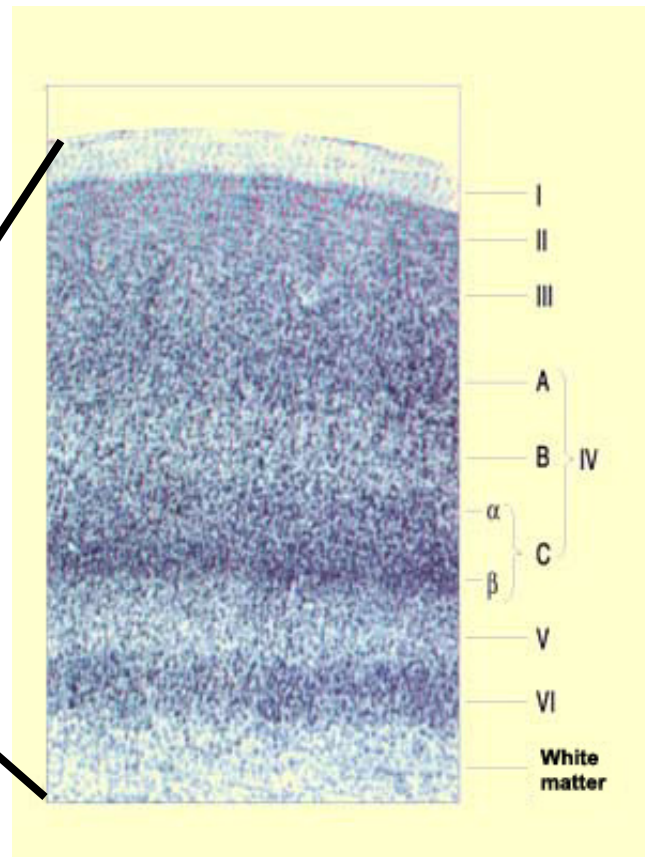# Neuronal and physical contributions to the LFP signal in the visual cortex

Dajun Xing

New York University

Optic Nerve LGN Primary Visual Cortex
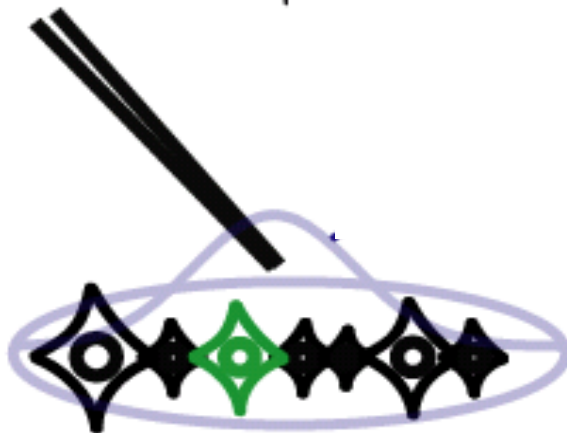
I
II
III
A
B ⎫ IV
C ⎫
  α
  β
V
VI
White matter
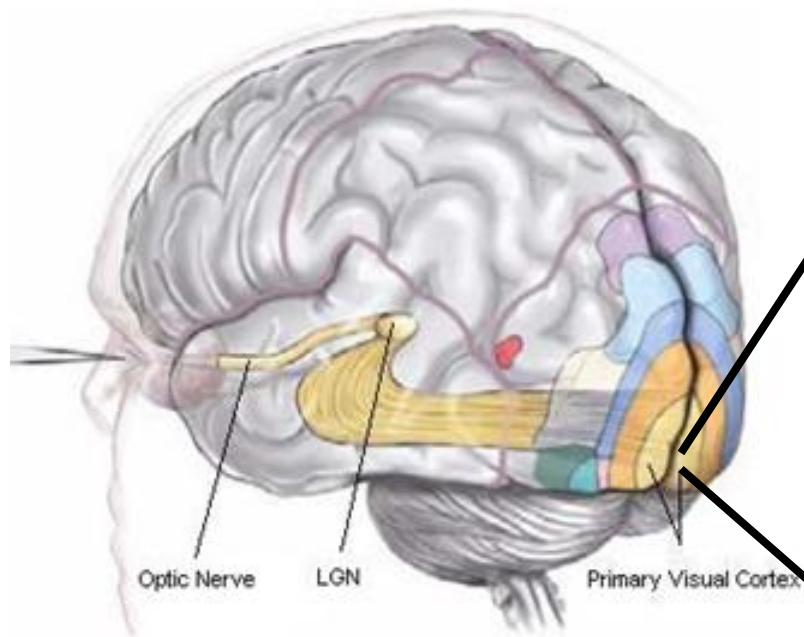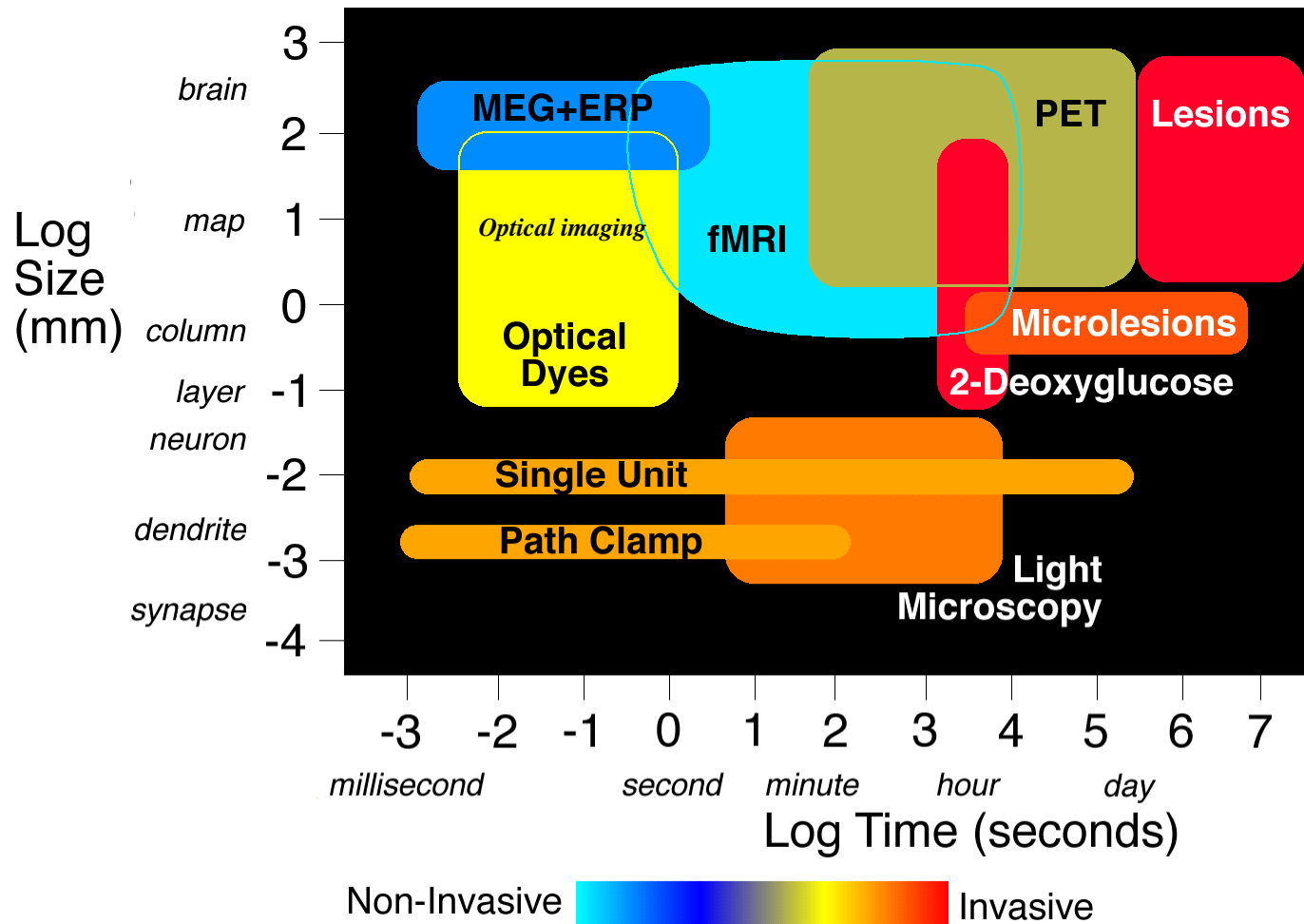
Cohen and Bookheimer (1994)

LFP in electrophysiology
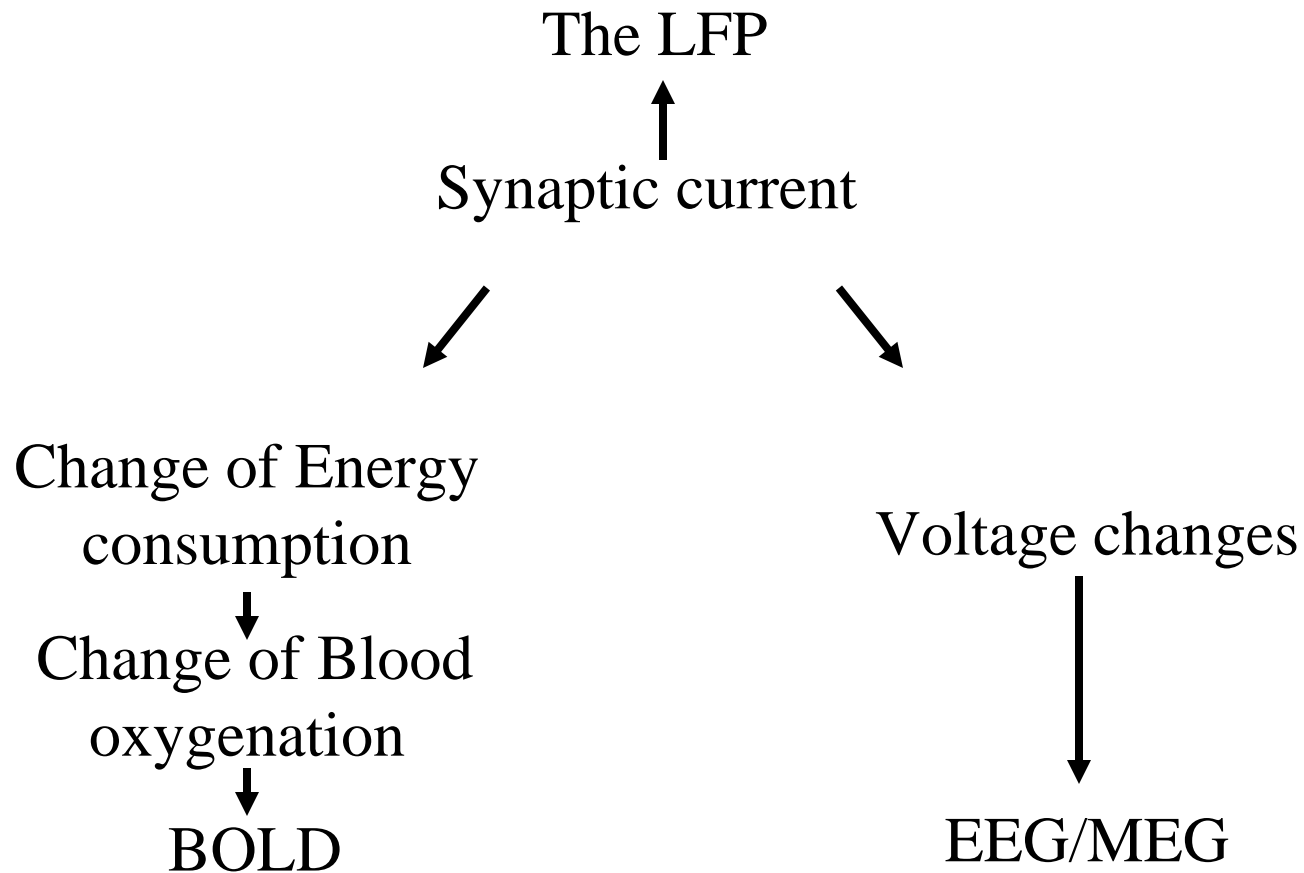
Extracellular recording (LFP, MUA and SUA)

Cortical Neurons

LFP: the Local Field Potential (< 100 Hz)

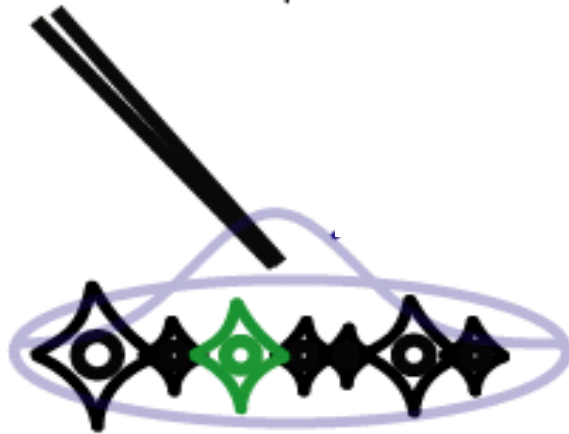MUA: Multi-unit Activity (>1000Hz)

SUA: Single-unit Activity (> 1000Hz & with well defined waveform)

LFP & Non-invasive recordings

The LFP

Synaptic current
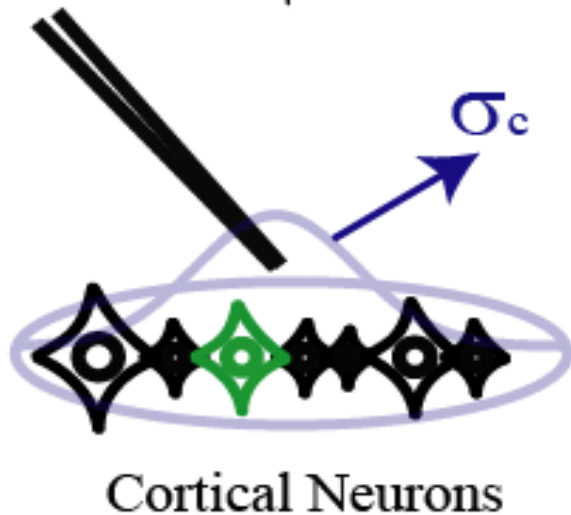
Change of Energy
consumption

Change of Blood
oxygenation

BOLD

Voltage changes

EEG/MEG

LFP & Neural prostheses

Cortical Neurons

The LFP

$\Rightarrow$ stable signal

$\Rightarrow$ neural prostheses

Population activity (medium scale)

fMRI, MEG and EEG (>3000 μm)

Local Field Potential (100-3000 μm)

Multi-Unit activity (30-140 μm)
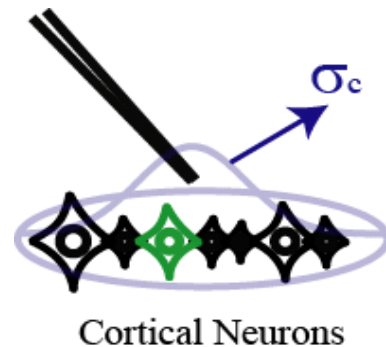
Single Unit (30 μm)

σ_c

Cortical Neurons
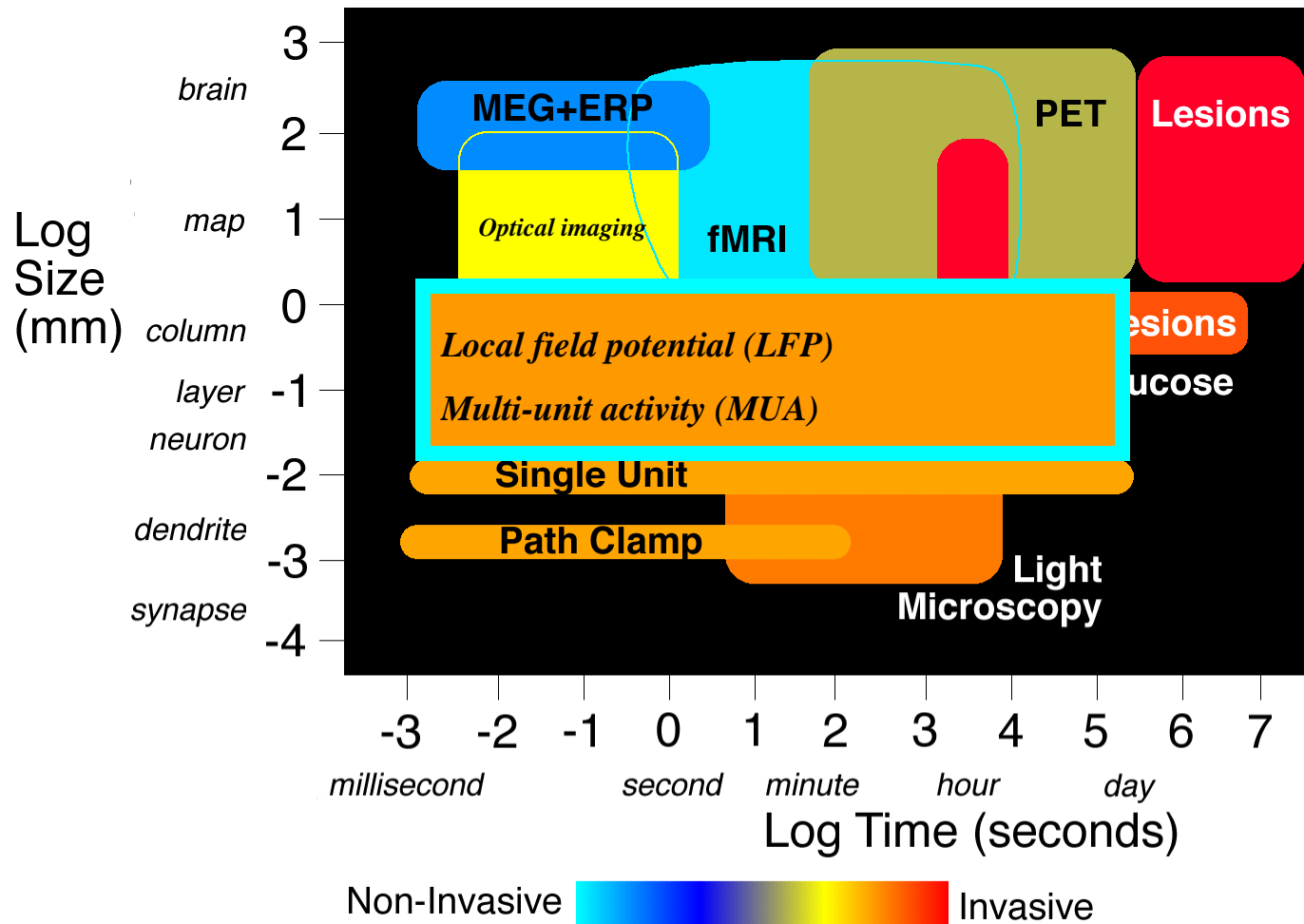
Cohen and Bookheimer (1994)

How local is the LFP ?

Spatial Scale: (controversial)

-- Spikes (SUA/MUA): 30-140 μm

-- LFP: 100-3000 μm

Cortical Neurons

Katzner et al., 2009
Berens et al., 2008
Logothetis et al., 2007
Liu and Newsome, 2006
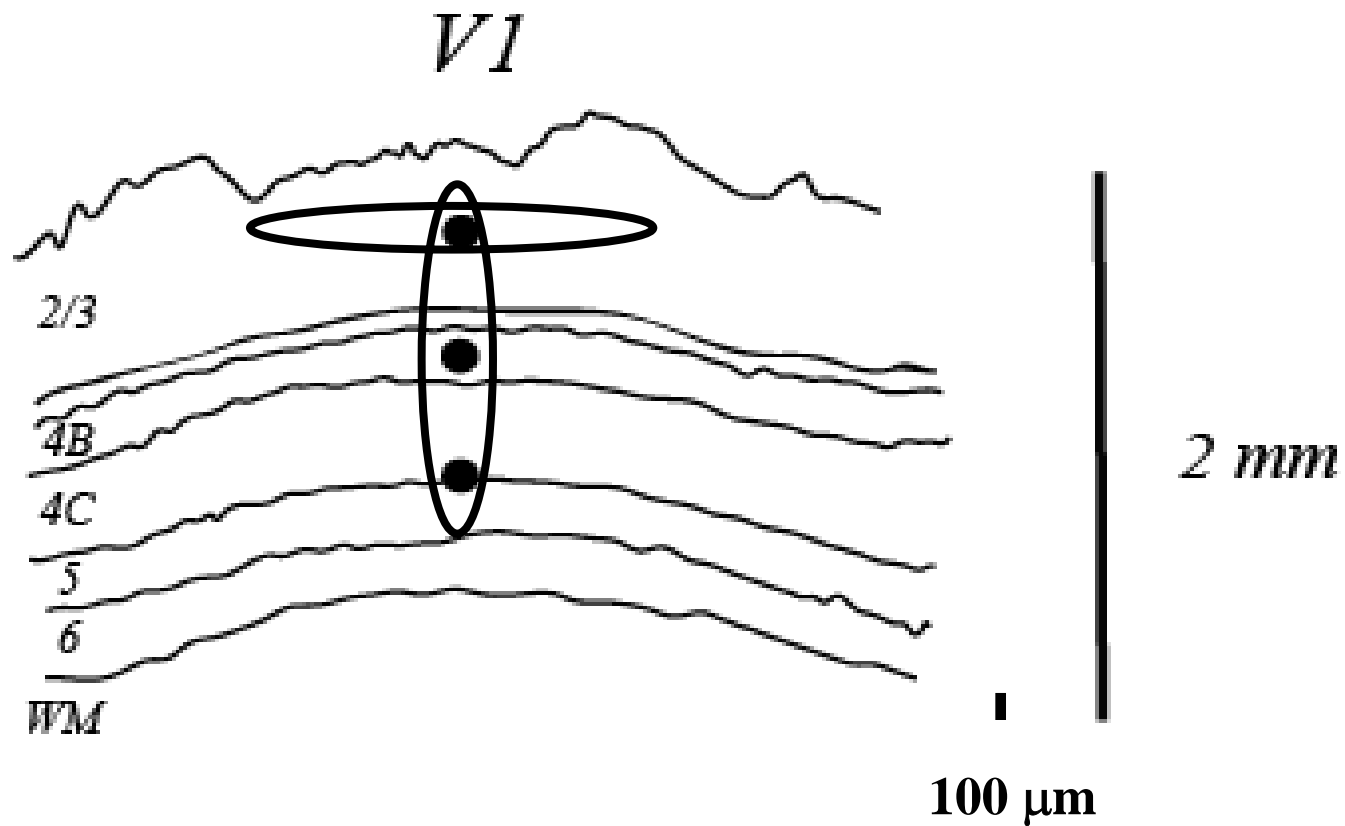Kreiman et al., 2006
Gail et al., 2003
Pesaran et al., 2002
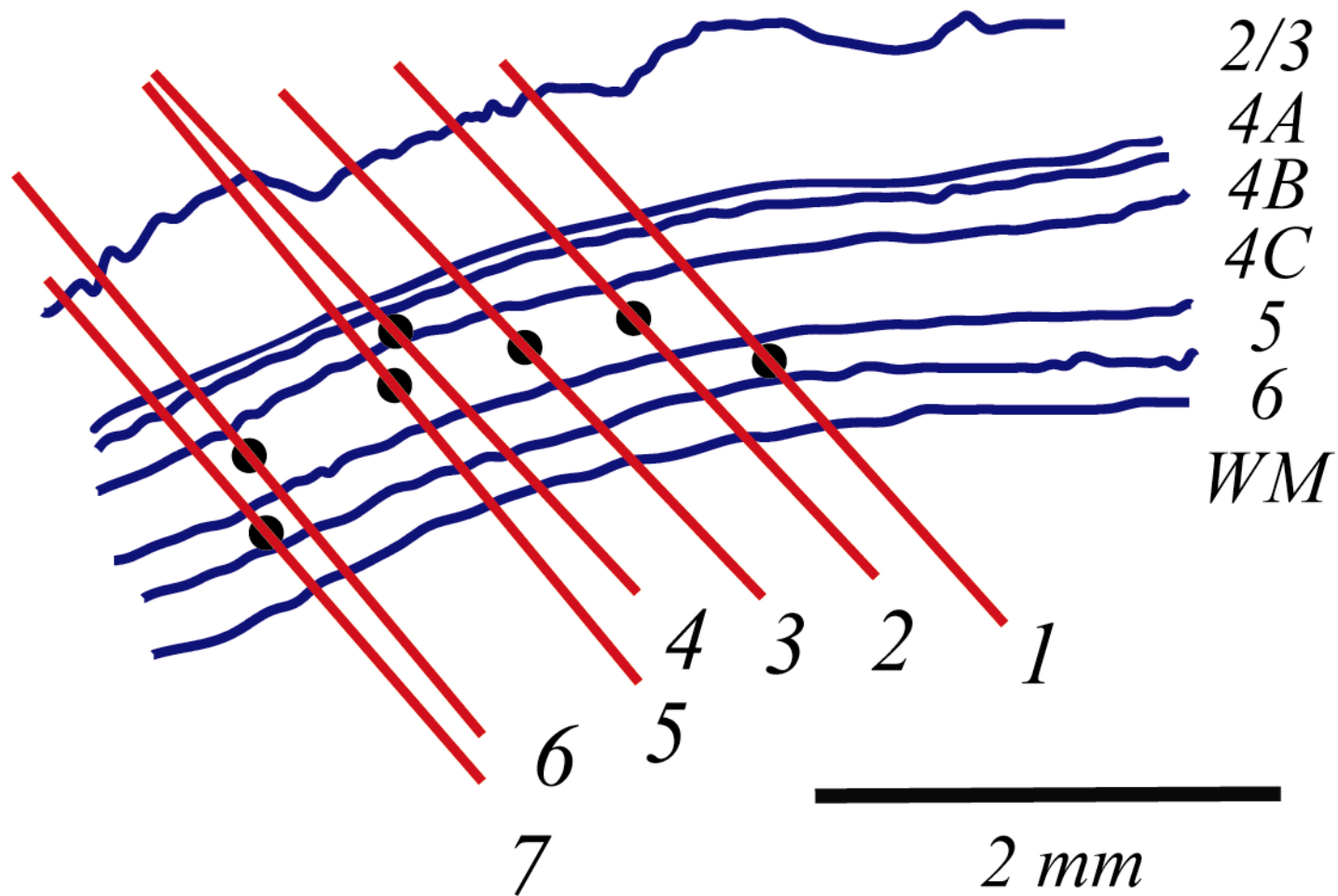Kruse and Eckhorn, 1996
Mitzdorf, 1987

How local is the LFP ?

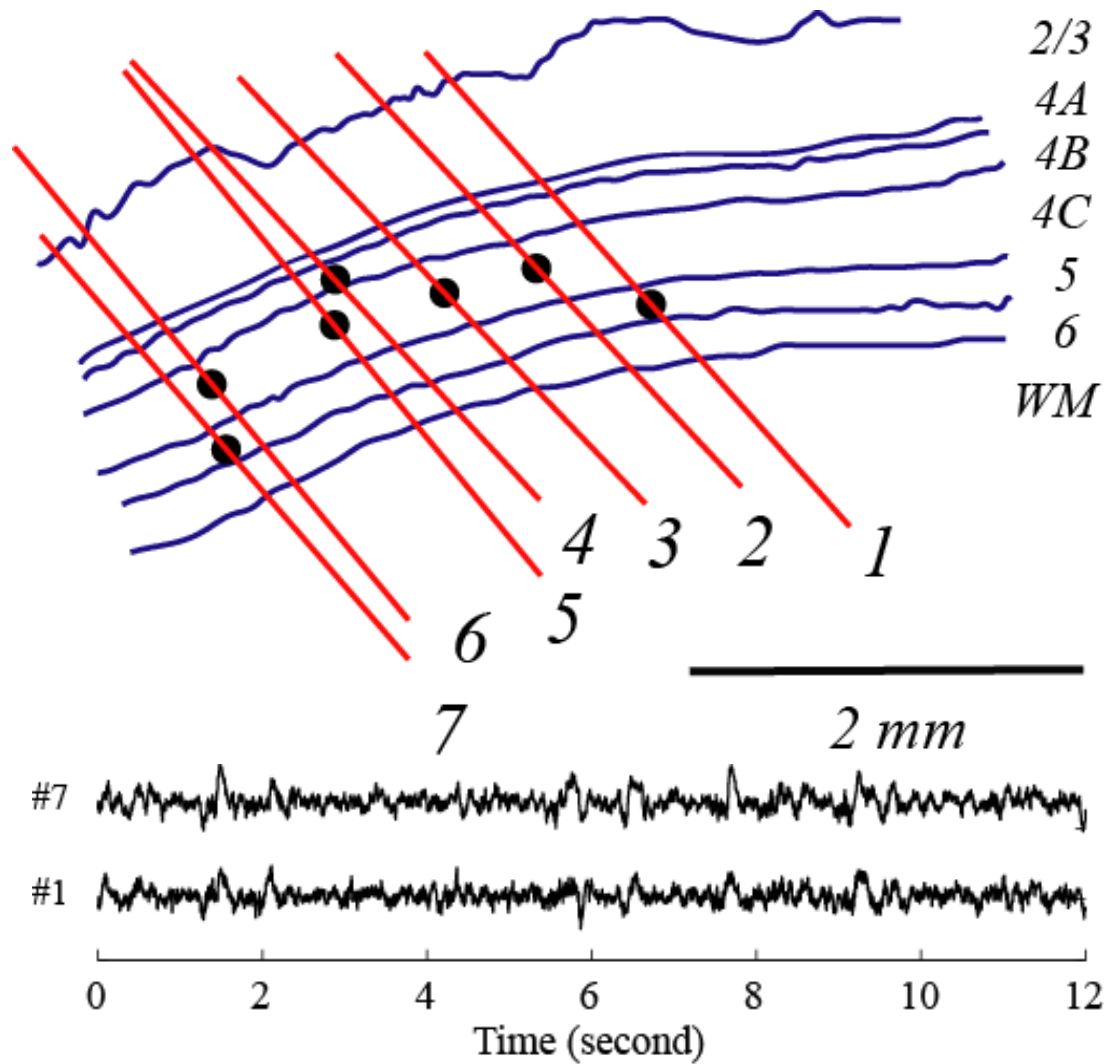-- Signal blurring horizontally & vertically

Electrophysiology + Neuroanatomy

Multi-electrode recording

The LFPs at distant sites look similar

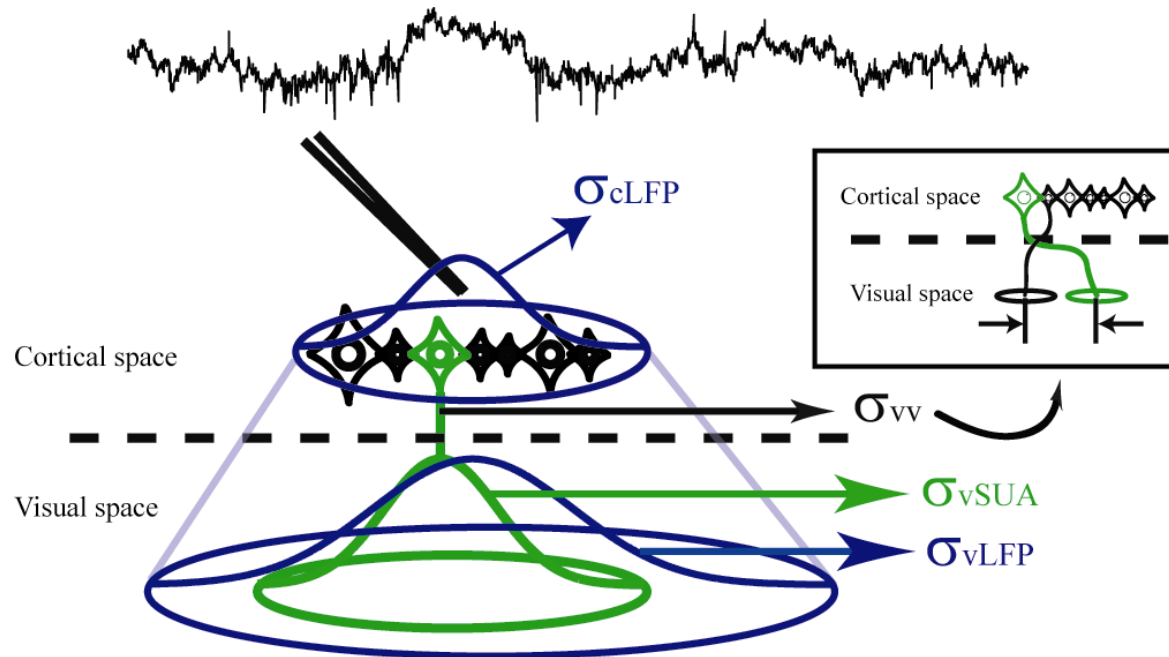# **Physical spread** and **Neural spread**

Physical spread:

how far a signal can go through the brain tissue

Neural spread:

how far a signal can go through the neural circuitry

Brain Signal = F(Physical spread, Neural spread)

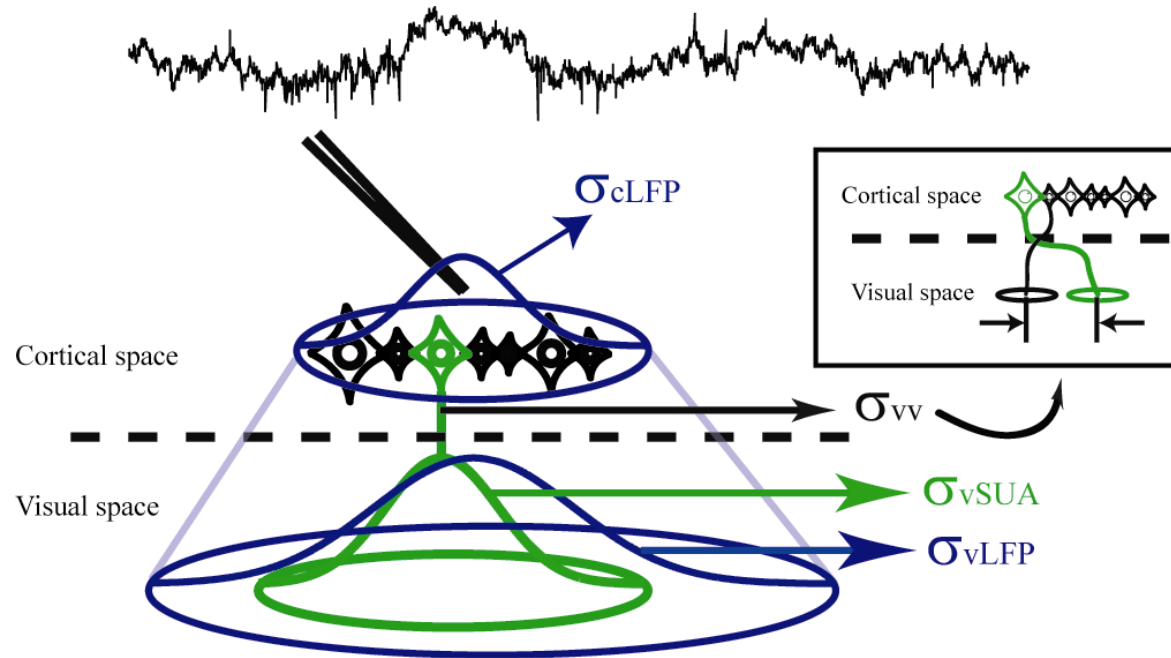# Physical spread, Neural spread, and Visual Field

Physical spread: how far a signal can travel in the brain

Visual field: how far in visual space can a stimulus affect a neuron--
    depends on physical and neural spreads

Physical spread and Neural spread

Visual field = F(Physical spread, Neural spread)

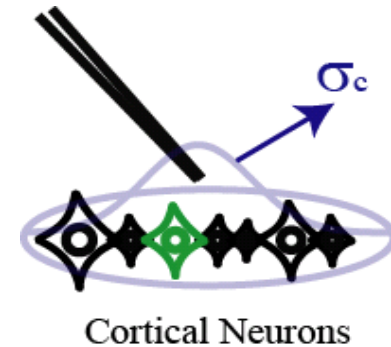$$\sigma_{vLFP} \qquad\qquad \sigma_{cLFP} \qquad\qquad \sigma_{vSUA} \quad \sigma_{vv}$$

Physical spread and **Neural spread**

$$f_{vLFP}(x, y) = f_{cLFP}(x, y) \otimes f_{vSUA}(x, y) \otimes f_{vv}(x, y)$$

$$\sigma^2_{vLFP} = \sigma^2_{cLFP} / MF^2 + \sigma^2_{vSUA} + \sigma^2_{vv}$$

$$\sigma^2_{vMUA} = \sigma^2_{cMUA} / MF^2 + \sigma^2_{vSUA} + \sigma^2_{vv}$$

σ_c

Cortical Neurons

$$\sigma_{cLFP} = \sqrt{MF^2 \bullet \left(\sigma^2_{vLFP} - \sigma^2_{vMUA} \right) + \sigma^2_{cMUA}}$$

Physical spread and Neural spread

Magnification factor?

Visual field?

$$\sigma_{cLFP} = \sqrt{MF^2 \bullet \left(\sigma^2_{vLFP} - \sigma^2_{vMUA} \right) + \sigma^2_{cMUA}}$$

physical spread of the MUA?

physical spread of the LFP?

Visual field of the LFP & MUA
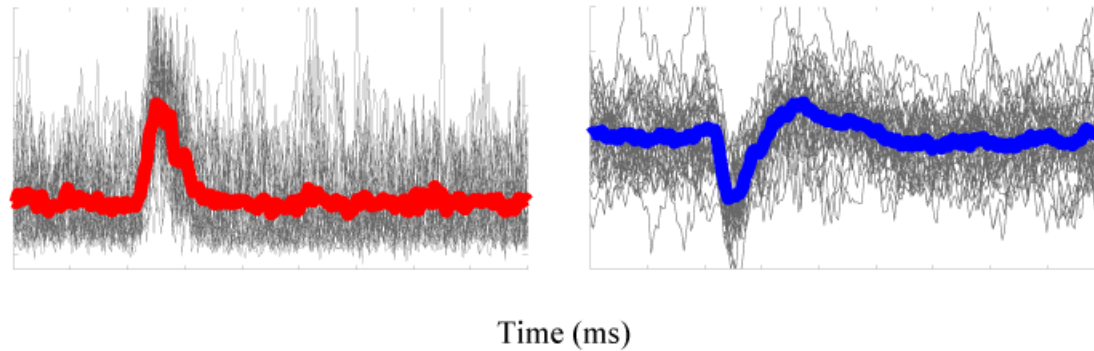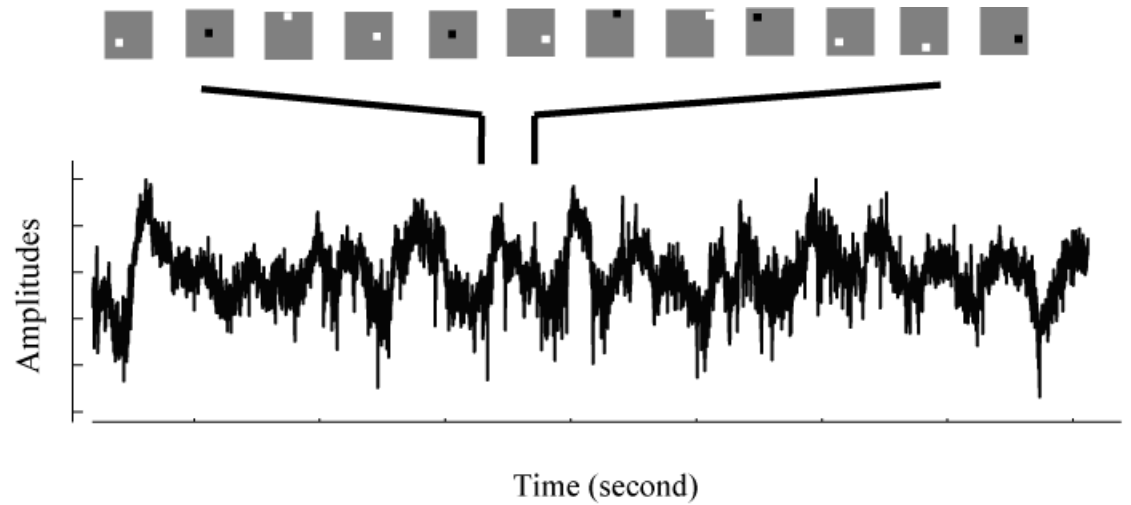
Visual field of the LFP & MUA

Visual field in different layers

Physical spread and **Neural spread**

Magnification factor?
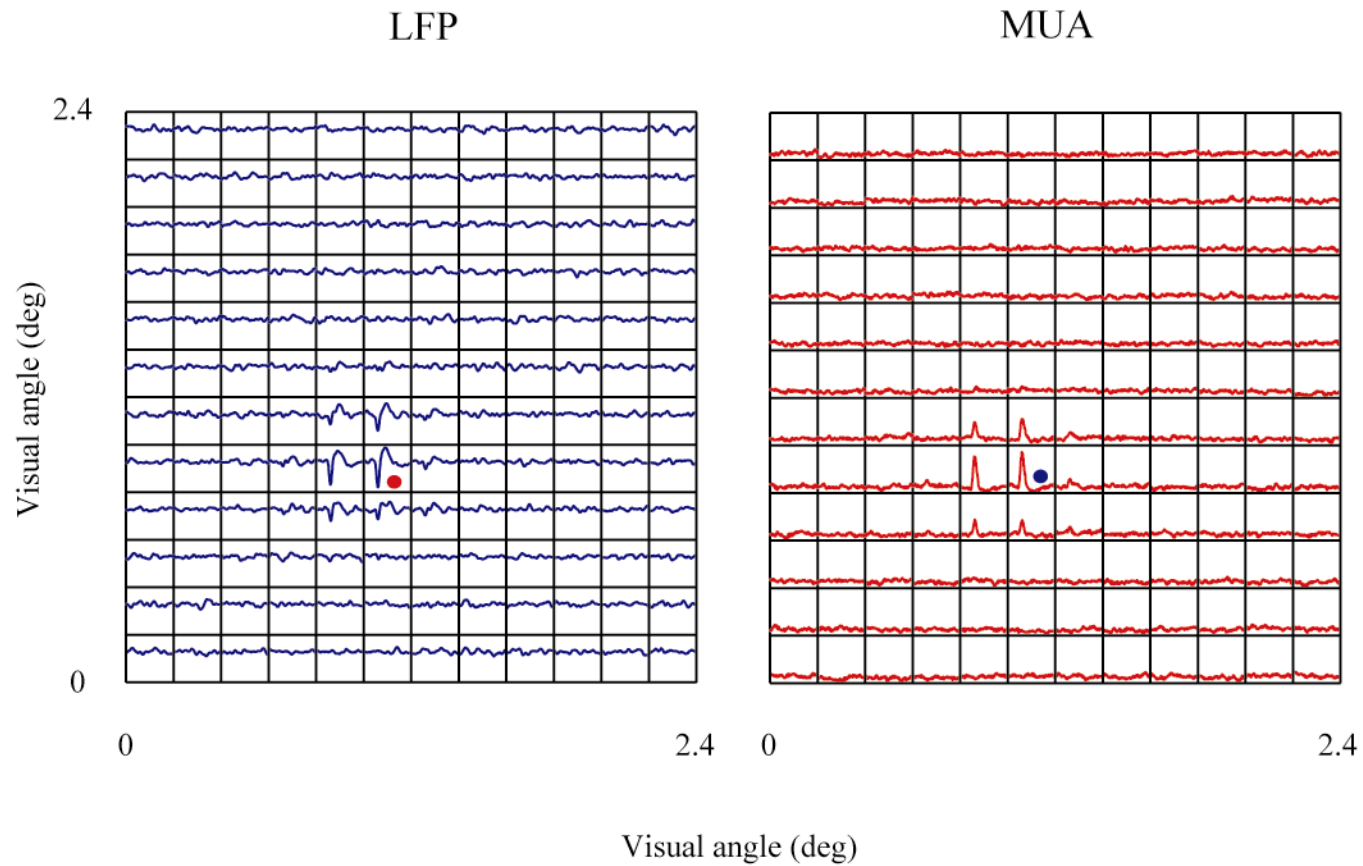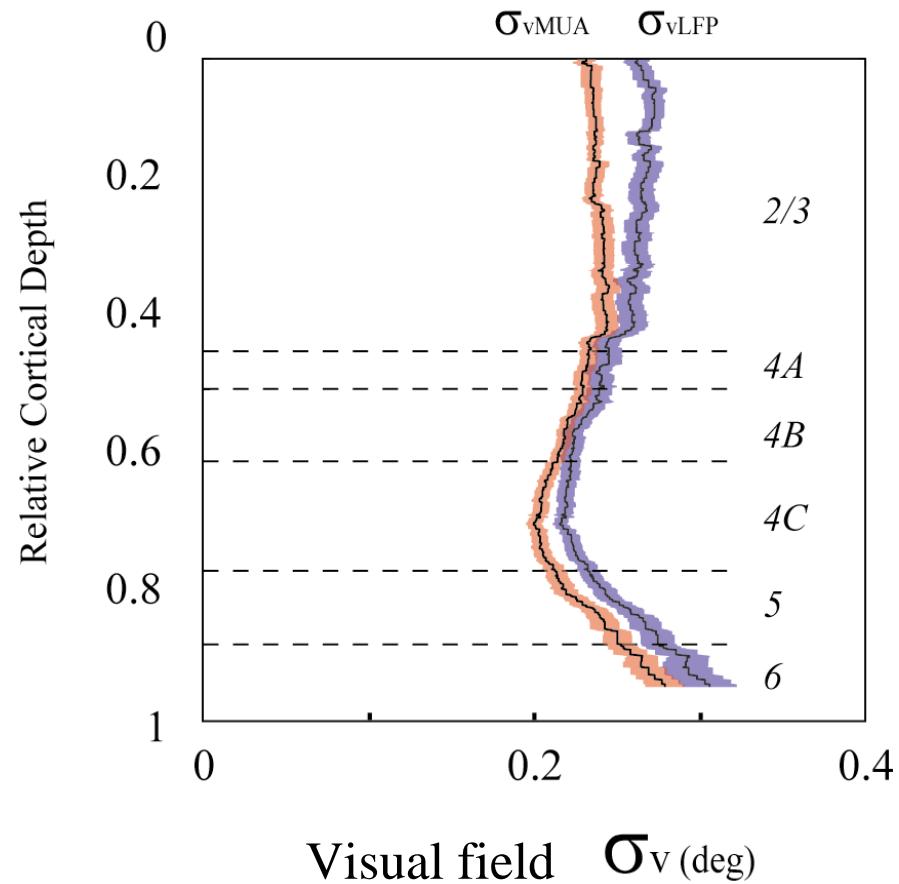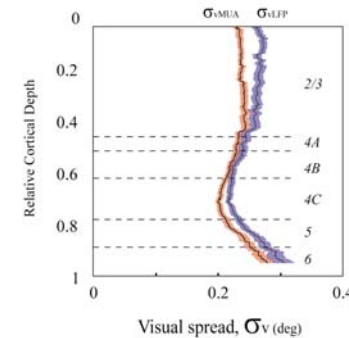
Visual field
~ 0.25 deg

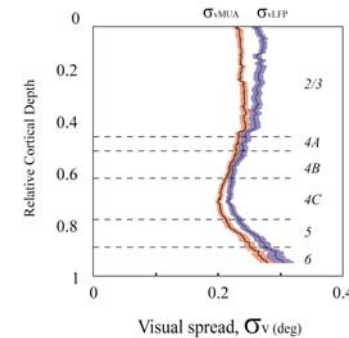$$\sigma_{cLFP} = \sqrt{MF^2 \bullet \left(\sigma^2_{vLFP} - \sigma^2_{vMUA} \right) + \sigma^2_{cMUA}}$$

Physical spread of the LFP?

Physical spread
of the MUA?

Physical spread and Neural spread

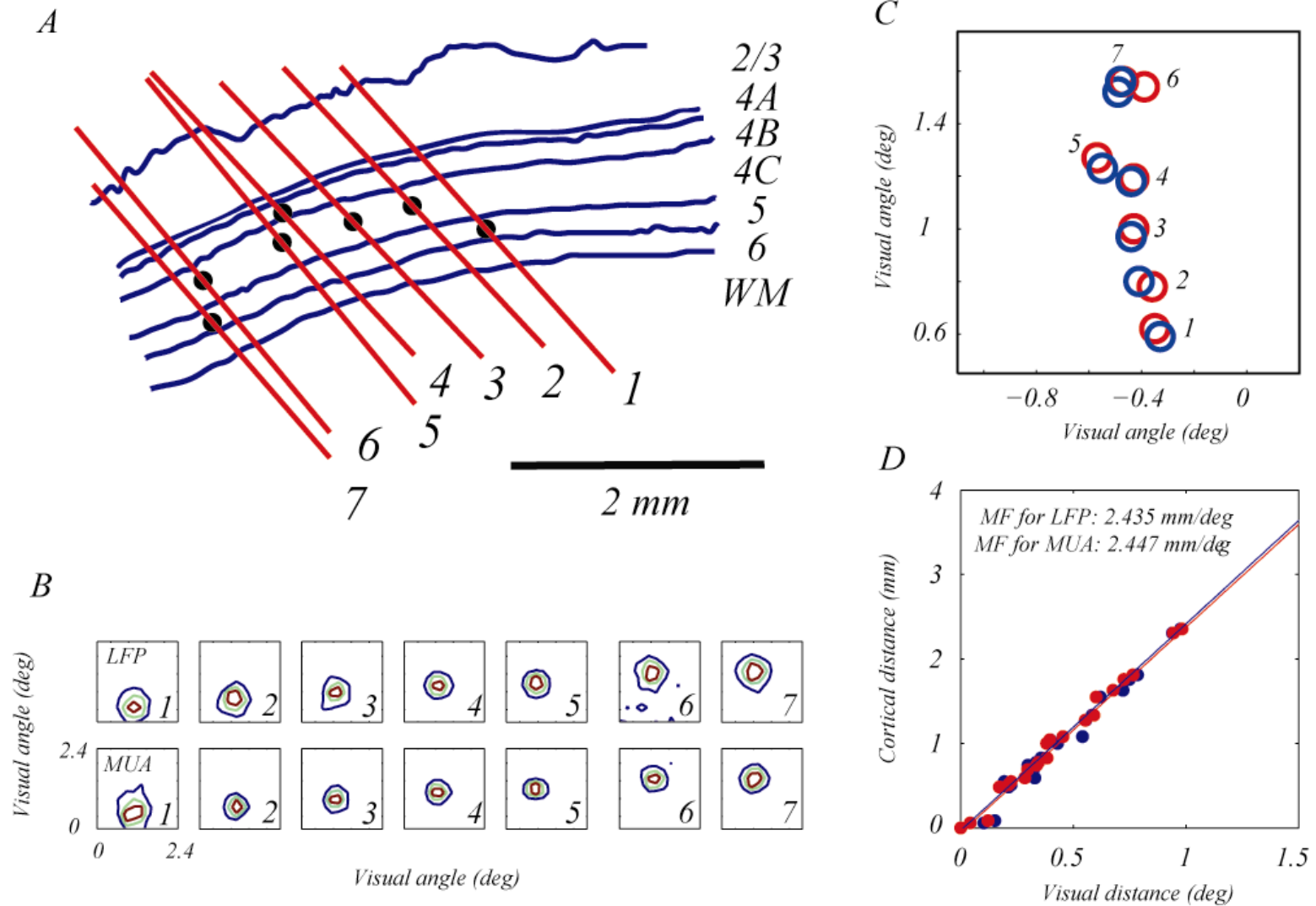Magnification factor?

Visual field
~ 0.25 deg

Physical spread of the LFP?

Physical spread
of the MUA
~60 μm

$$\sigma_{cLFP} = \sqrt{MF^2 \bullet \left(\sigma^2_{vLFP} - \sigma^2_{vMUA} \right) + \sigma^2_{cMUA}}$$

Magnification factor (MF)

A

2/3
4A
4B
4C
5
6
WM

4 3 2 1
6 5
7

2 mm

B

LFP 1 2 3 4 5 6 7

MUA 1 2 3 4 5 6 7

Visual angle (deg)

2.4

0   2.4

Visual angle (deg)

C

Visual angle (deg)

1.4

1

0.6

−0.8   −0.4   0

Visual angle (deg)

7 6
5 4
3
2
1

D

Cortical distance (mm)

MF for LFP: 2.435 mm/deg
MF for MUA: 2.447 mm/dg

4
3
2
1
0

0   0.5   1   1.5

Visual distance (deg)

Physical spread and Neural spread

Magnification factor
~2500 μm /deg

Visual field
~ 0.25 deg

$$\sigma_{cLFP} = \sqrt{MF^2 \bullet \left(\sigma^2_{vLFP} - \sigma^2_{vMUA} \right) + \sigma^2_{cMUA}}$$
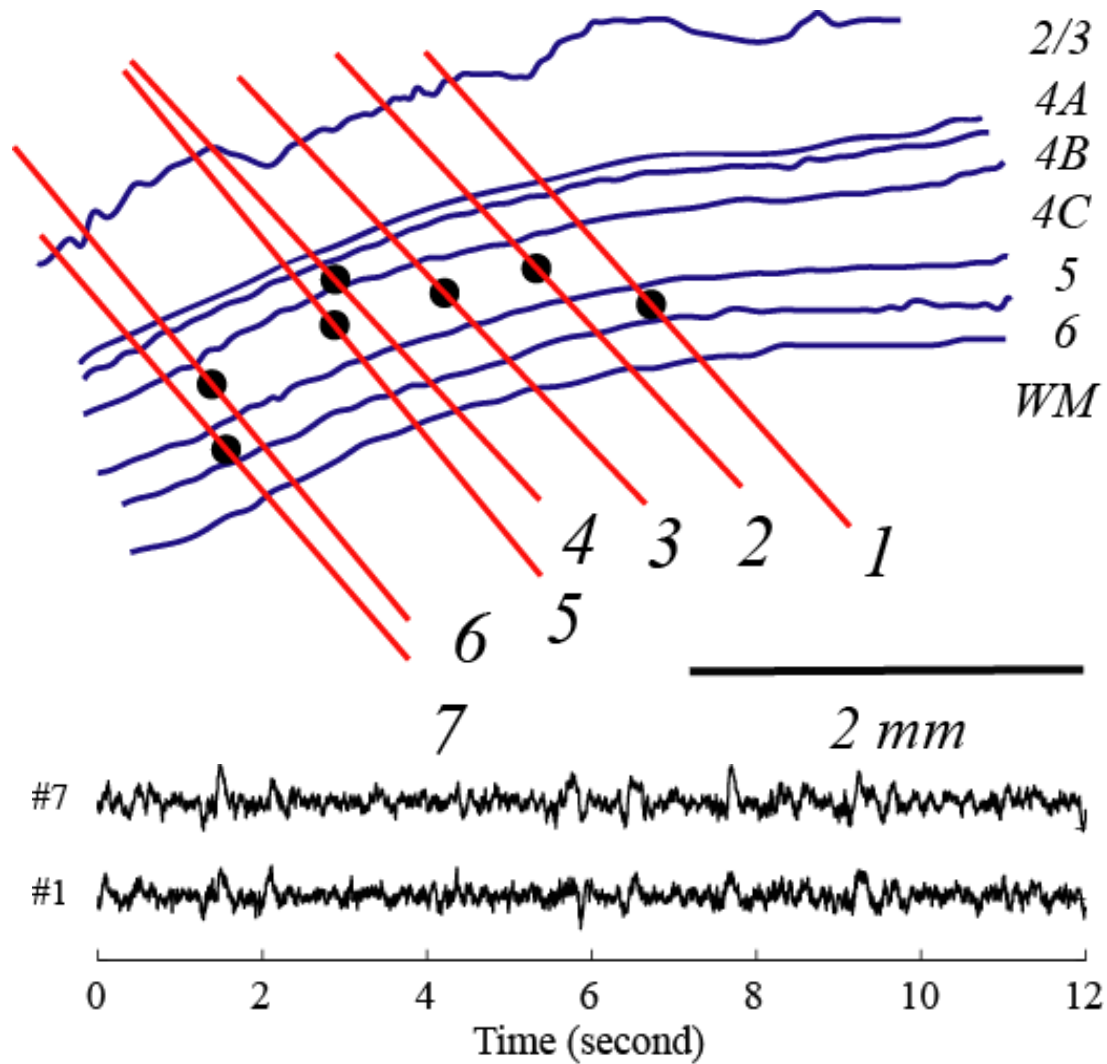
Physical spread of the LFP?

Physical spread
of the MUA
~60 μm

Physical spread and **Neural spread** of the LFP
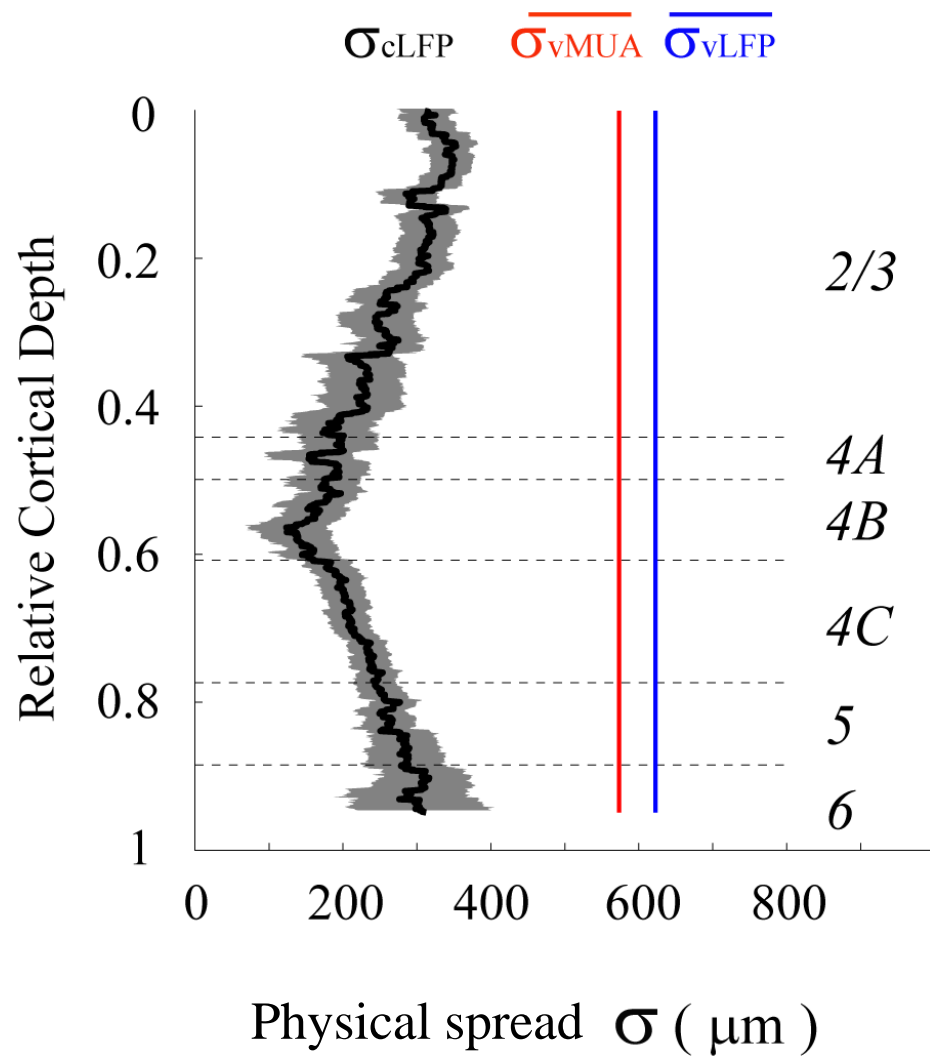
The LFPs at distant sites look similar

Conclusion

1) The physical spread of the LFP is local (<200 µm)

2) The neural spread of the LFP is broader than its physical spread (~ 600 µm in V1).

Acknowledgements

- Bob Shapley
- Chun-I Yeh
- Patrick Williams
- Marianne Maertens
- Sam Burns

- Mike Hawken,
- Siddhartha Joshi
- Anita Disney
- Bijan Pesaran
- Jonathan Victor
- Dario Ringach