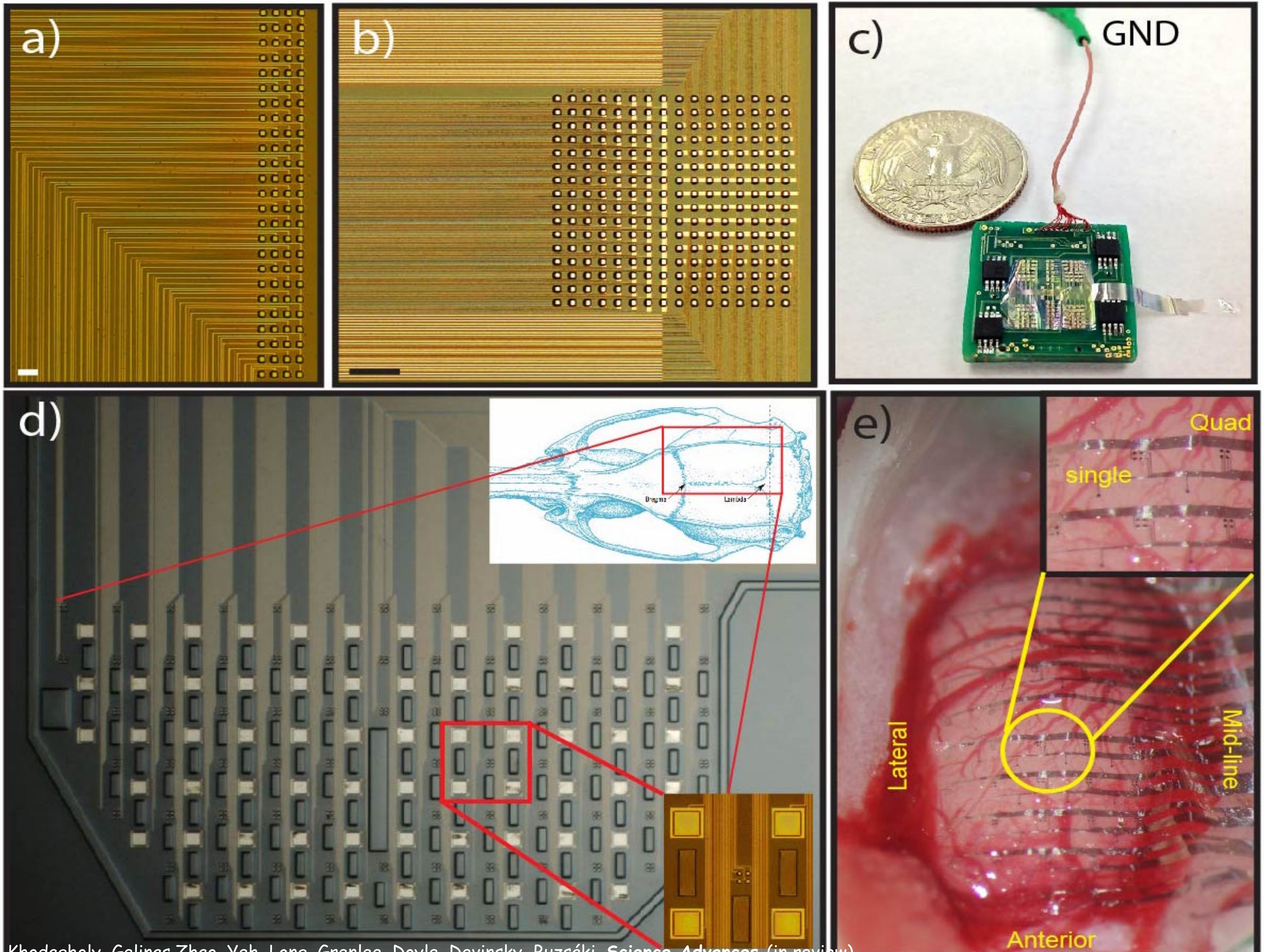


Khodagholy, Gelinas, Thesen, Doyle, Devinsky, Malliaras, Buzsáki, **Nature Neurosci** (2014)

Recording of spikes from the cortical surface

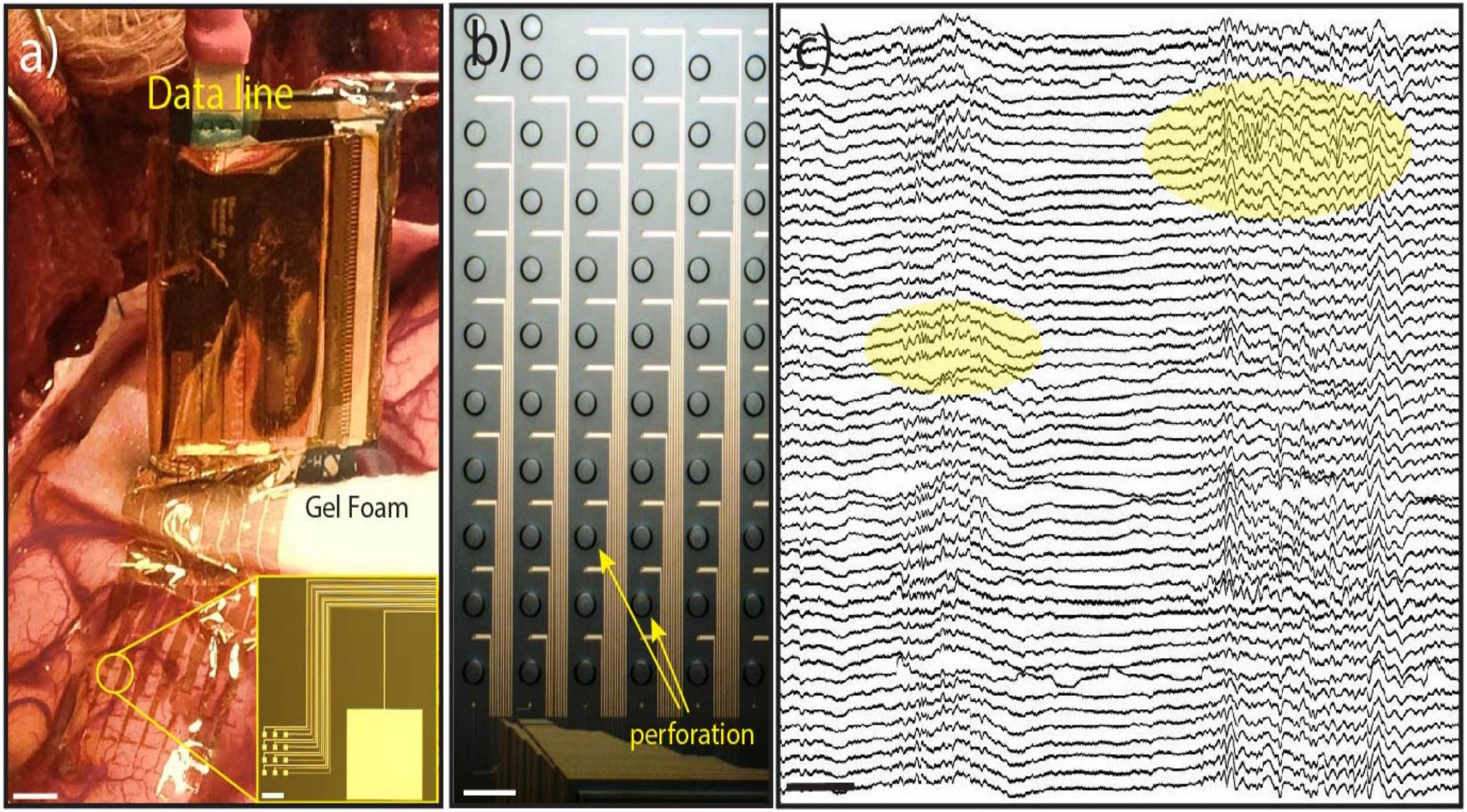


Khodagholy, Gelinas, Thesen, Doyle, Devinsky, Malliaras, Buzsáki, **Nature Neurosci** (2014)



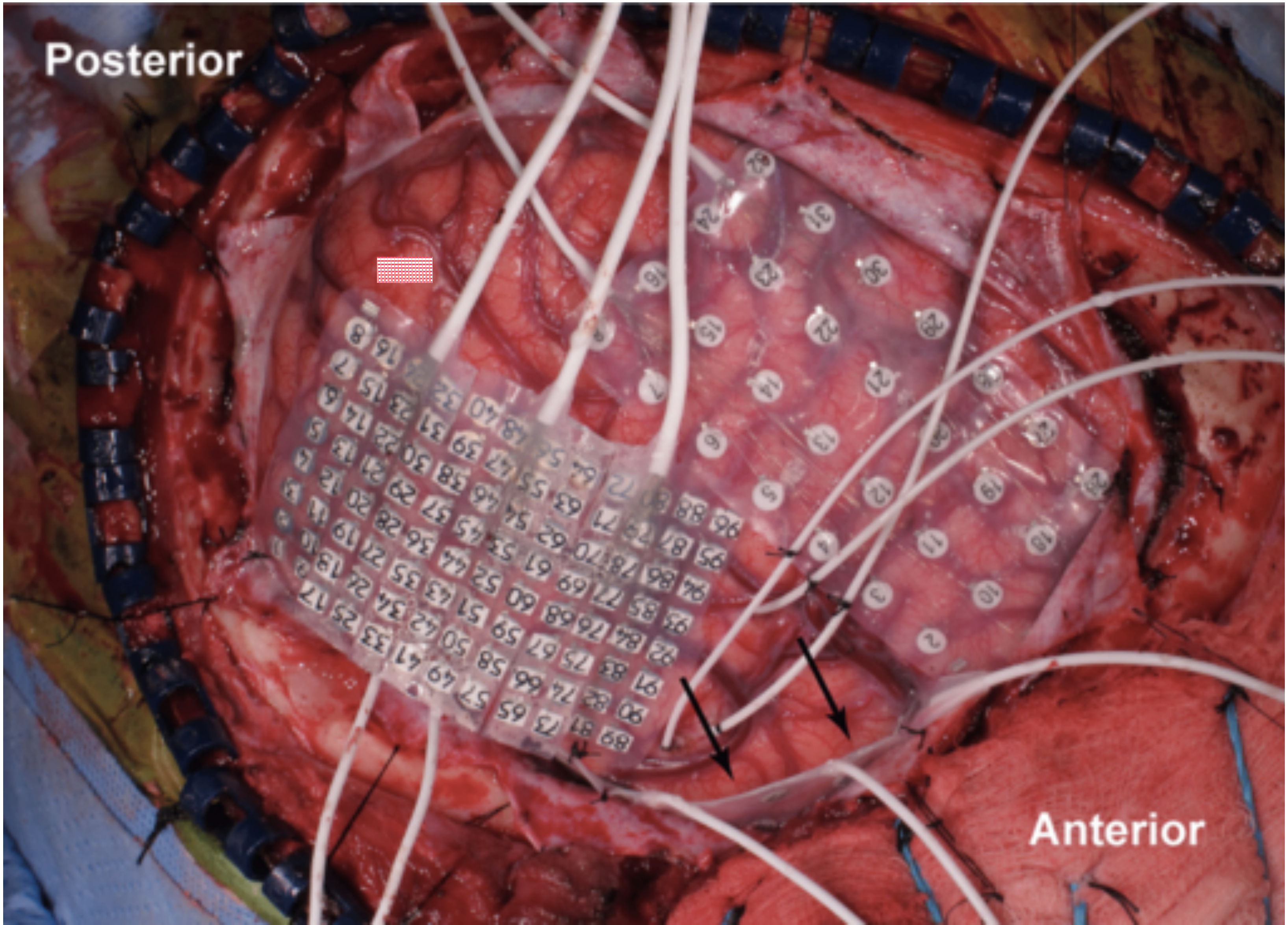
Khodagholy, Gelinas,Zhao, Yeh, Long, Grenlee, Doyle, Devinsky, Buzsáki **Science Advances** (in review)

Recordings from the cortical surface in humans

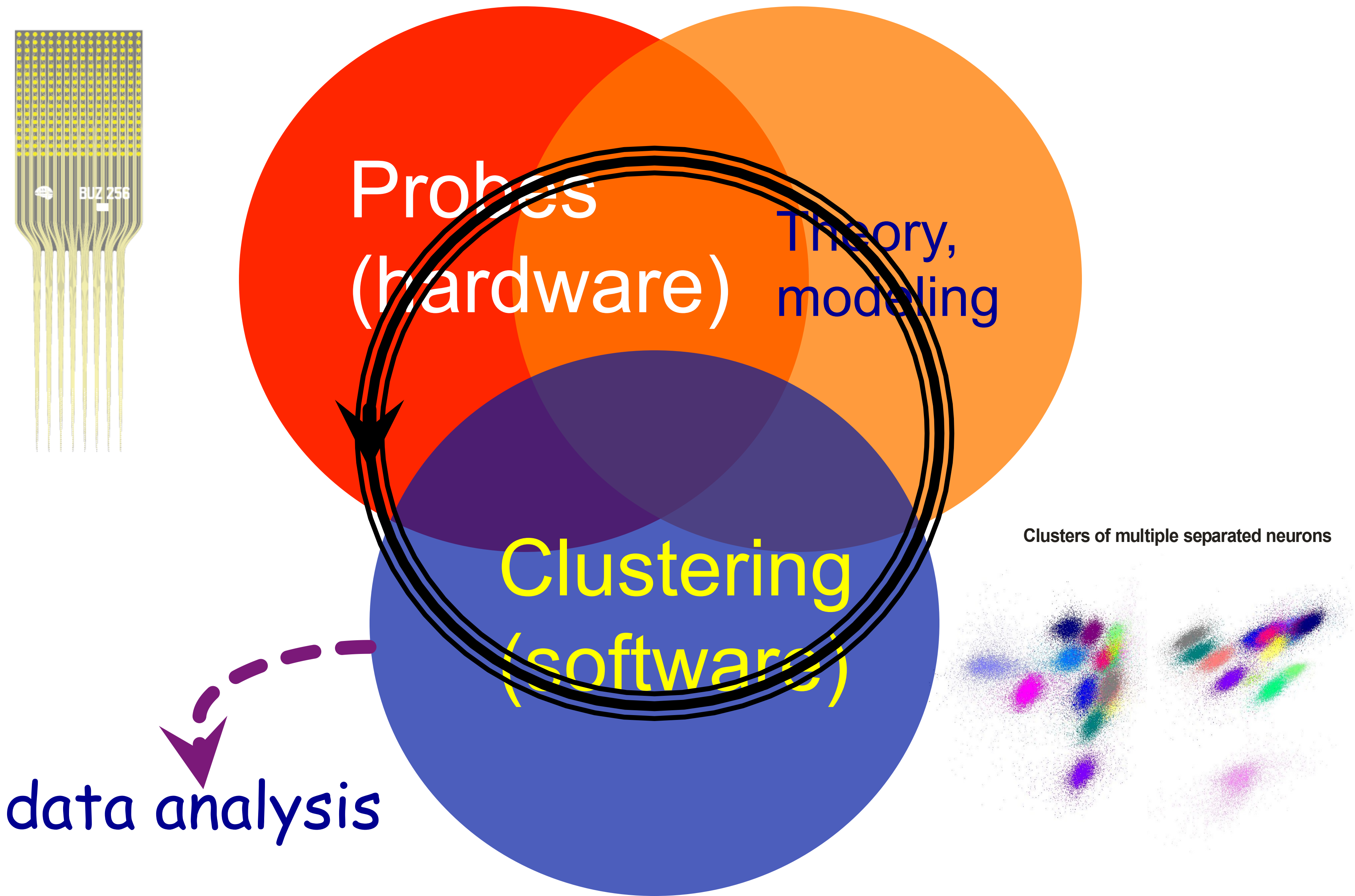


Khodagholy, Gelinas,Zhao, Yeh, Long, Grenlee, Doyle, Devinsky, Buzsáki **Science Advances** (in review)

Subdural grid
(sadly: current state-of-the-art in humans)



Prerequisites of reliable data



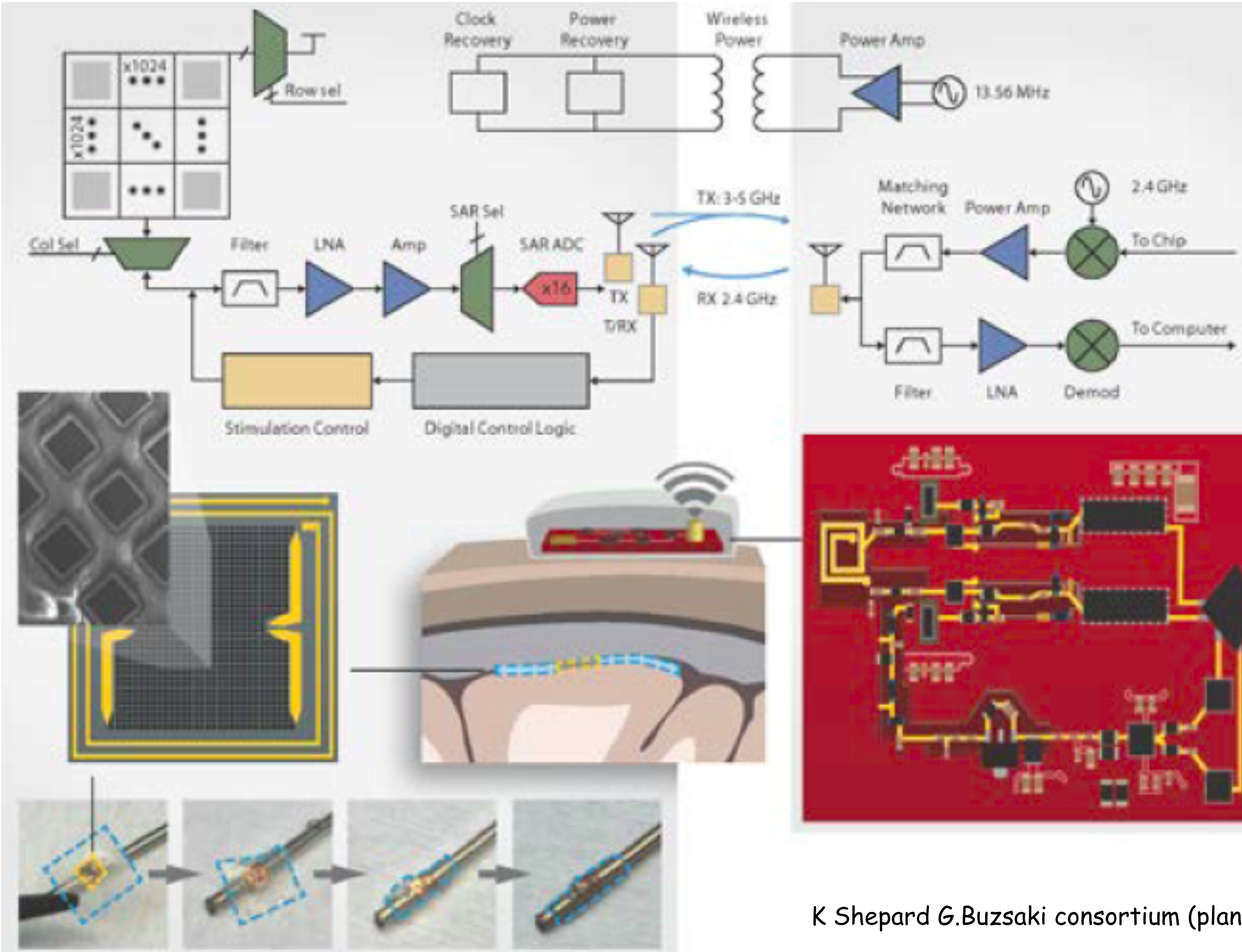
Luke Sjulson

Anli Liu

Orrin Devinsky

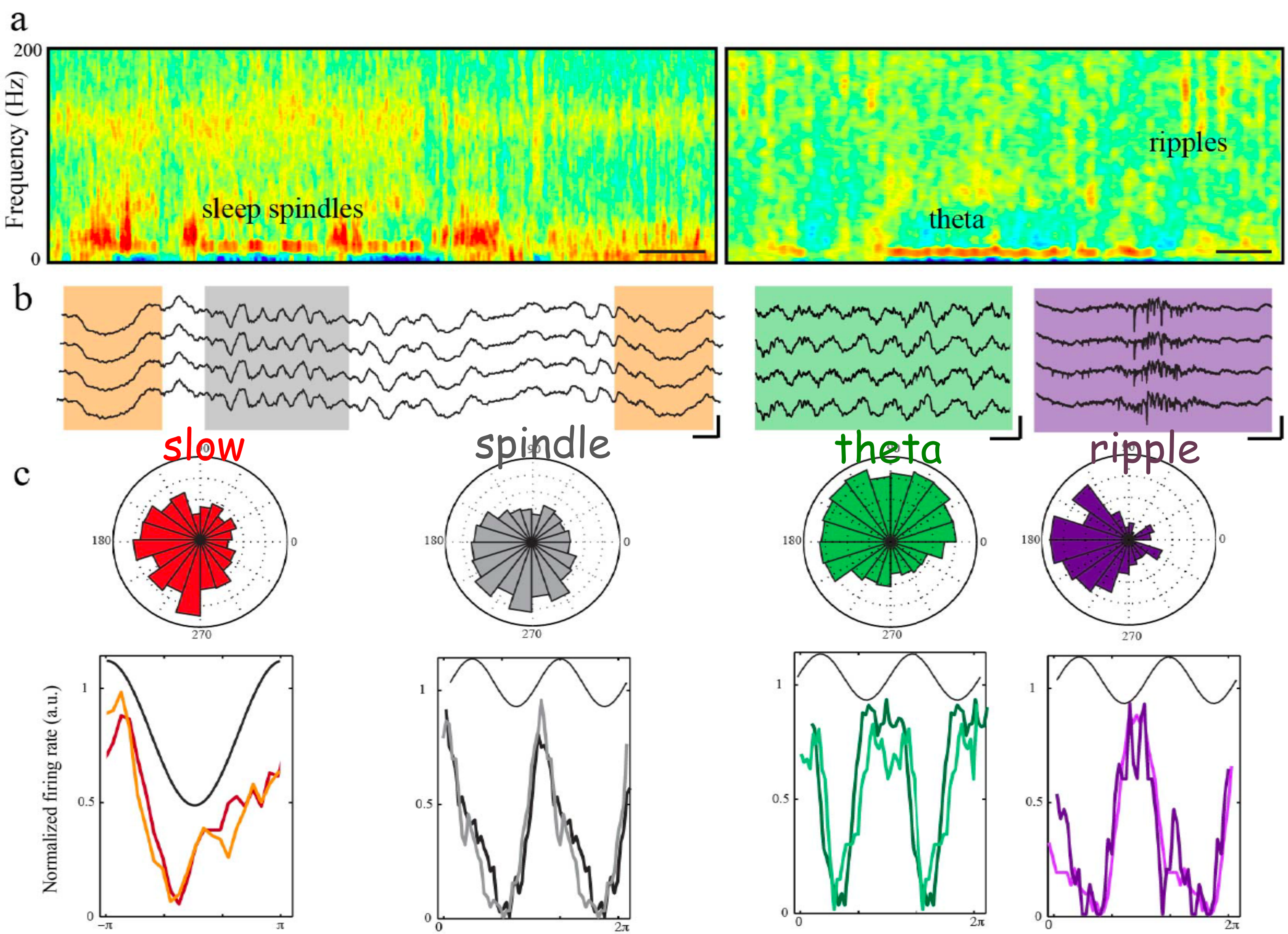
Werner Doyle

'Active', large-scale NeuroGrid



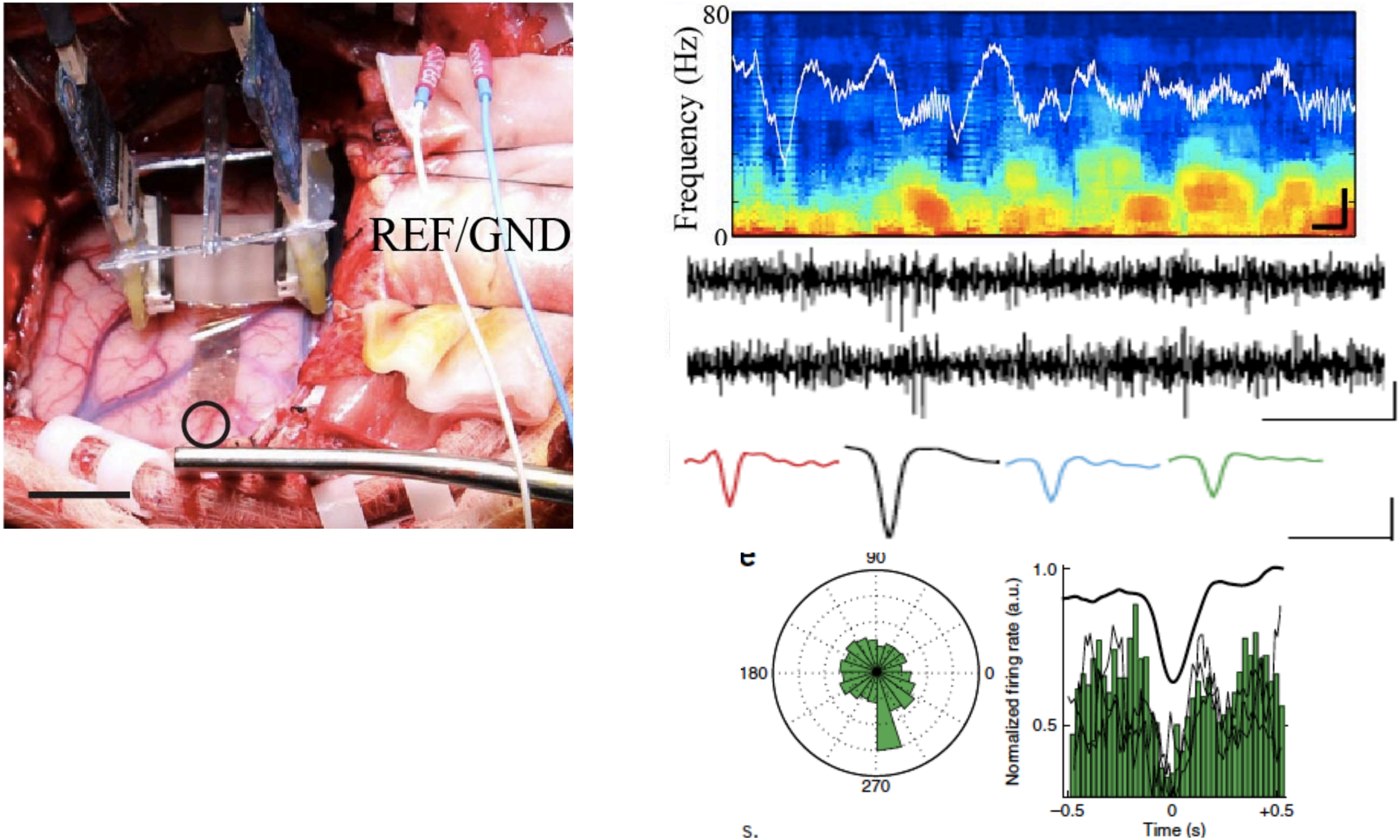
K Shepard G.Buzsaki consortium (planned)

Recording of spikes from the cortical surface



Khodagholy, Gelinas, Thesen, Doyle, Devinsky, Malliaras, Buzsáki, **Nature Neurosci** (2014)

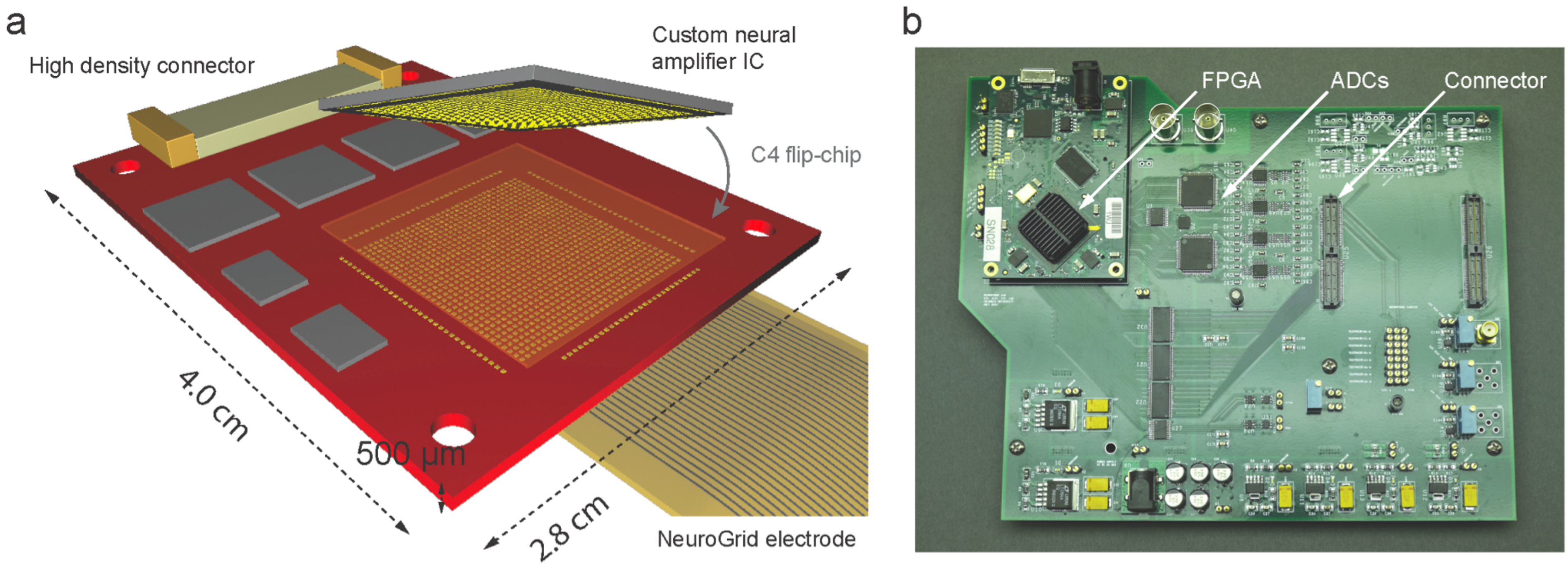
Recording of spikes from the human cortical surface



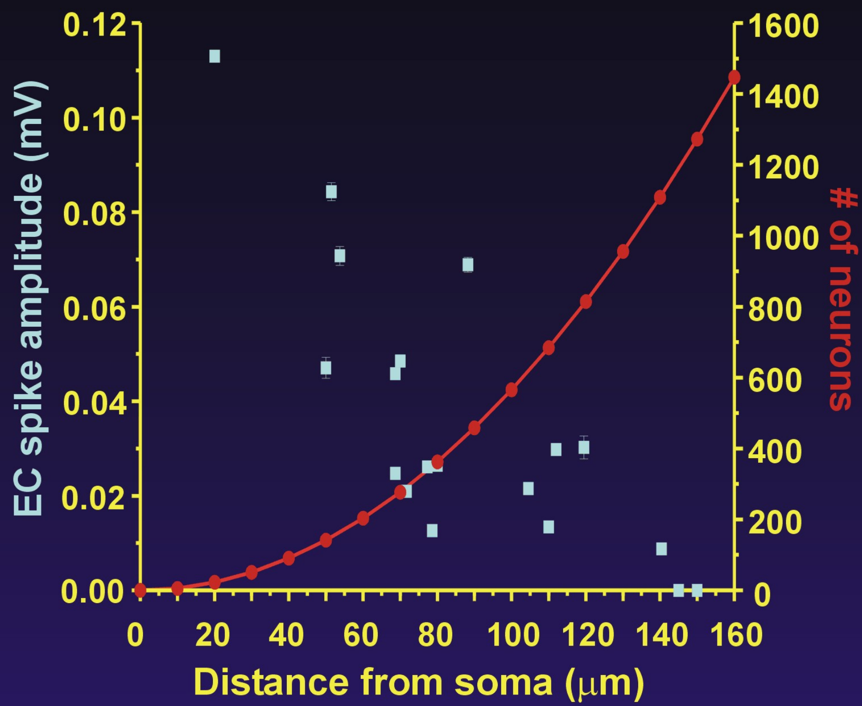
Khodagholy, Gelinas, Thesen, Doyle, Devinsky, Malliaras, Buzsáki, **Nature Neurosci** (2014)

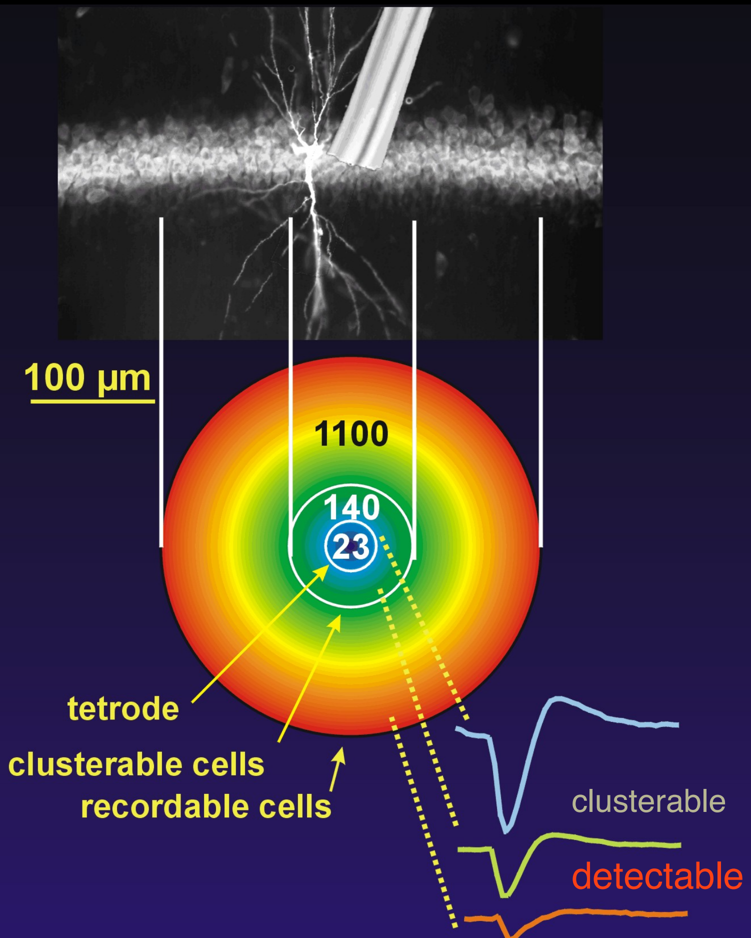
1000-channel multiplexer

(with Kenneth Shepard, Columbia U)



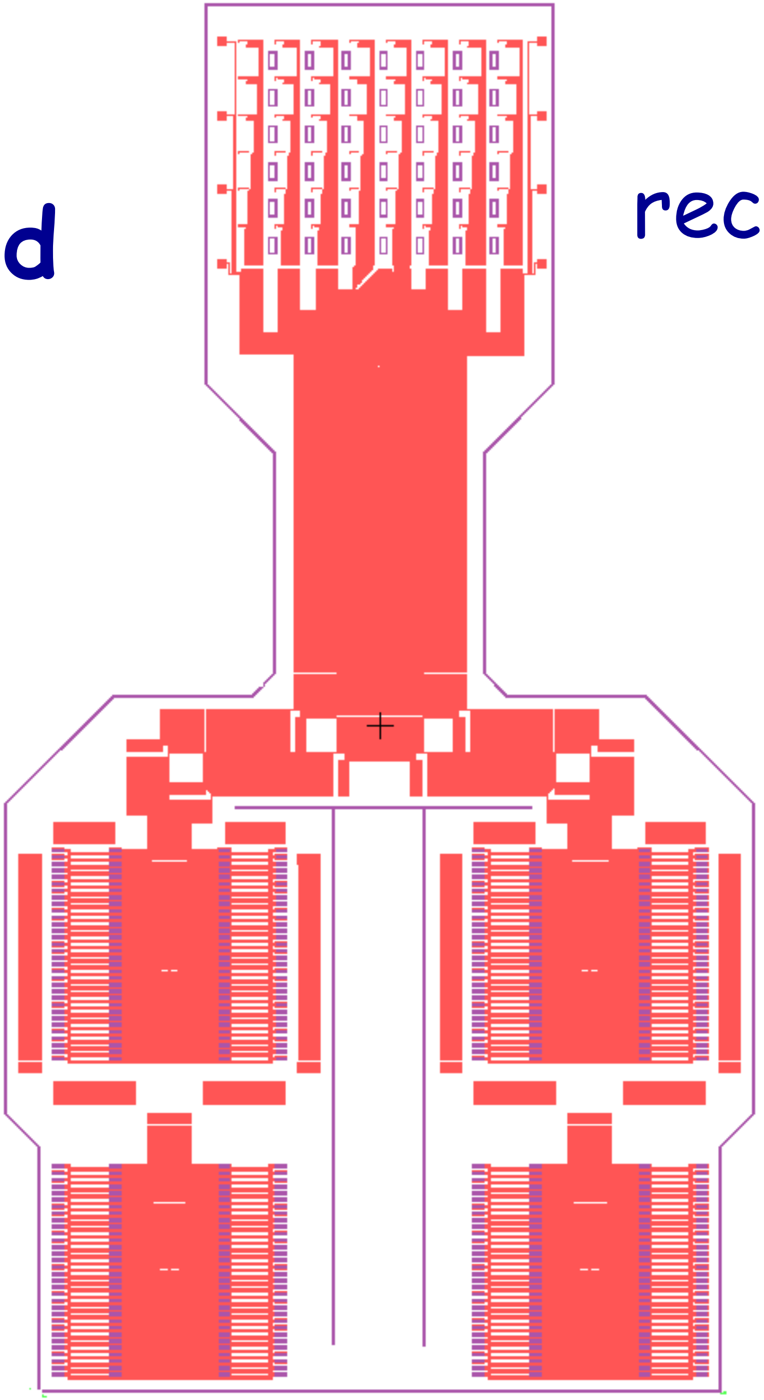
Extracellular spike amplitude decreases rapidly with distance from the source

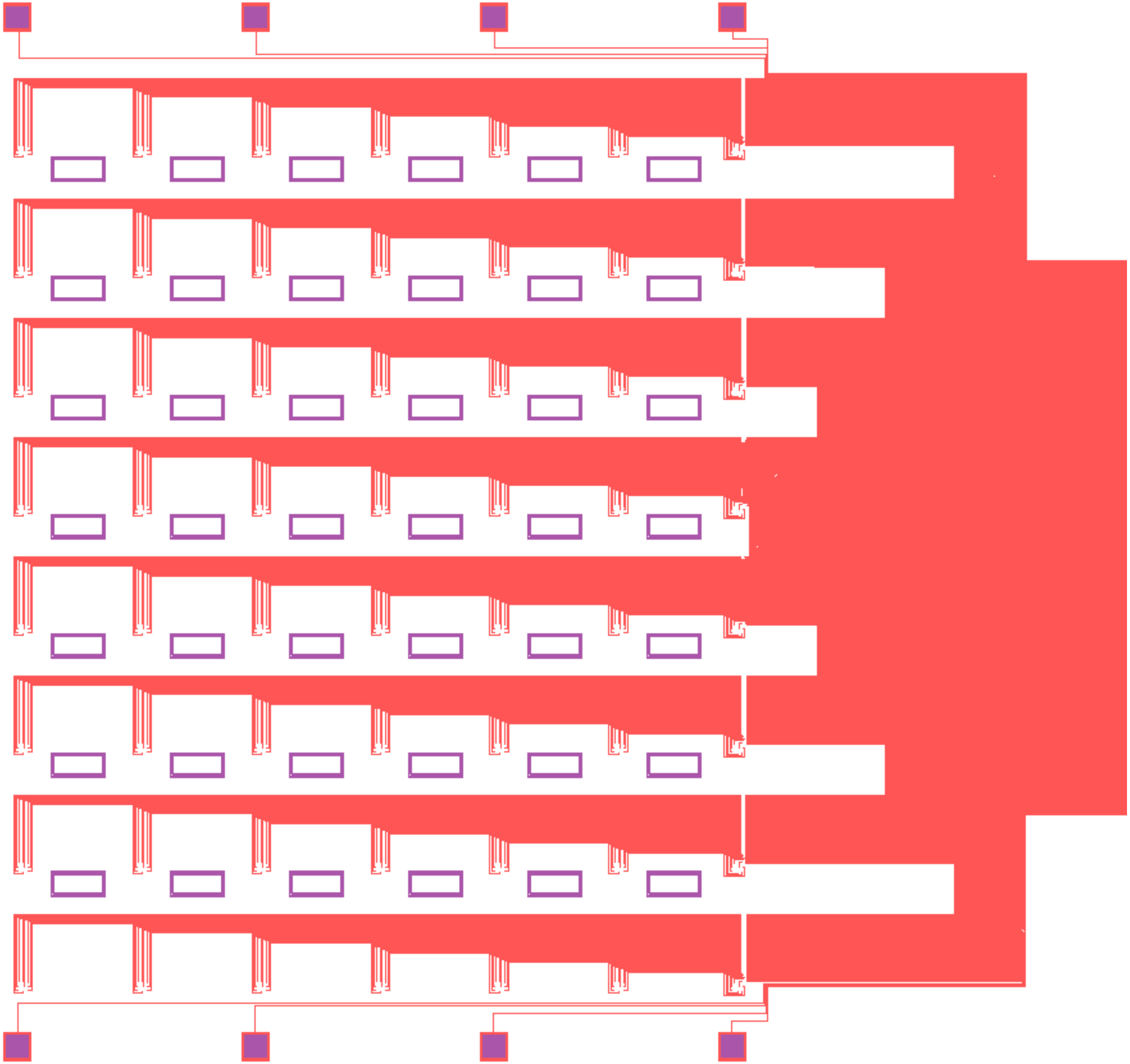


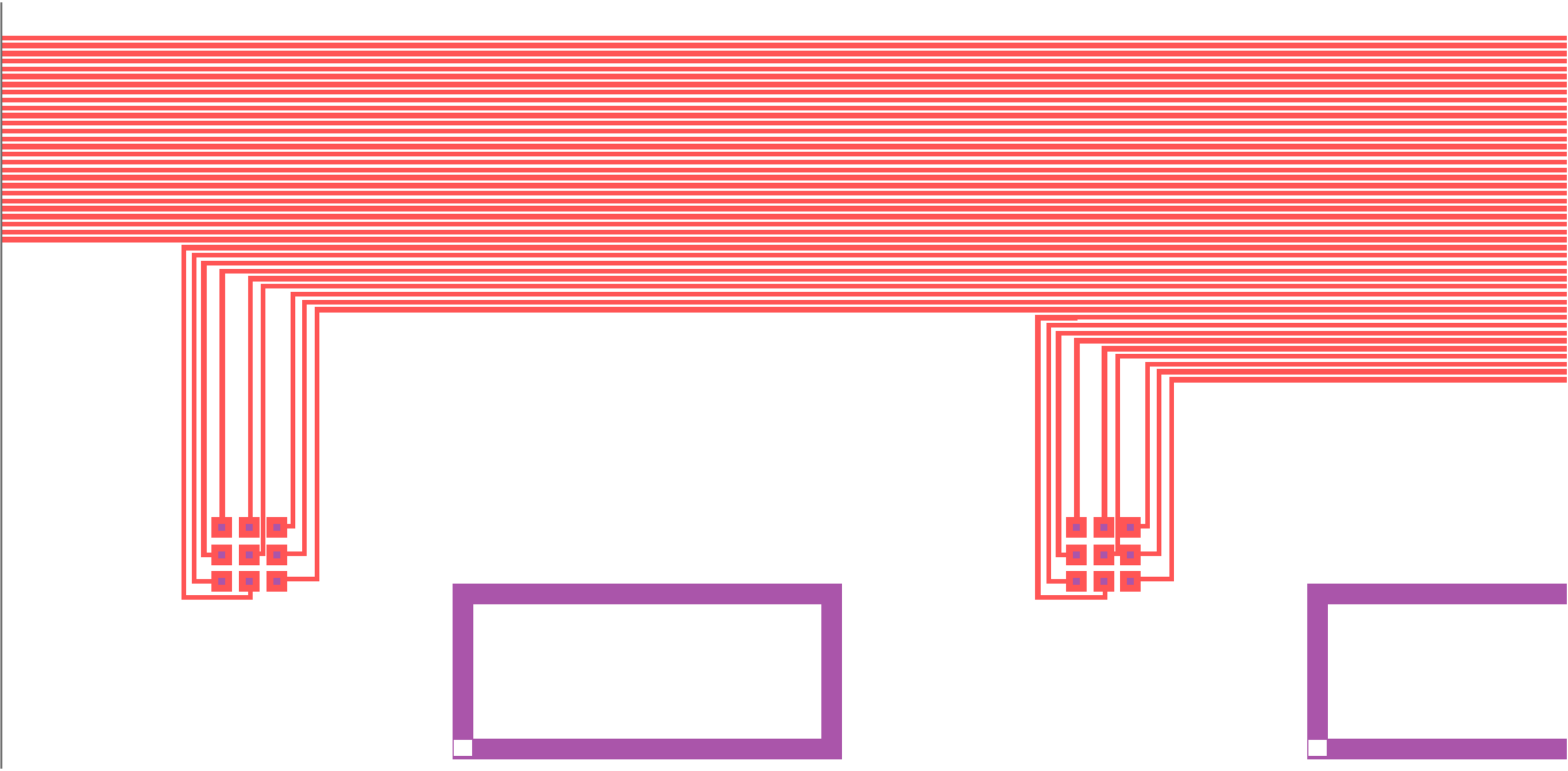


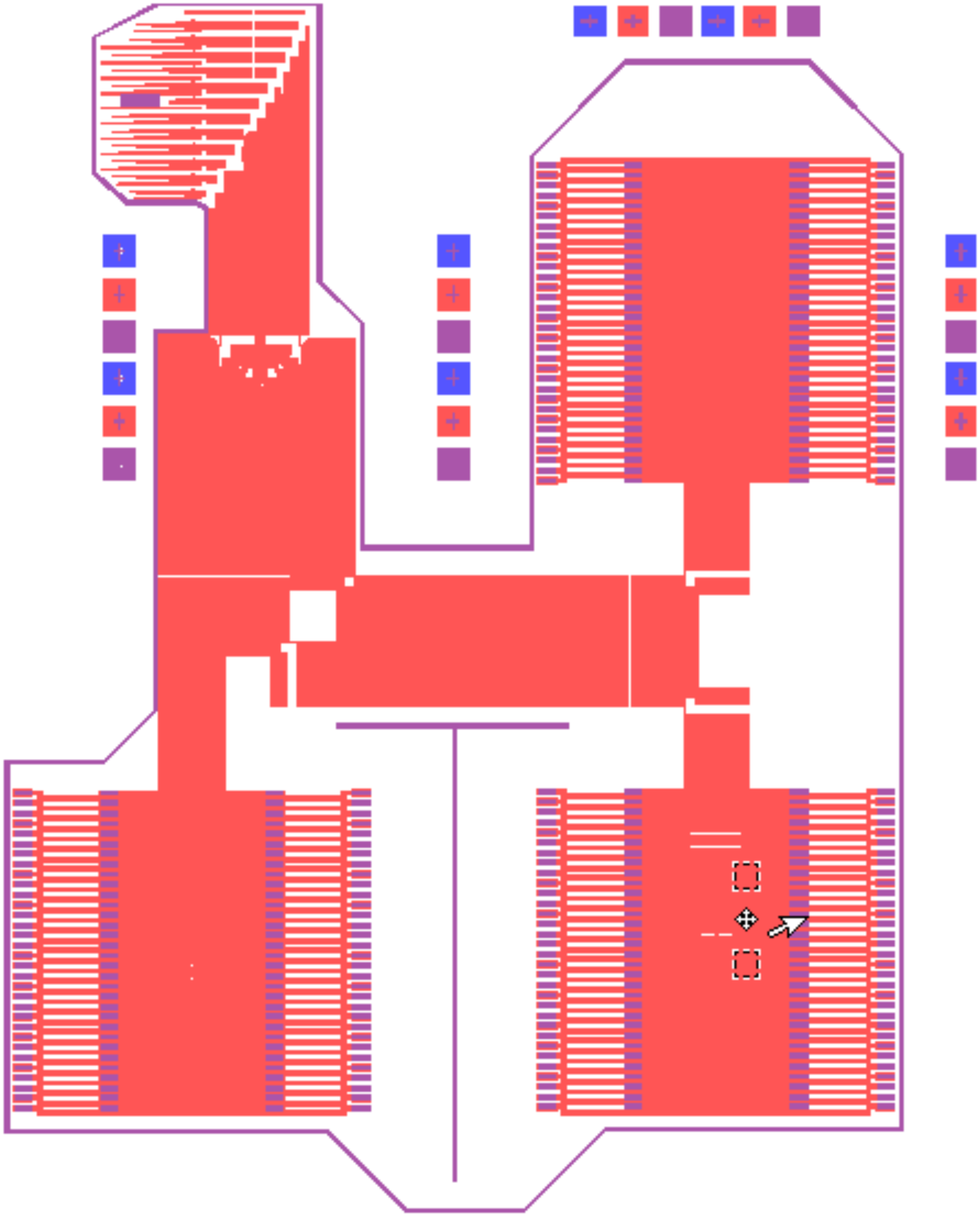
Henze, Borhegyi, Csicsvari, Mamiya, Harris, Buzsaki, J Neurophysiol 2000

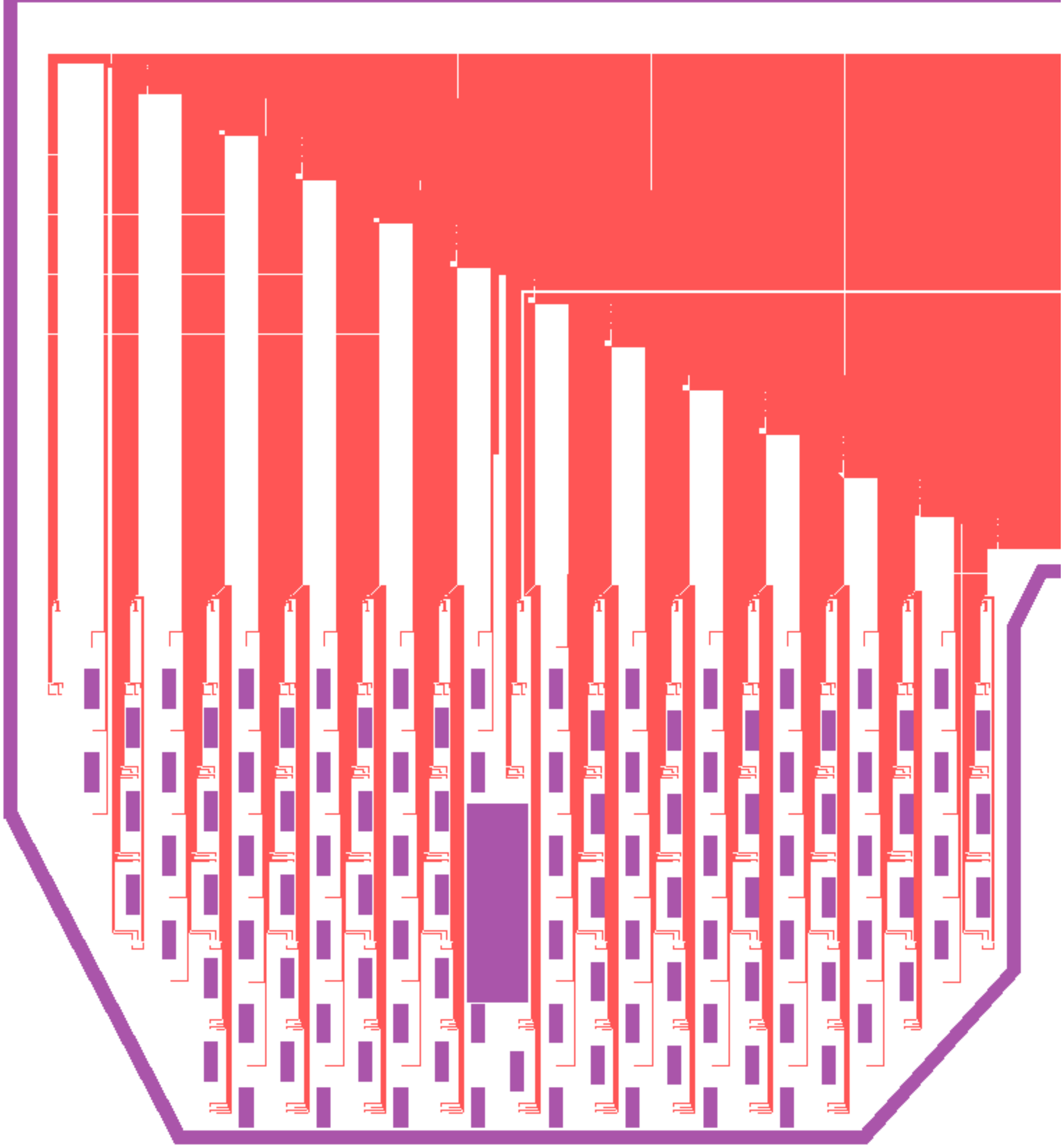
384-site NeuroGrid

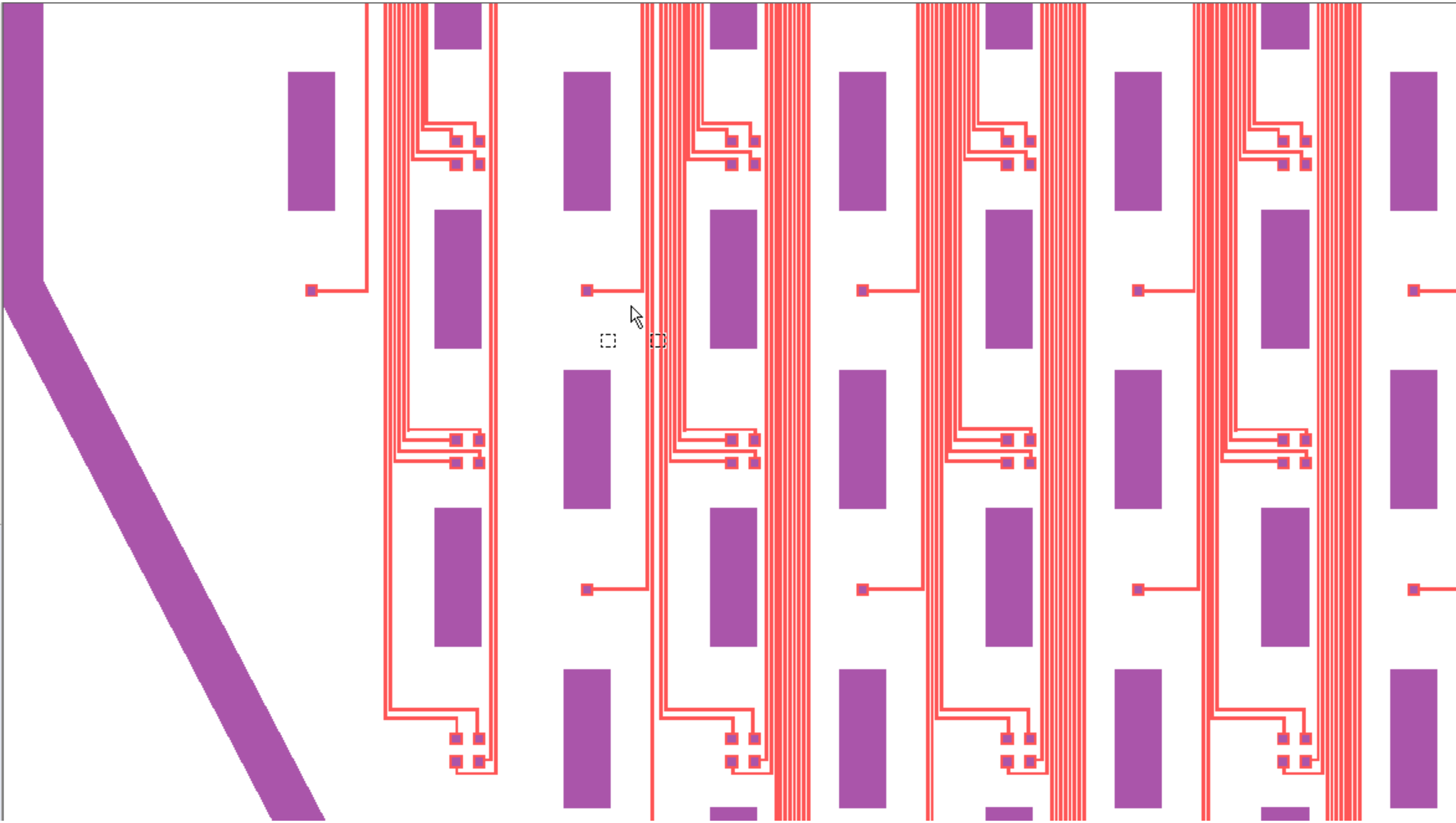


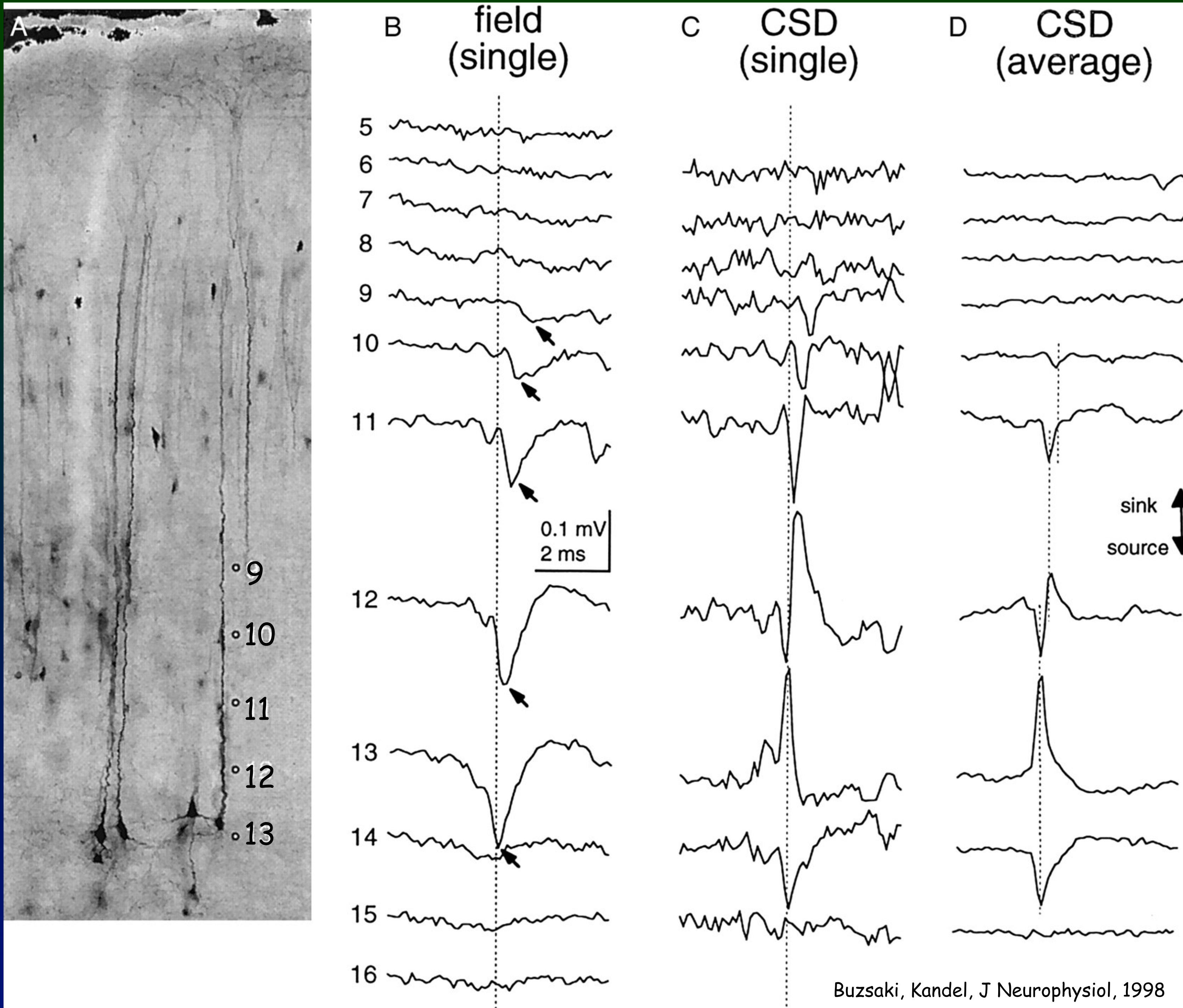






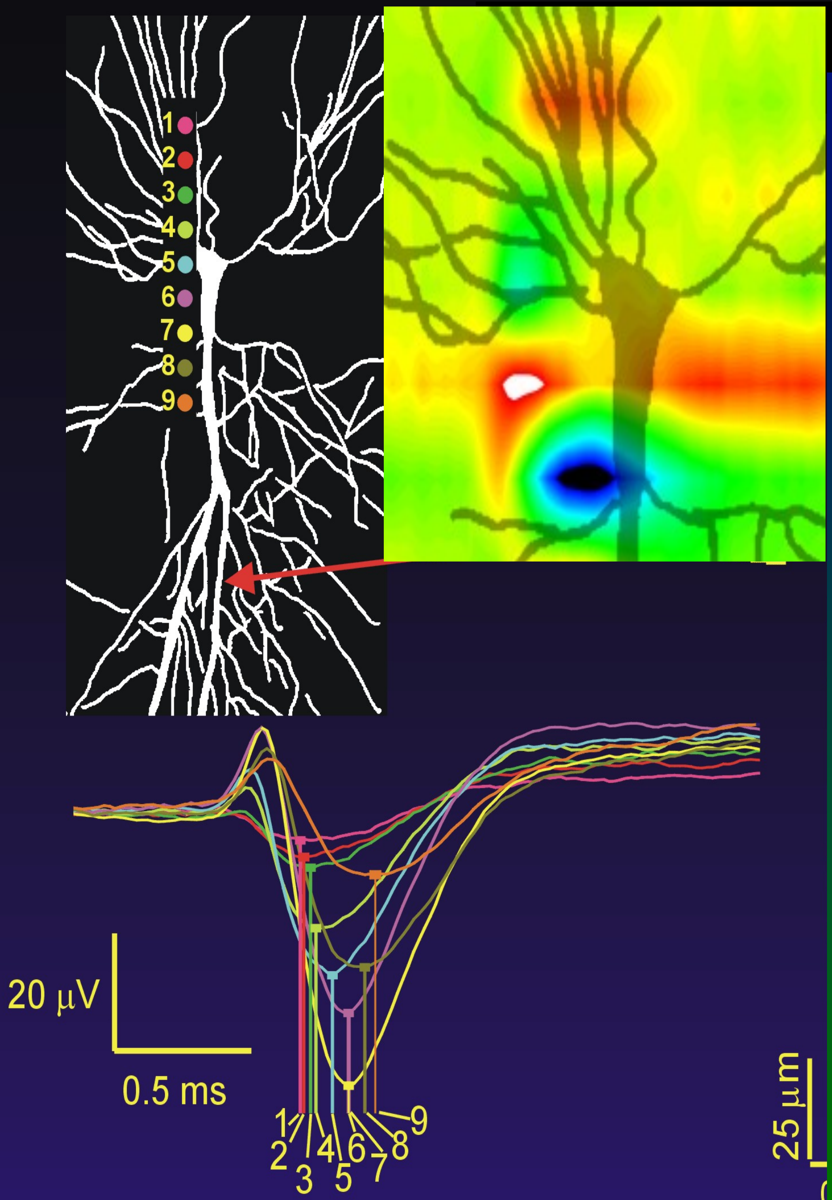






Buzsaki, Kandel, J Neurophysiol, 1998

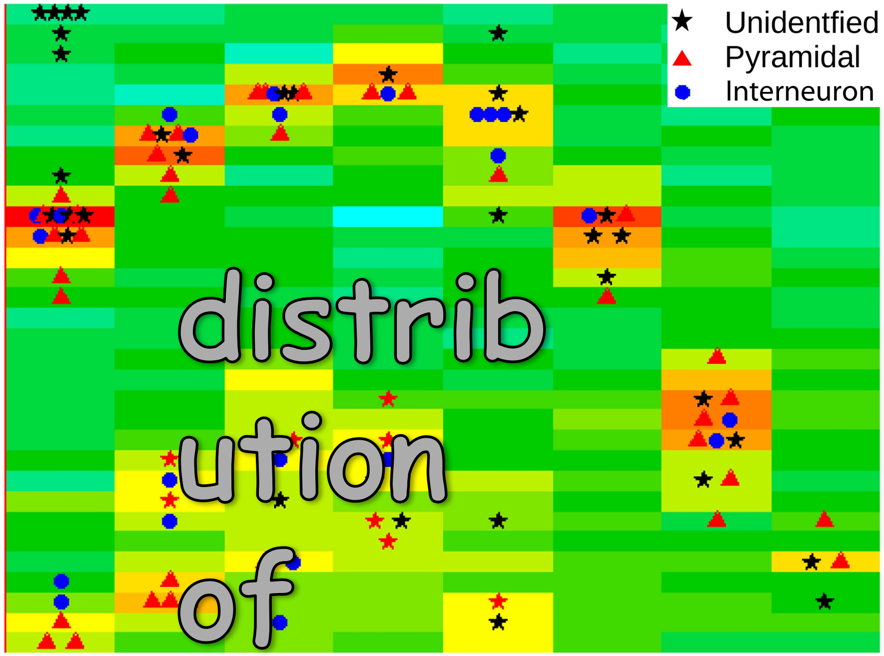
Waveform variability in space

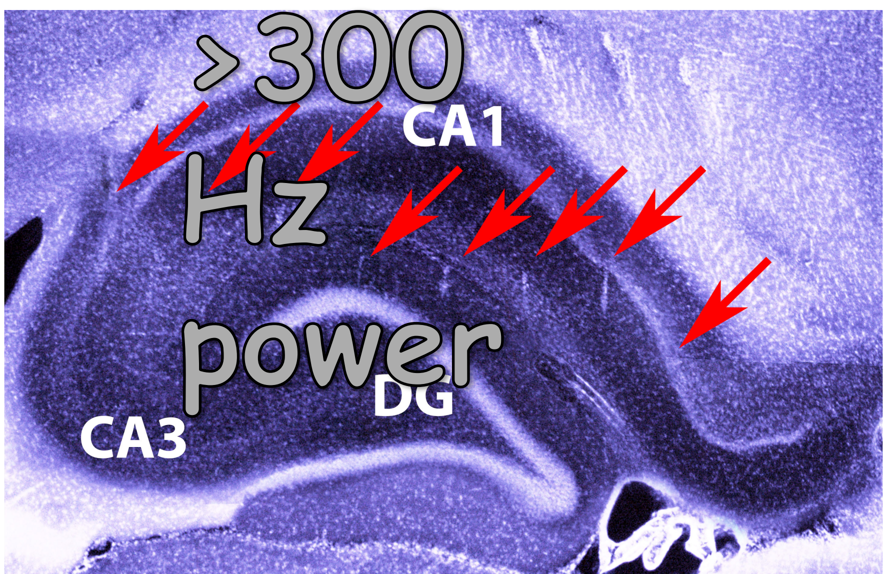


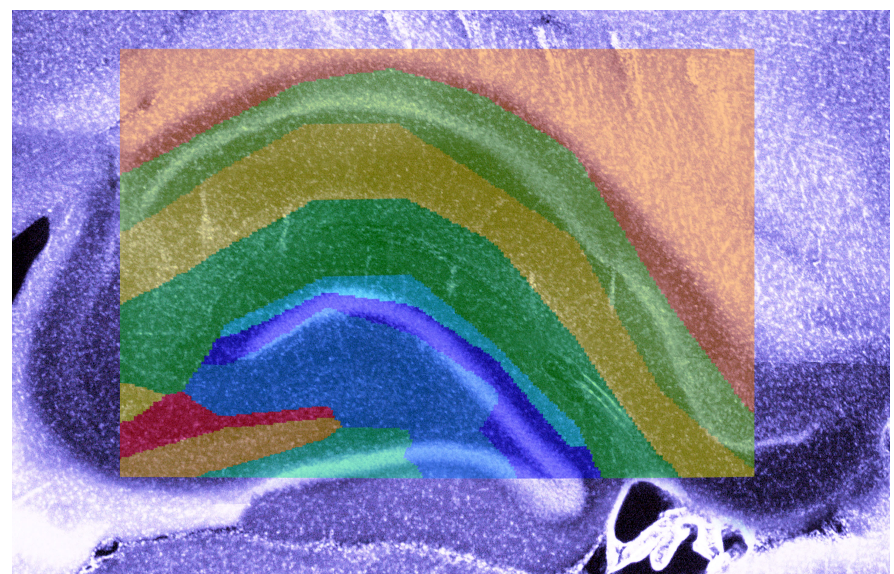
- Spike amplitude and waveform depend on neuron geometry
- Largest amplitude spike occurs next to the soma
- Waveform varies mainly parallel to the somatodendritic axis

Henze and Buzsaki 2003

Electroanatomy of cortical layers

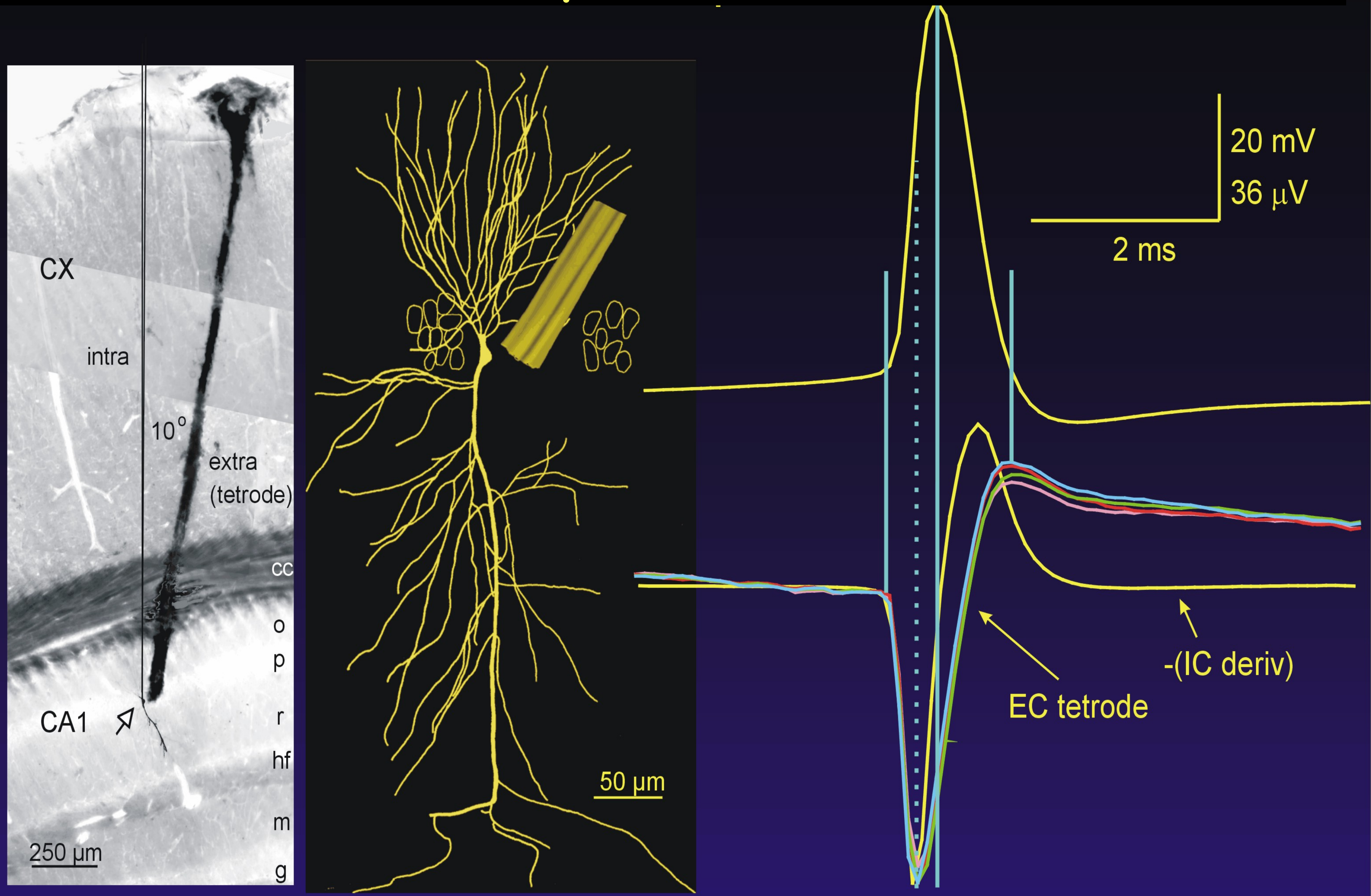






Berenyi, Stark, Roux, Harris, Leonardo, Buzsaki **J Neurophysiol** 2013

Relationship between intracellular and extracellular action potentials



Henze, Borhegyi, Csicsvari, Mamiya, Harris, Buzsaki, J Neurophysiol 2000

Pyramidal cells generate elongated extracellular fields

Problem:

The fields of many neurons strongly overlap

Gold, Henze, Koch, Buzsaki, J Neurophysiol 2006

~$15,000 head-gear/rat