The Origin of Consciousness

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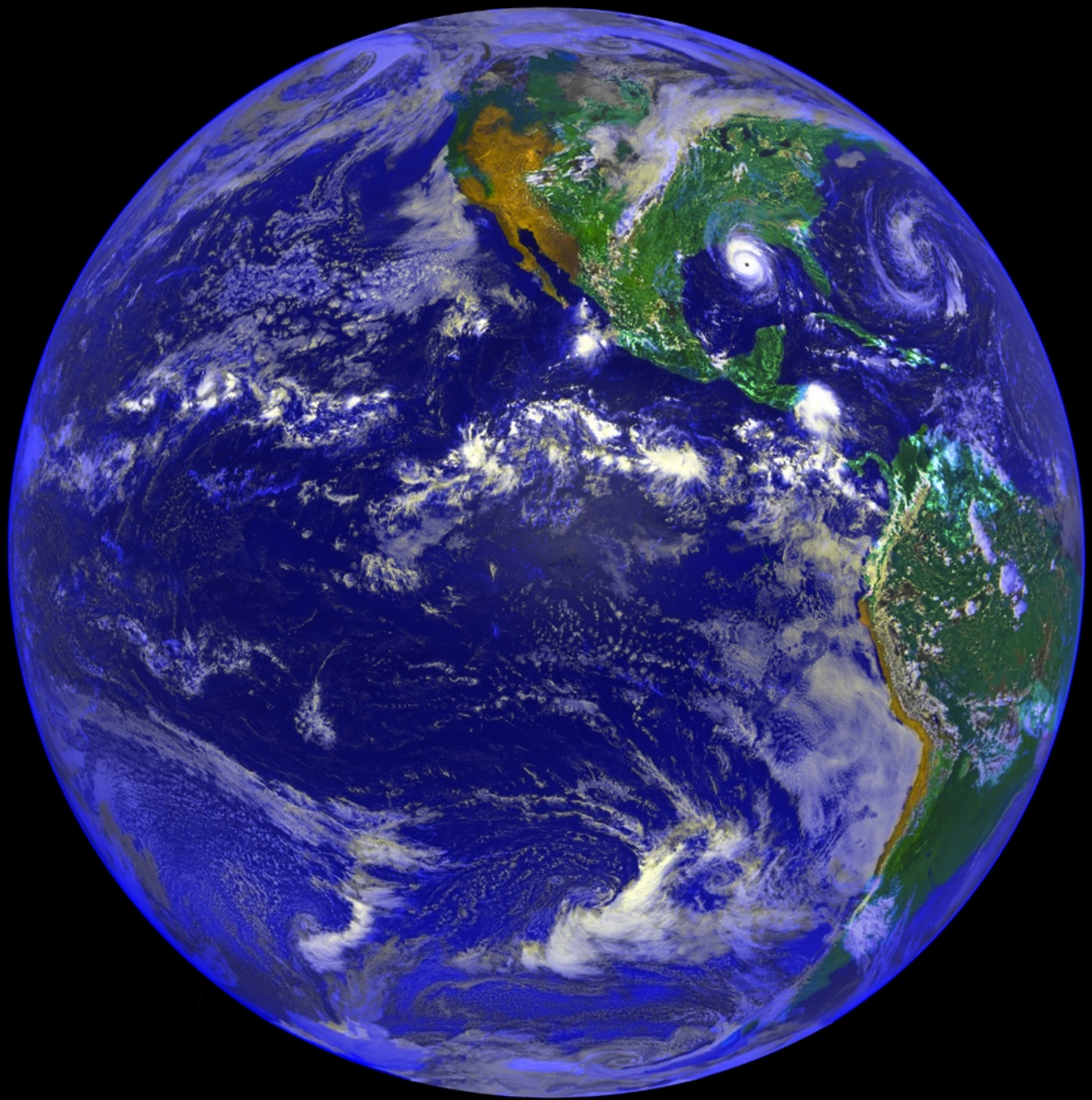
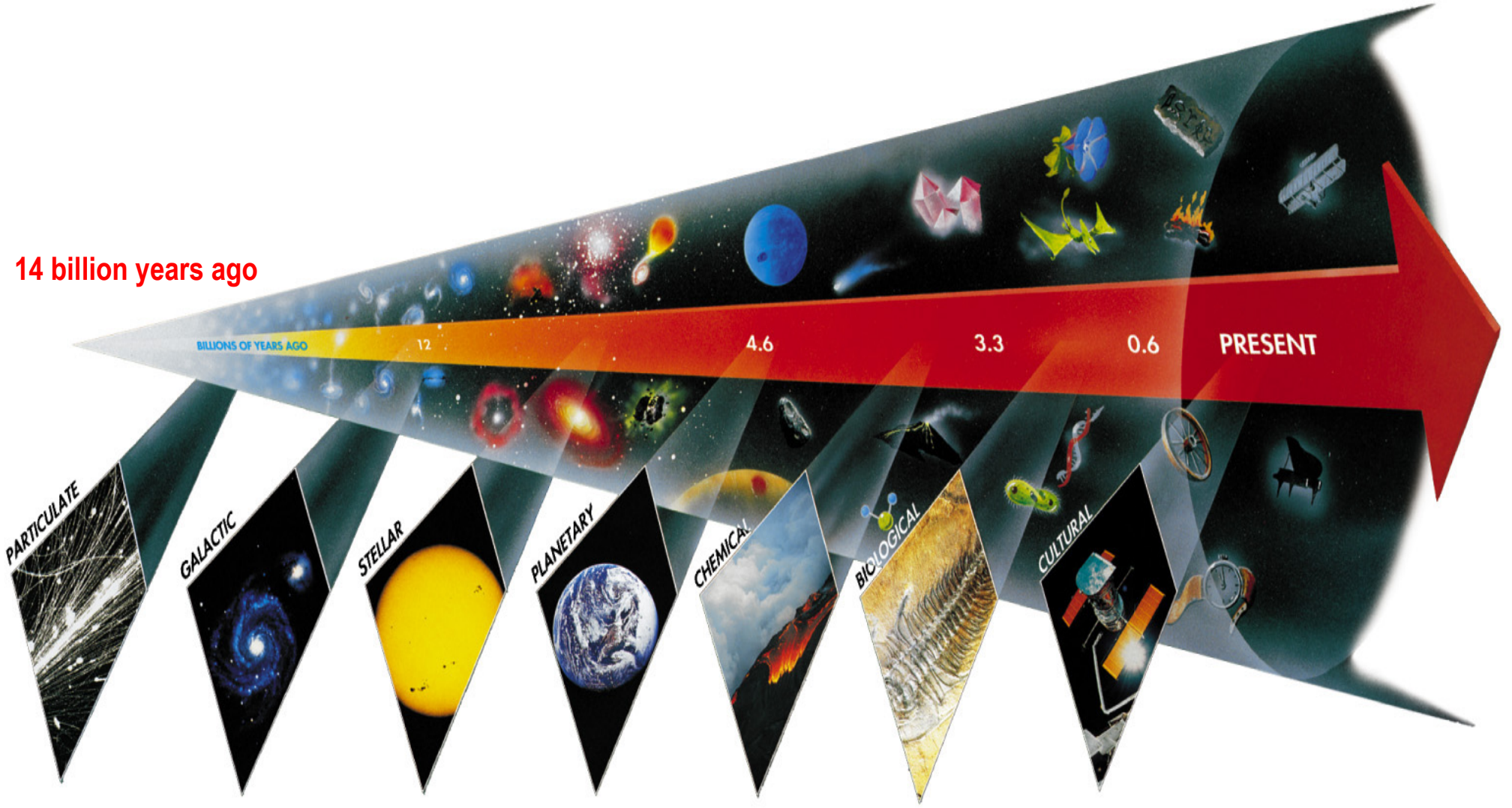


Why are we here?

Seven Phases of Cosmic Evolution



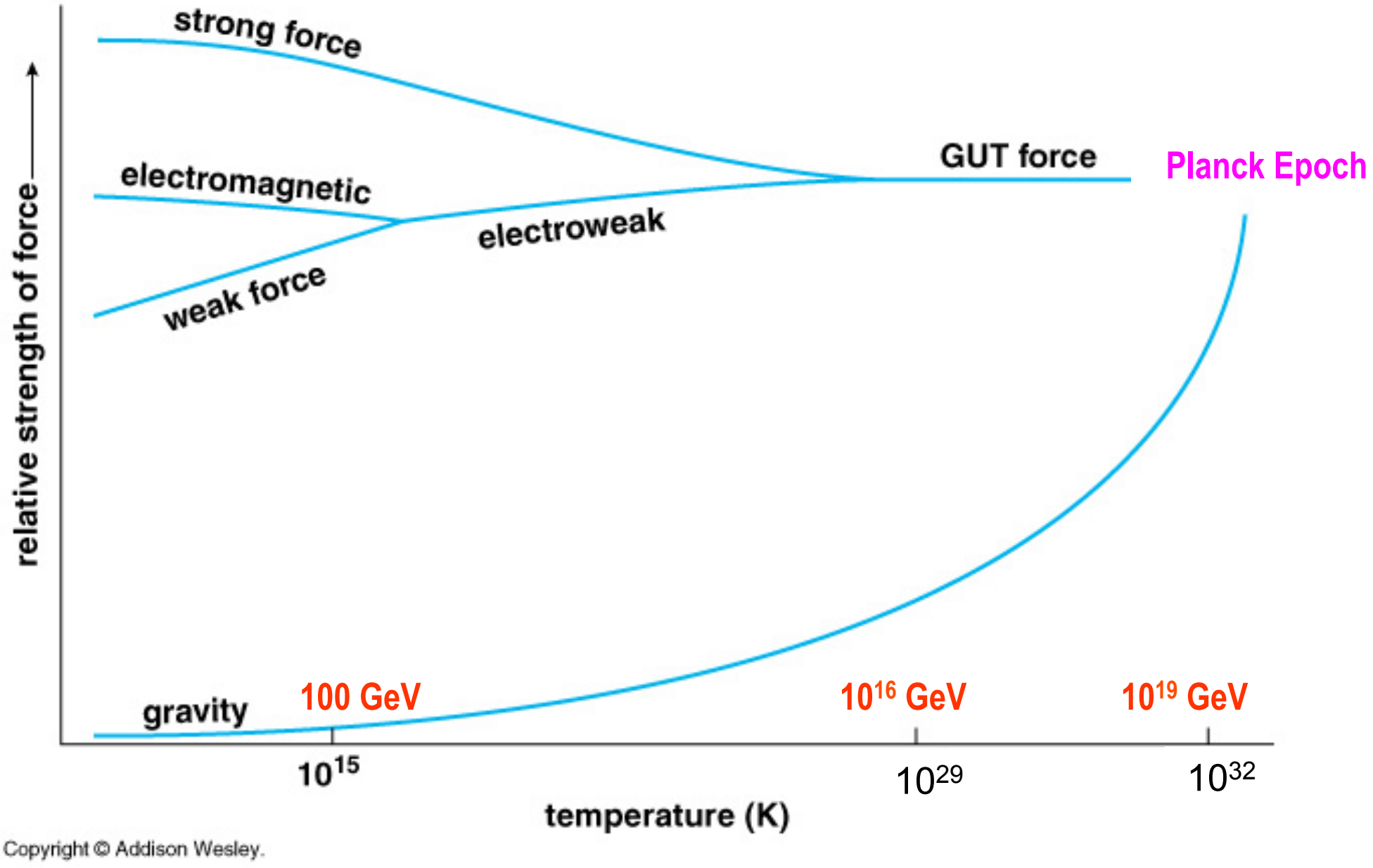
Origin of Particles

Origin of Structure

Origin of Life

Origin of Consciousness

Unification of Forces



Physicists' View of Early Universe

Fiat lux

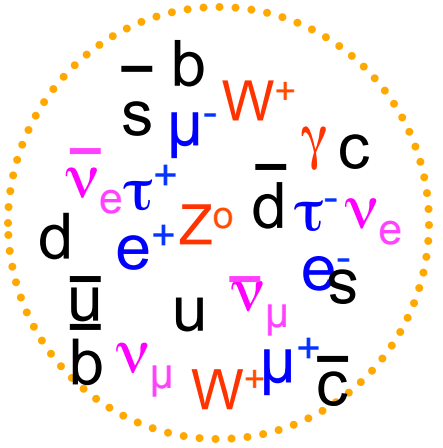
Let there be light

Symmetry Breaking

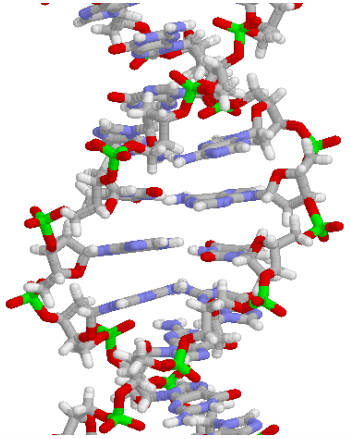
Time
0
1B years
2
3
4
5
6
7
8
9
10
11
12
13
14

Simple

Symmetry Break Down

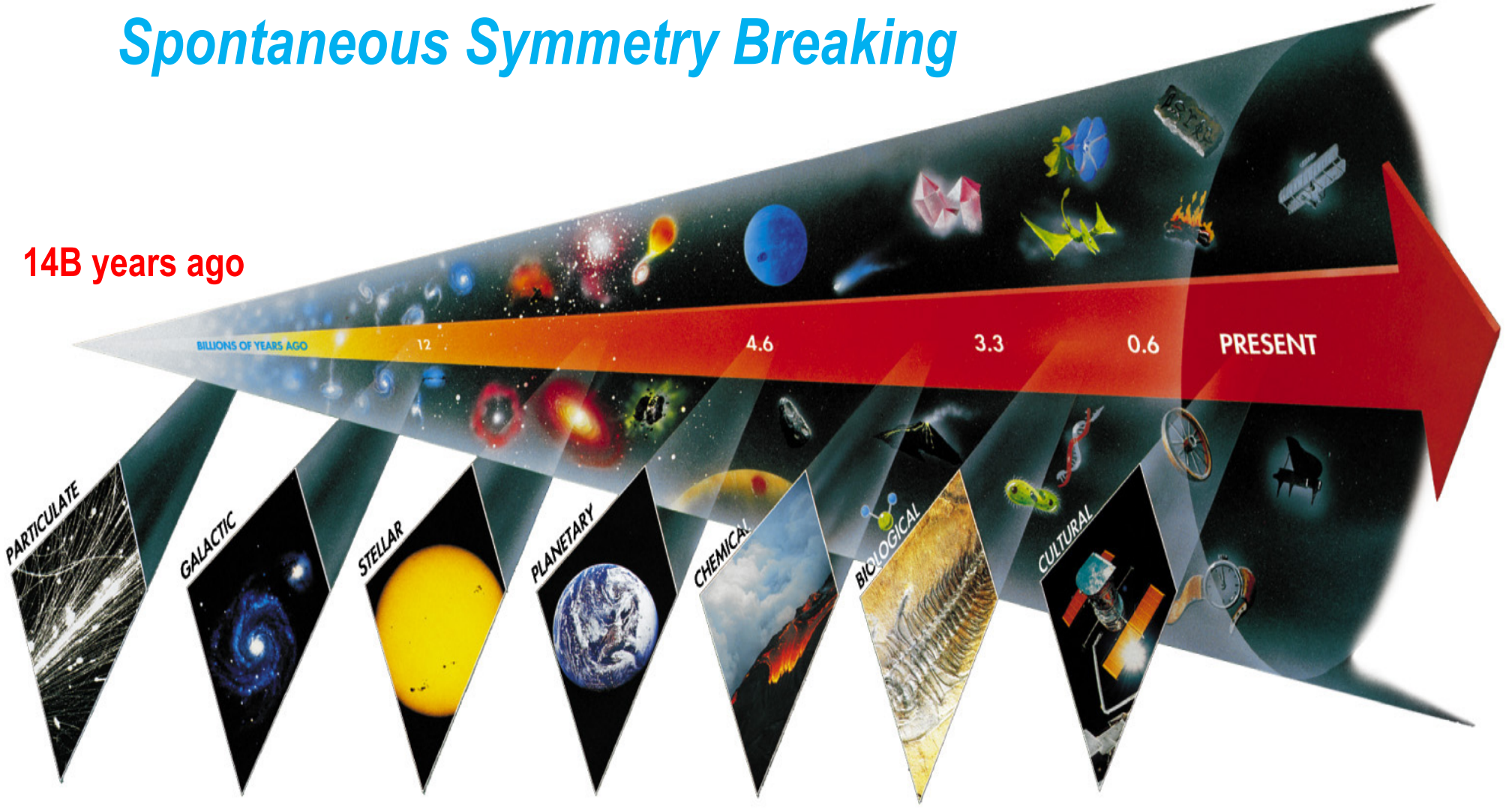


Complex



Seven steps of cosmic evolution

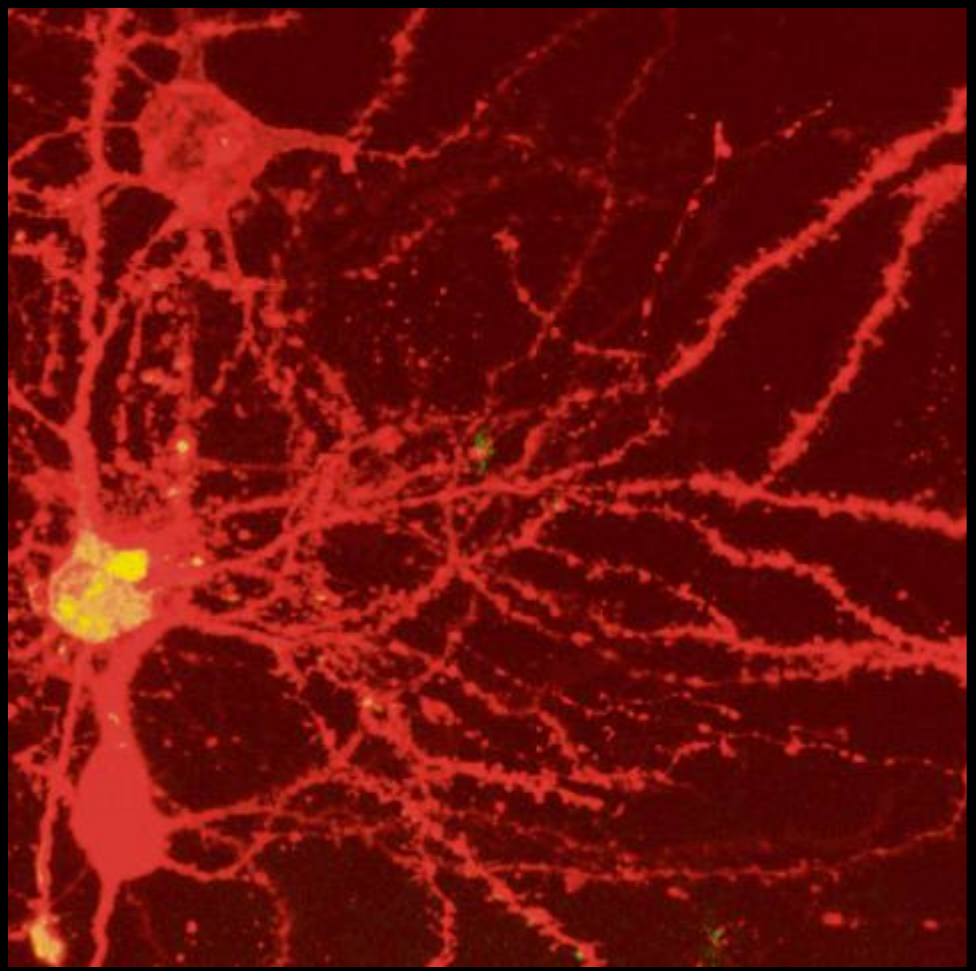
Spontaneous Symmetry Breaking



Accelerator ← **Telescope** → ← **Microscope** →

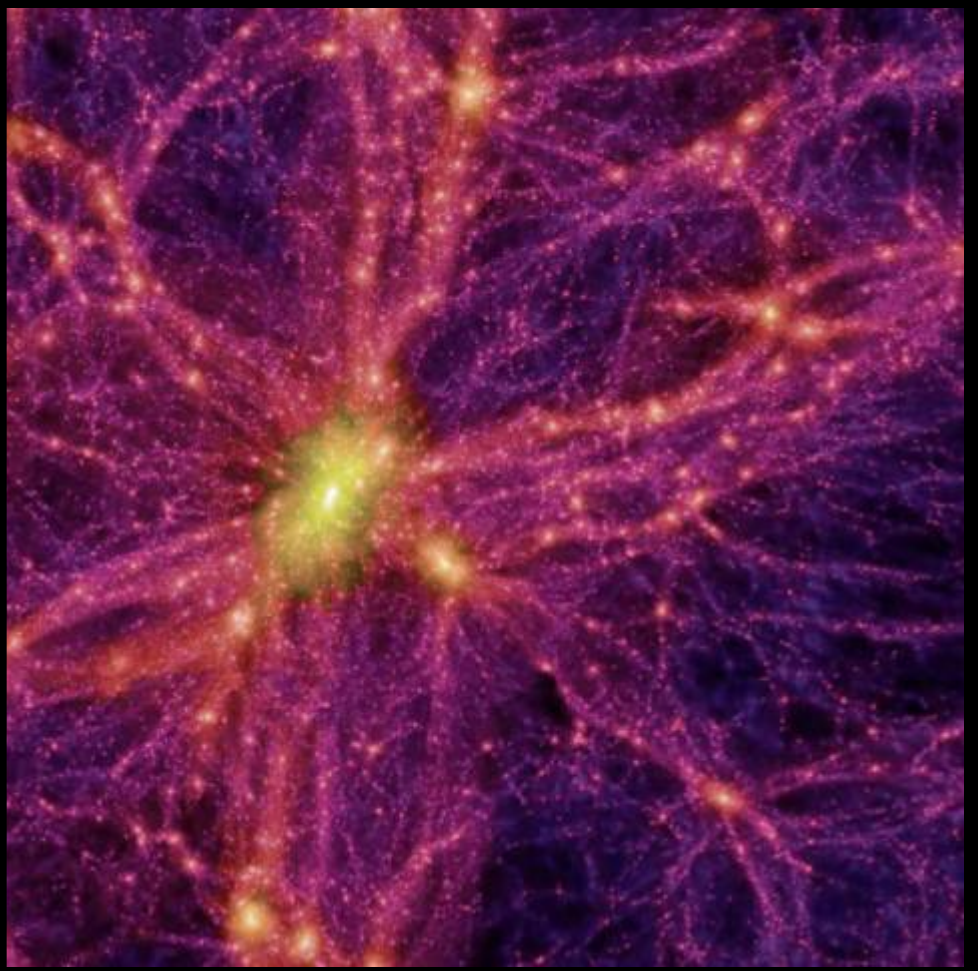
Origin of Consciousness

Brain



100 Billions Neurons

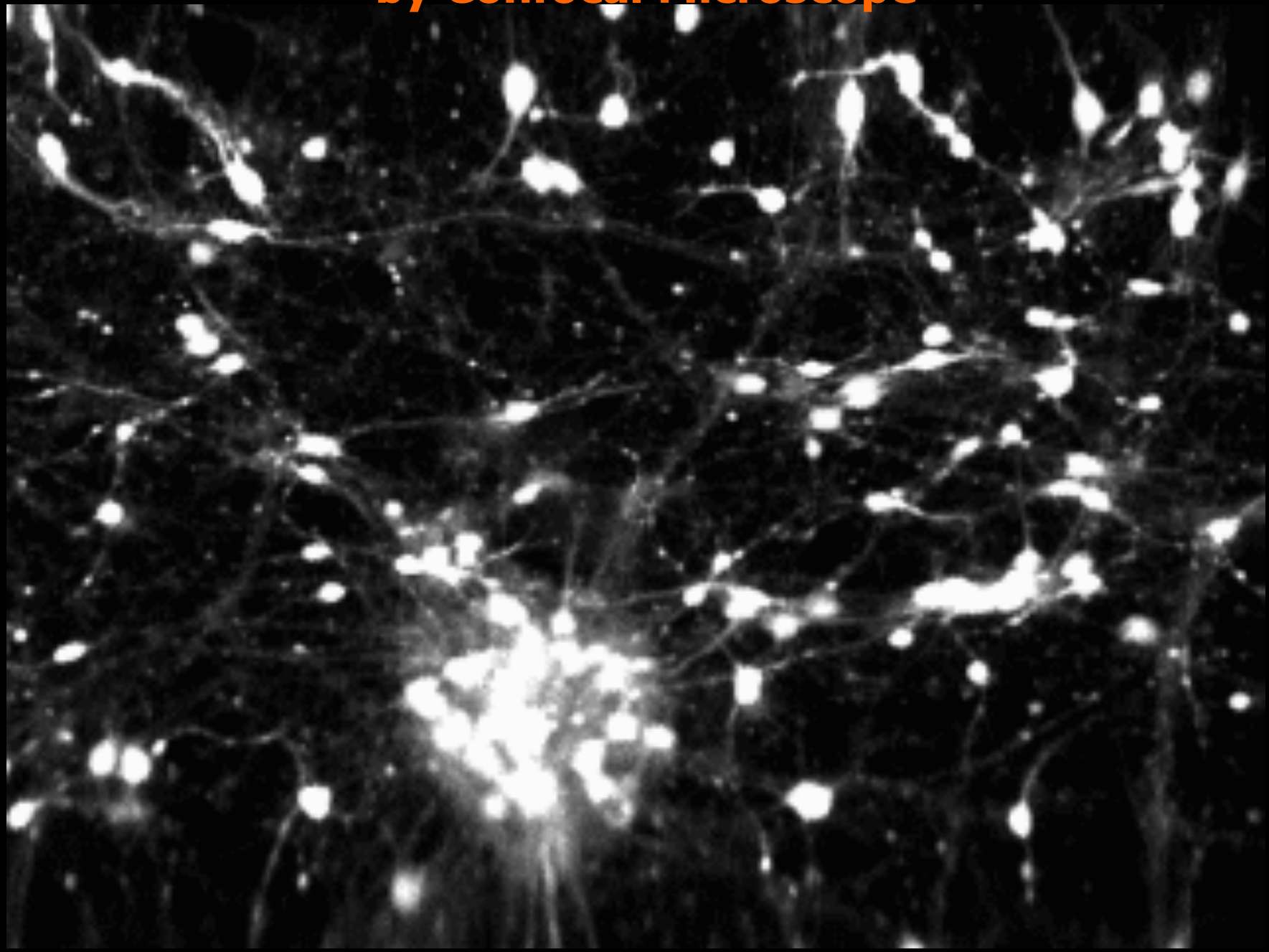
Universe



100 Billions Galaxies

New York Times 8/21/2006

Ca^{2+} Signal in cultivated Rat's Brain by Confocal Microscope

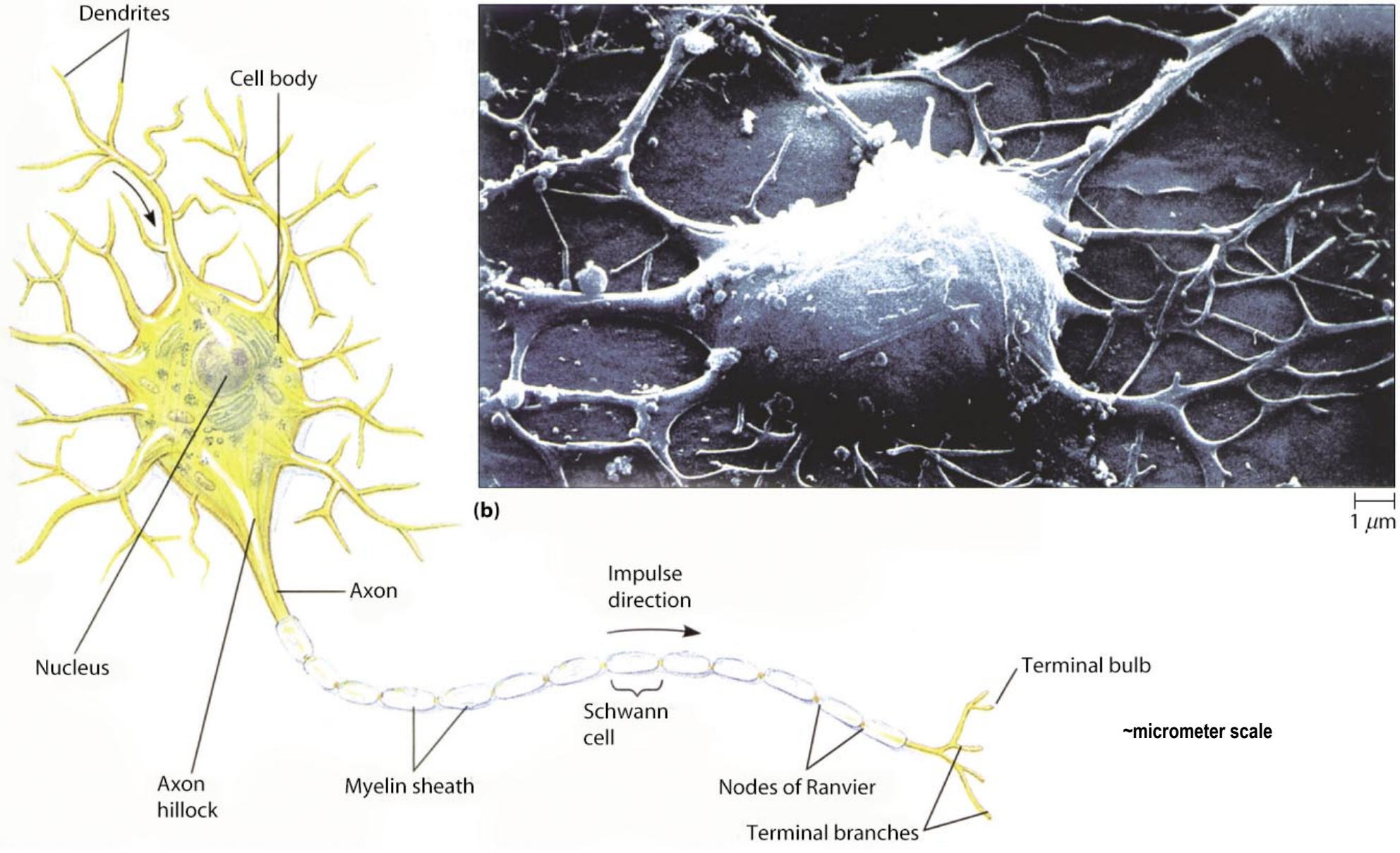


Andrew Charles (Neurobiology)

15 frame/sec

Neurons

Each Neuron has ~1,000 connections (10^{11} x 1000 = 10^{14})



IBM's Watson on 'Jeopardy': The machine has won

February 16, 2011 | 9:11 pm (42) (19) Comments (2)

The machine has won.

Watson defeated the two biggest "Jeopardy" winners of all time: Ken Jennings and Brad Rutter.

The IBM computer finished the final round of competition on Wednesday night with $77,147 in winnings over Jennings' $24,000 and Rutter's $21,600.

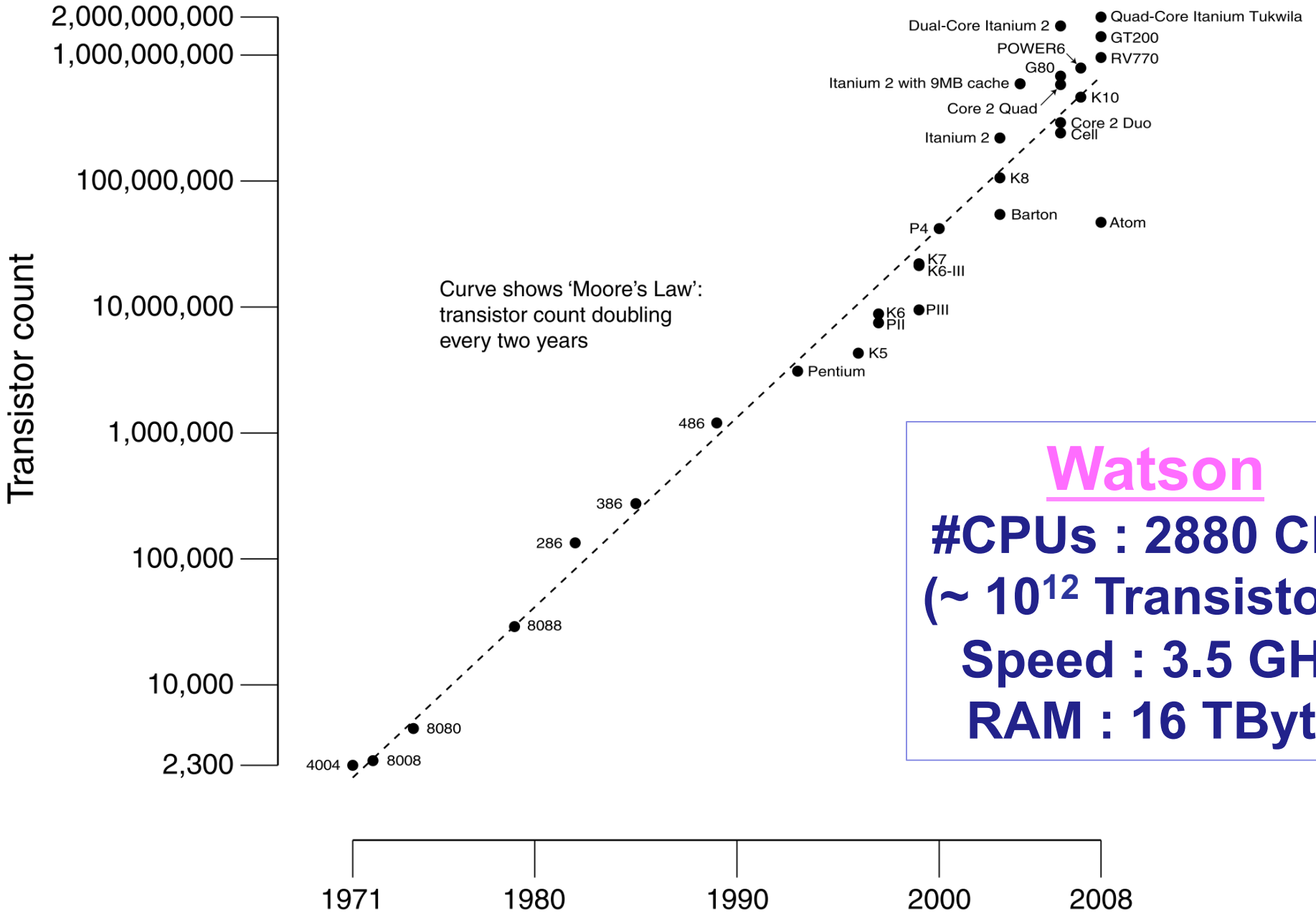
Jennings holds the record for number of consecutive Jeopardy matches won, with 74. Rutter has won more money than anyone else on Jeopardy.

The two men competed against each other in a 2005 tournament that resulted in a Rutter victory.

Since Watson won, IBM is awarded $1 million -- all of it going to charities World Vision (an anti-poverty group) and World Community Grid (which builds computer grids to address social issues such as water shortages).

"Moore's Law" Transistors in Computer

Watson



Watson

#CPUs : 2880 CPU

(~ 10^{12} Transistors)

Speed : 3.5 GHz

RAM : 16 TByte

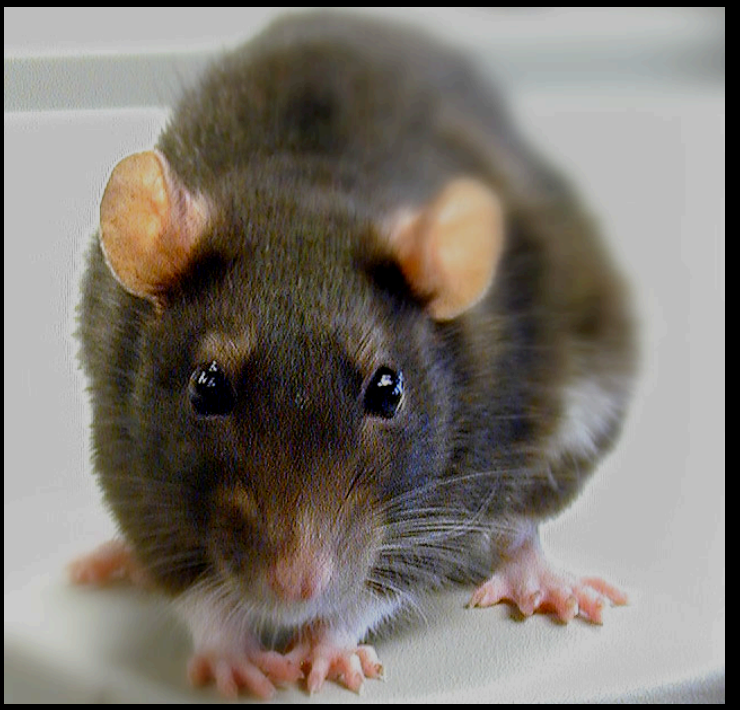
From No Brain to Big Brain

Paramecium (Single Cell)

Lymnaea (~1,000 neurons)

Zebrafish (~10,000 neurons)

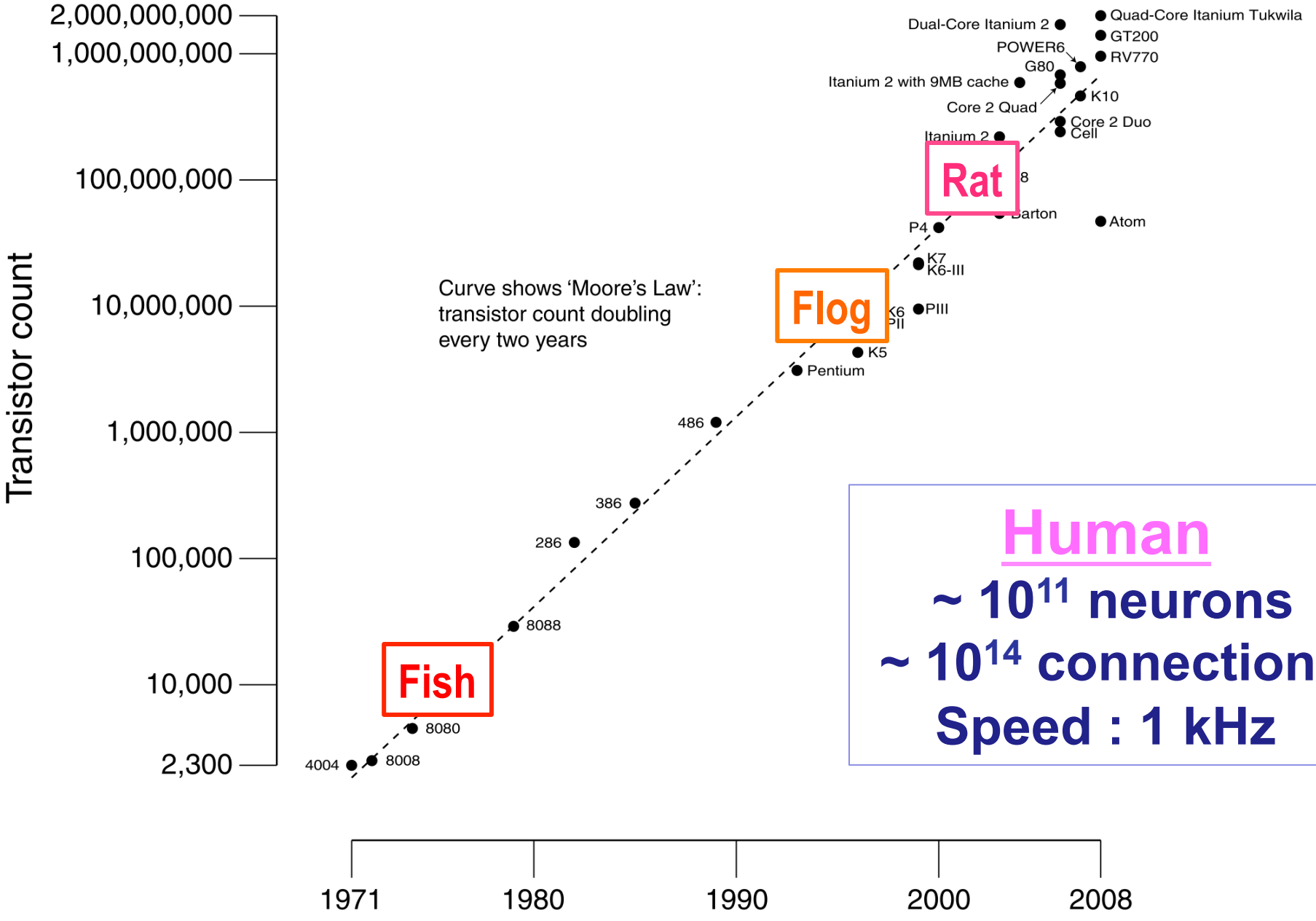
Bullfrog (~10^7 neurons)



Rat (~10^8 neurons)

Neurons in Brain

Human



Human

~ 10^{11} neurons

~ 10^{14} connections

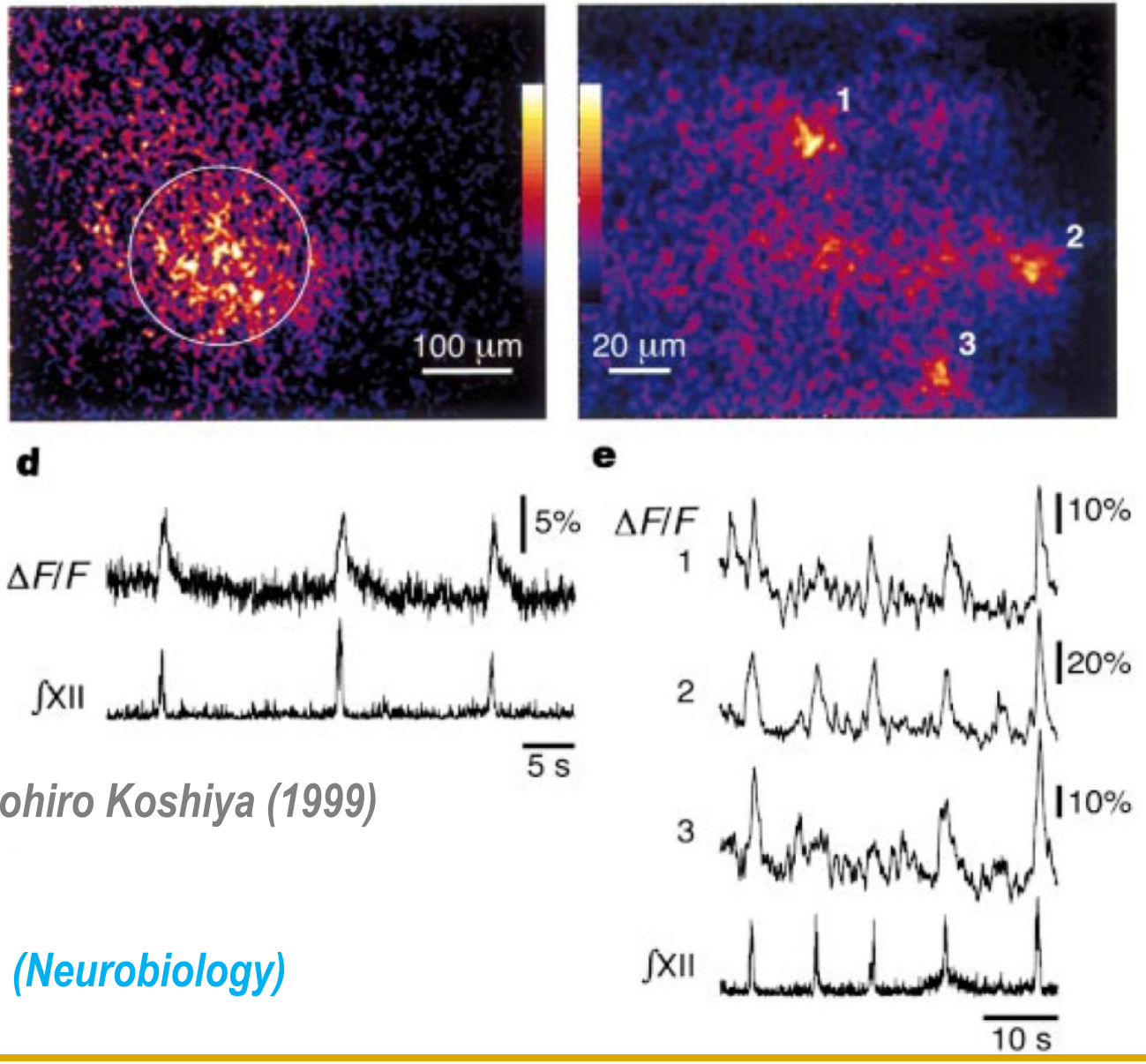
Speed : 1 kHz

Computer vs. Brain

	Computer (Watson)	Human Brain
Key Unit	Transistor	Neuron
No. of units	~ 10^9 (~10^{12})	~ 10^{11}
Connection	Copper Wire	Axon + Dendrite
No. of Connections	~ 10^{10} (~10^{13})	~ 10^{14}
Signal Carrier	Electrons	Ions (Na+, Ca+, K+)
Clock Speed	~ 1 GHz	~ 1 kHz
Method	Sequential	Parallel Processing

Neural Networks for Breathing

~300 neurons in rat's brain (pre-Botzinger Cells) responsible for breathing



Nature by Naohiro Koshiya (1999)

Jack Feldman (Neurobiology)

How to speed up microscopes

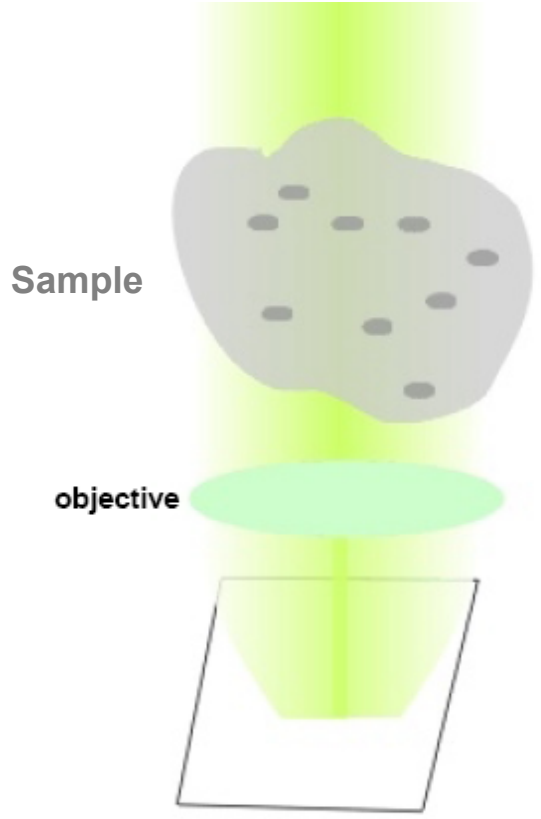
- All the existing microscopes are limited by the narrow bandwidth of readout.
  - Just one channel of FADC (Flash Analog to Digital Converter) running at 10 – 50 MHz
  - So-called Video Rate (30 frame/sec)

- The first step is to adopt multiple channels of FADC for massive parallel processing.
  - Like high energy experiments (such as LHC)

- In addition, we need Single Photon Sensitivity with high Quantum Efficiency.

Principle of High-speed Bio Imaging

Wide Field

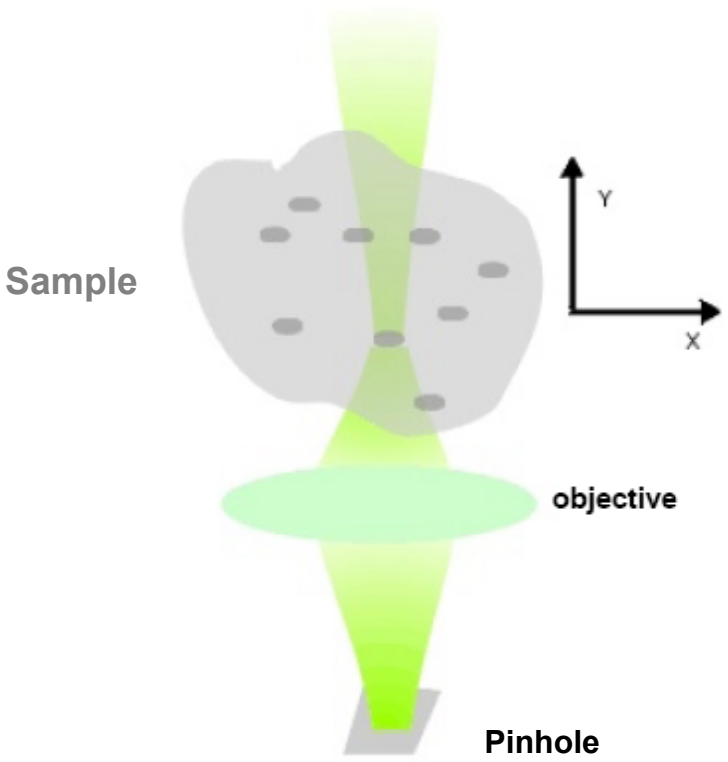


CCD + FADC (10 – 50 MHz)

⇩

CMOS [FADC (50 MHz) * 100]

Confocal



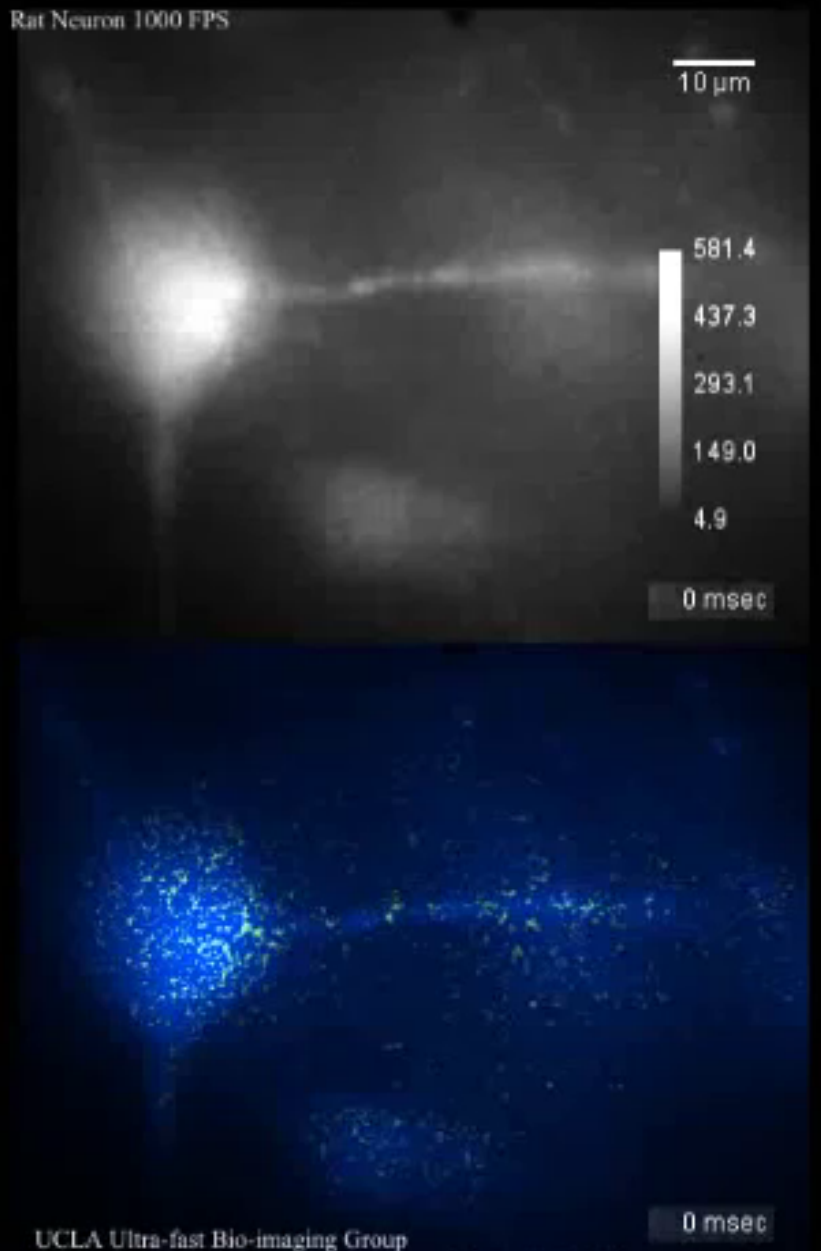
PMT + FADC (10 – 50 MHz)

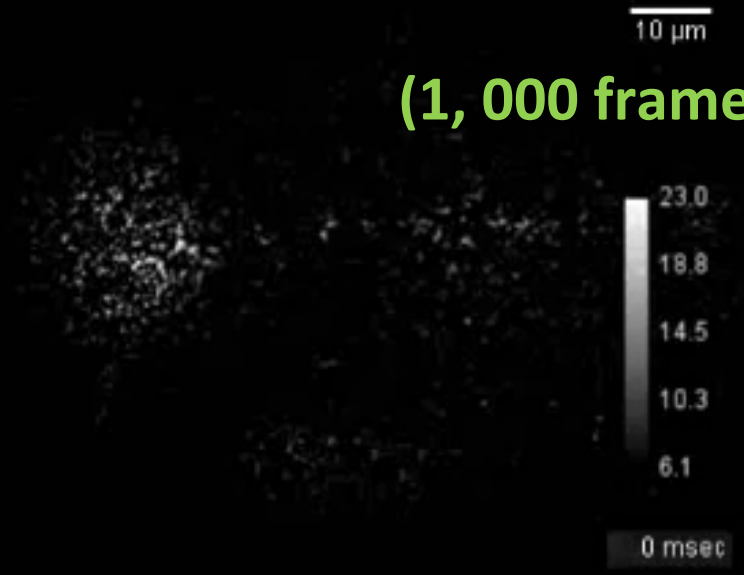
⇩

[HAPD + FADC (1 GHz)] * 64

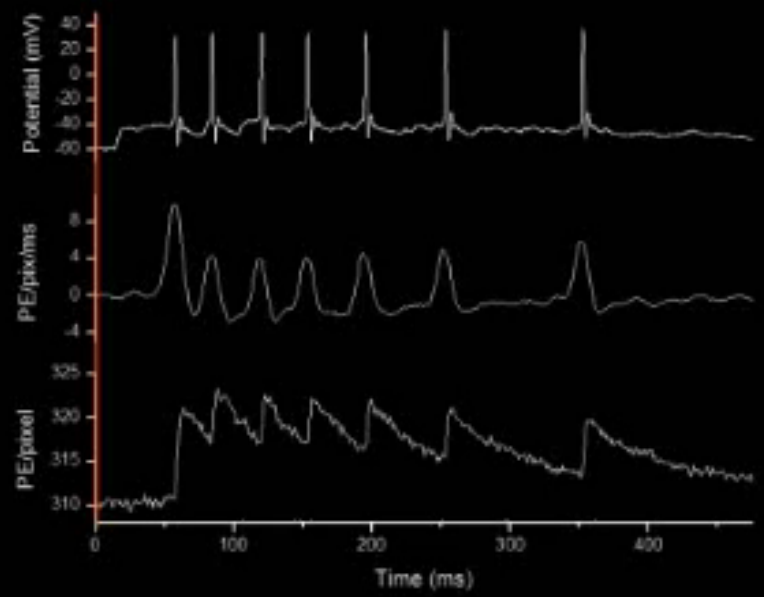
High-speed Ca^{2+} Imaging of pre-Botzinger Cells of Rats

Prof. Jack Feldman (Neurobiology)

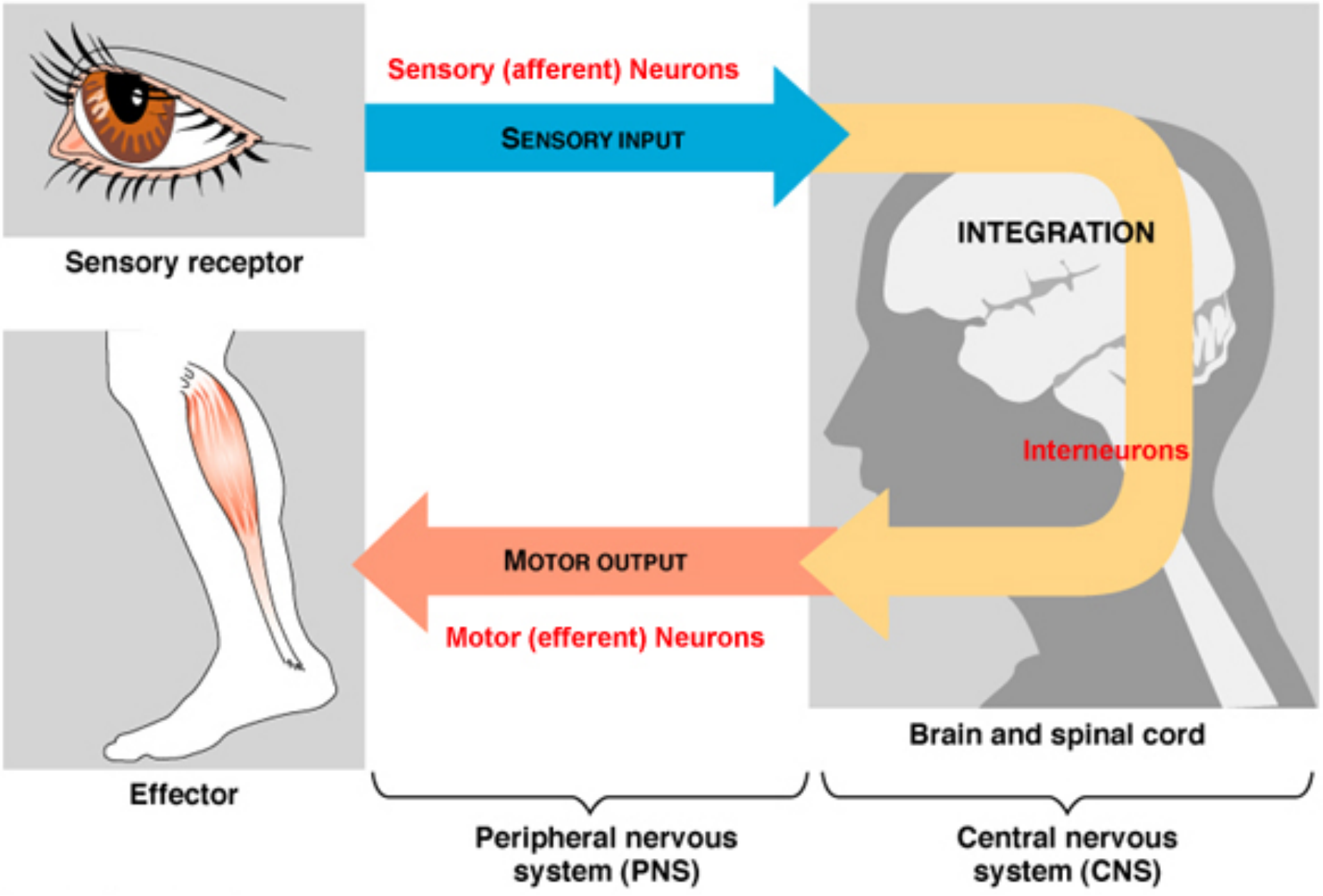




(1, 000 frame/sec)

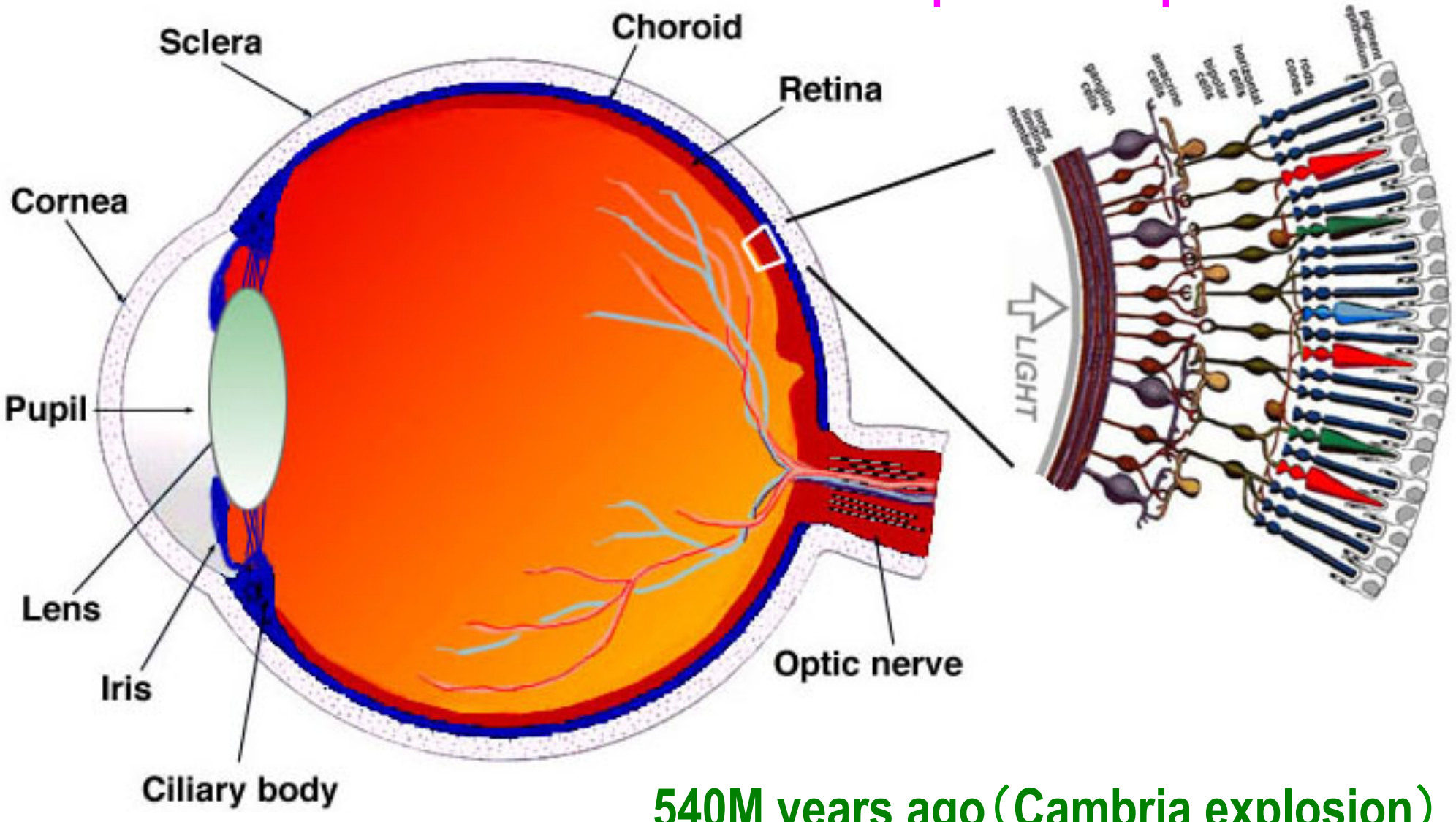


Sensory Input and Decision Making in Brain



Human Eyes

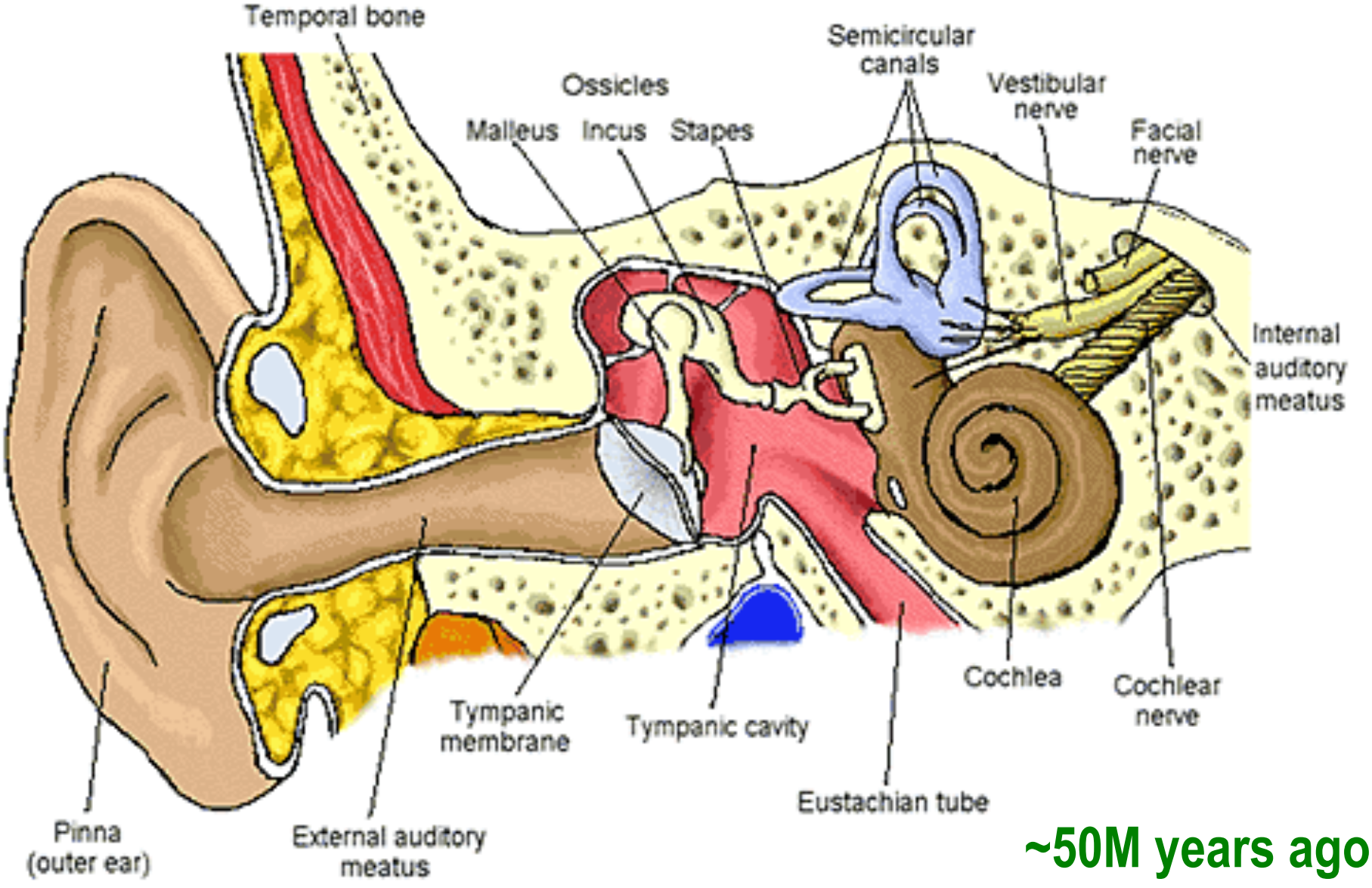
~100M photo receptors



540M years ago（Cambria explosion）

Human Ears

~10,000 Hair Cells

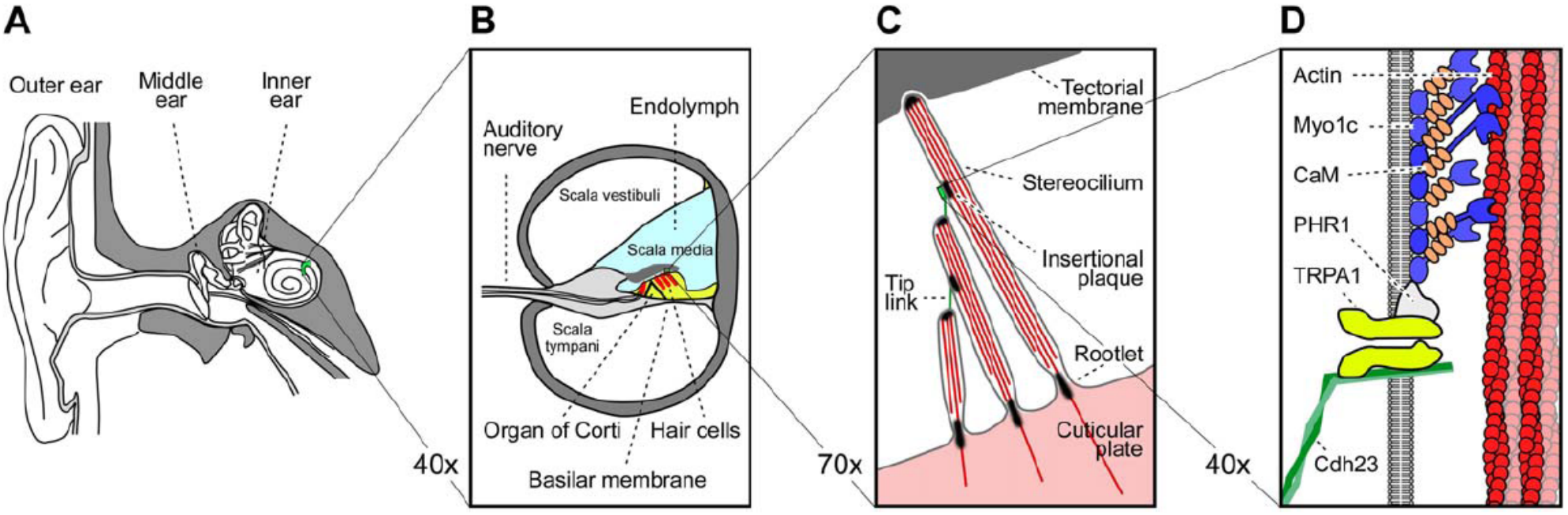


~50M years ago

Anatomy of Inner Ear

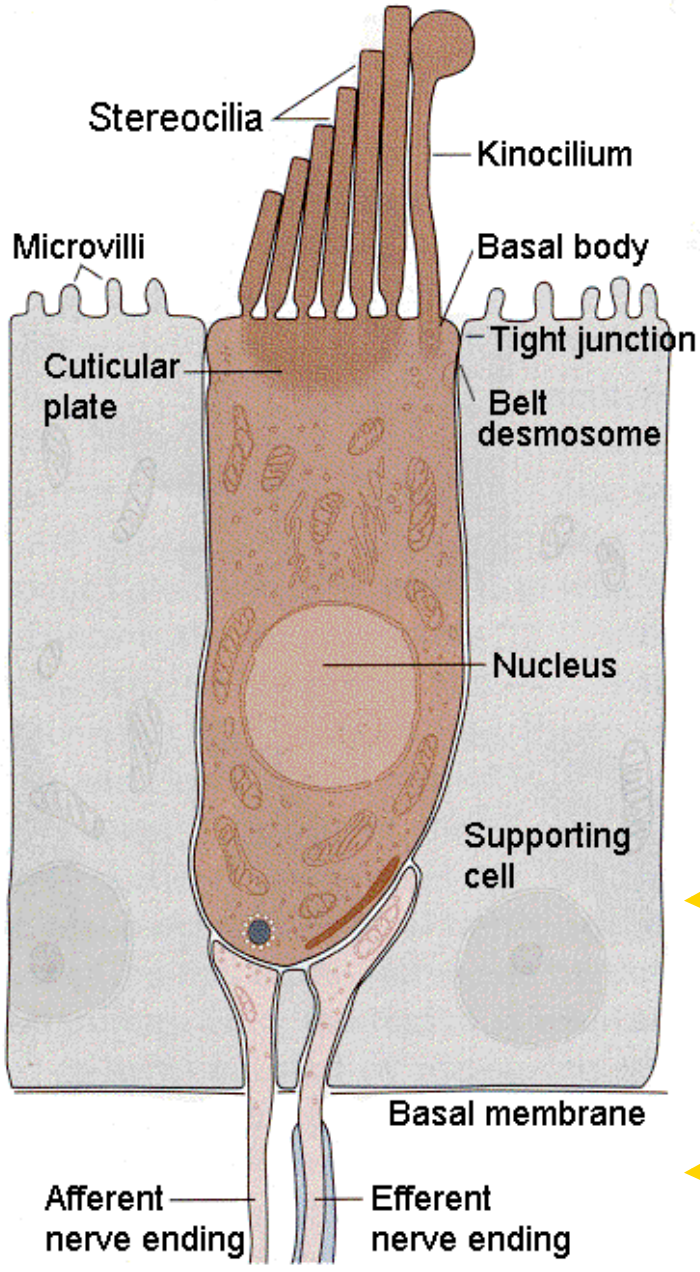
Dolores Bozovic (Physics)

Human auditory system | **Cross-section of the cochlear** | **Hair bundle** | **Molecular mechano-transduction machinery**



Meredith LeMasurier and Peter G. Gillespie, Neuron, Vol. 48,2005

Simultaneous observation of entire process



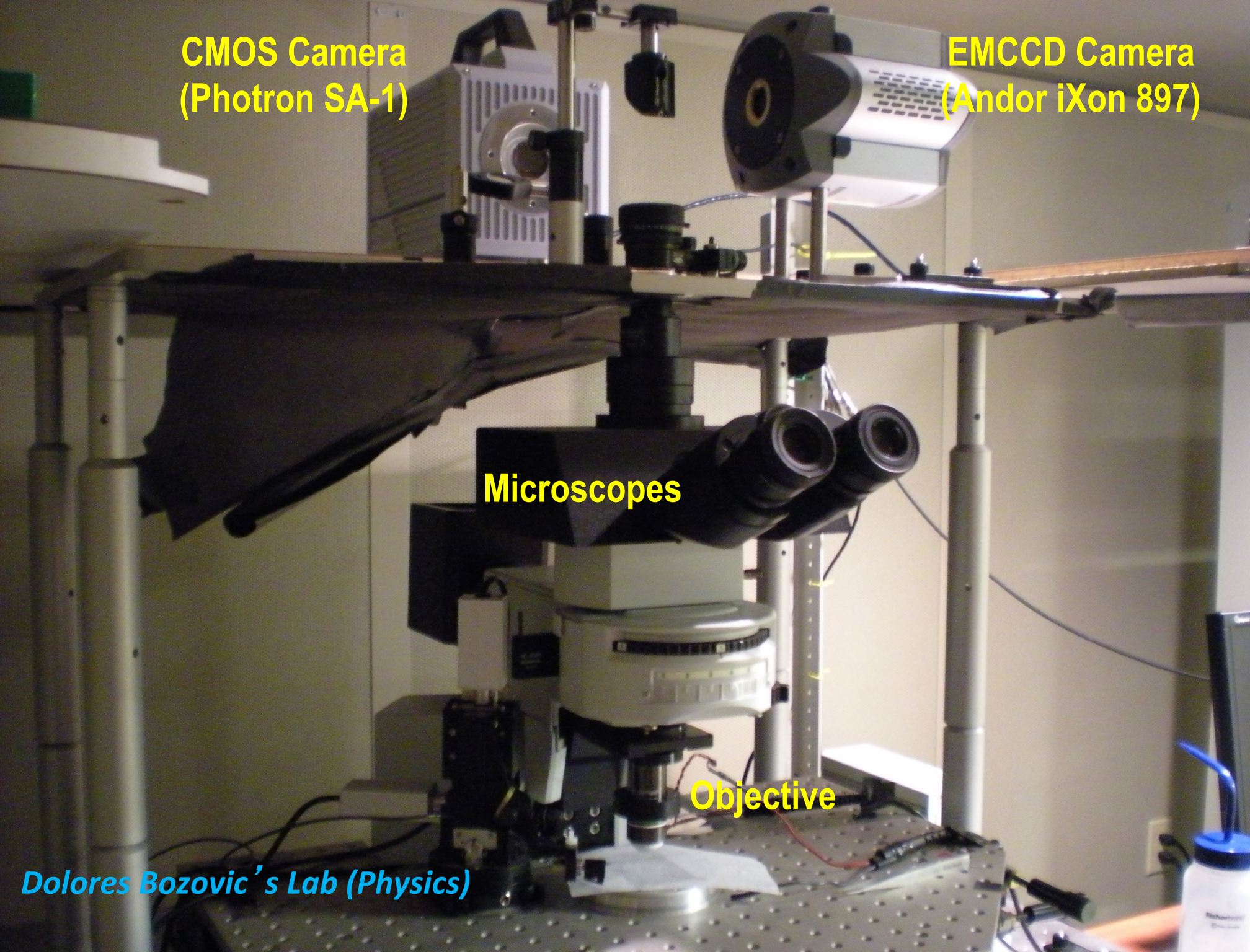
Mechanical Motion

Ca^{2+} Intake

Action Potential Propagation in Hair Cell

Receptor in Synapse

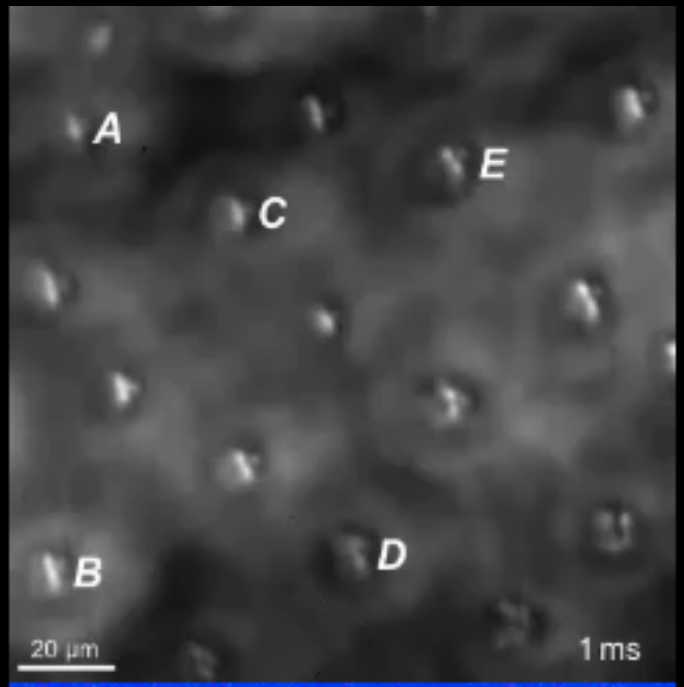
Action Potential Propagation Into Dendrite

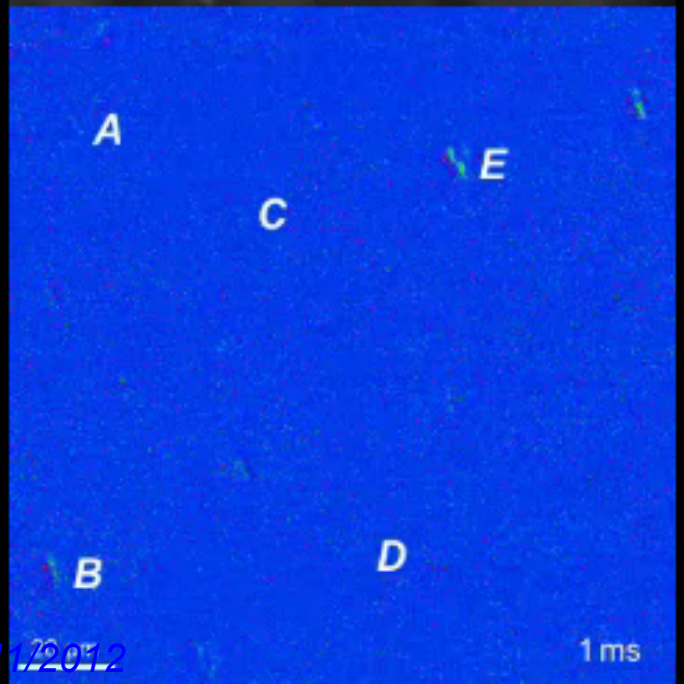

CMOS Camera
(Photron SA-1)
EMCCD Camera
(Andor iXon 897)
Microscopes
Objective
Dolores Bozovic's Lab (Physics)

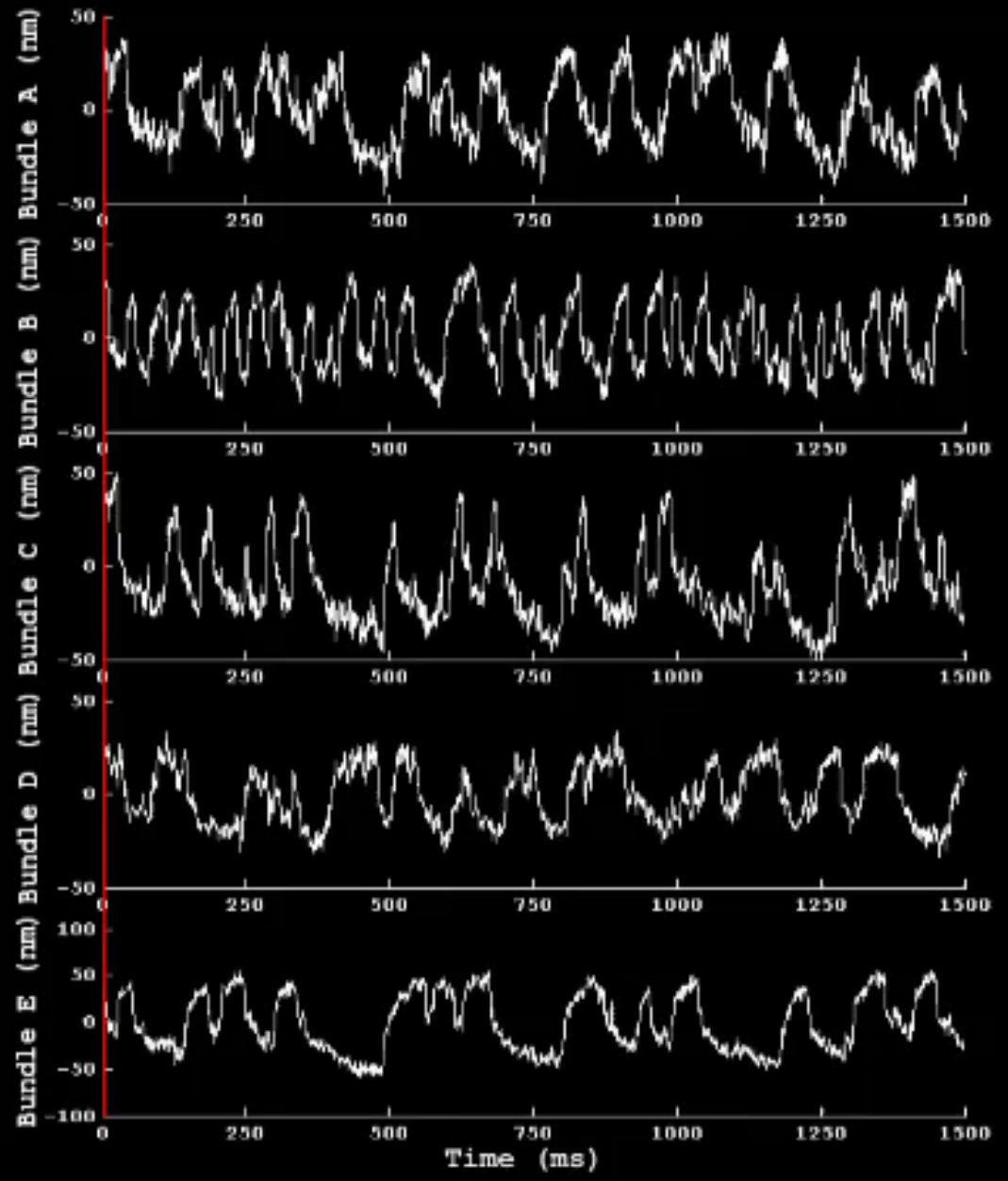
Mechanical Motion of Hair Cells in Inner Ear

Prof. Dolores Bozovic (Physics)

(1, 000 frame/sec)







UCLA Fast Bio-Imaging Group

L. Fredrickson, A. Cheung, K. Jawhurst, C. E. Strimbu, D. Bozovic, K. Arisaka

Mystery of Hearing

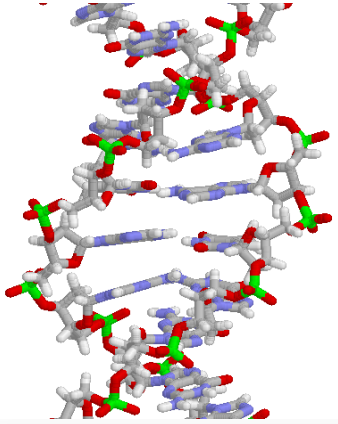
- **Extremely wide dynamic range in amplitude.**
  - 10^6 compressed to 100
  - Smallest amplitude is 0.3 nm
- **Extremely wide frequency range.**
  - 20 Hz – 20 kHz
    - Dynamic range of 1000
    - Corresponding to 10^6 in k
  - Selectivity of 0.2%
    - up to 5 kHz
  - How can the brain handle up to 20 kHz?
    - miss match to the speed of action potential of 1 kHz

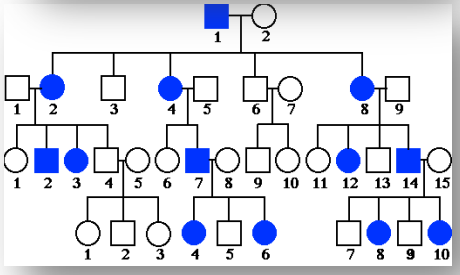
$$\omega = \sqrt{\frac{k}{m}}$$

How can I recognize a woman so far away?

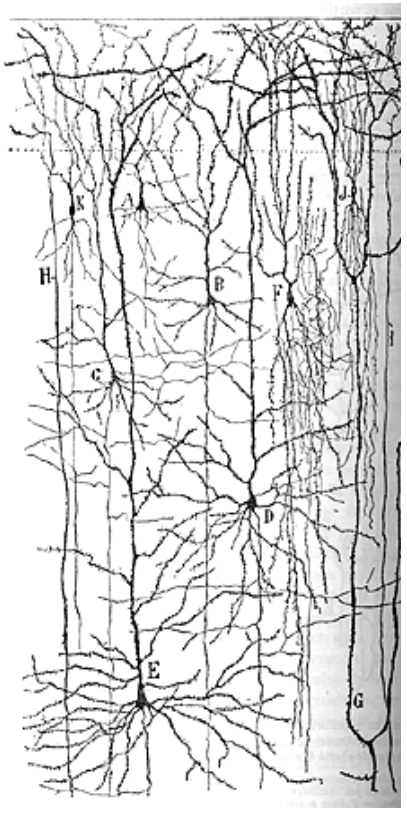
- Genetically encoded?
- Learning and memory?

Nature vs. Nurture

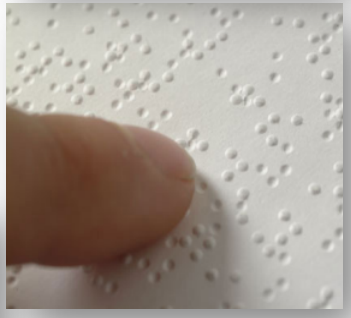


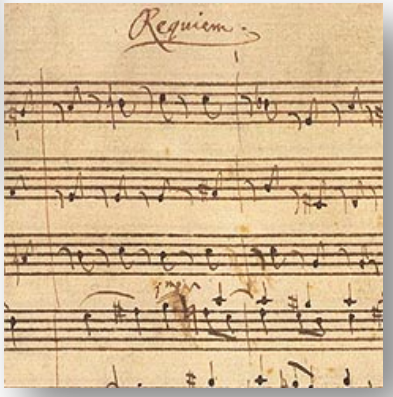


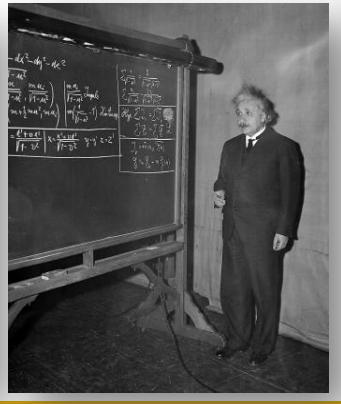
Nature



Nurture

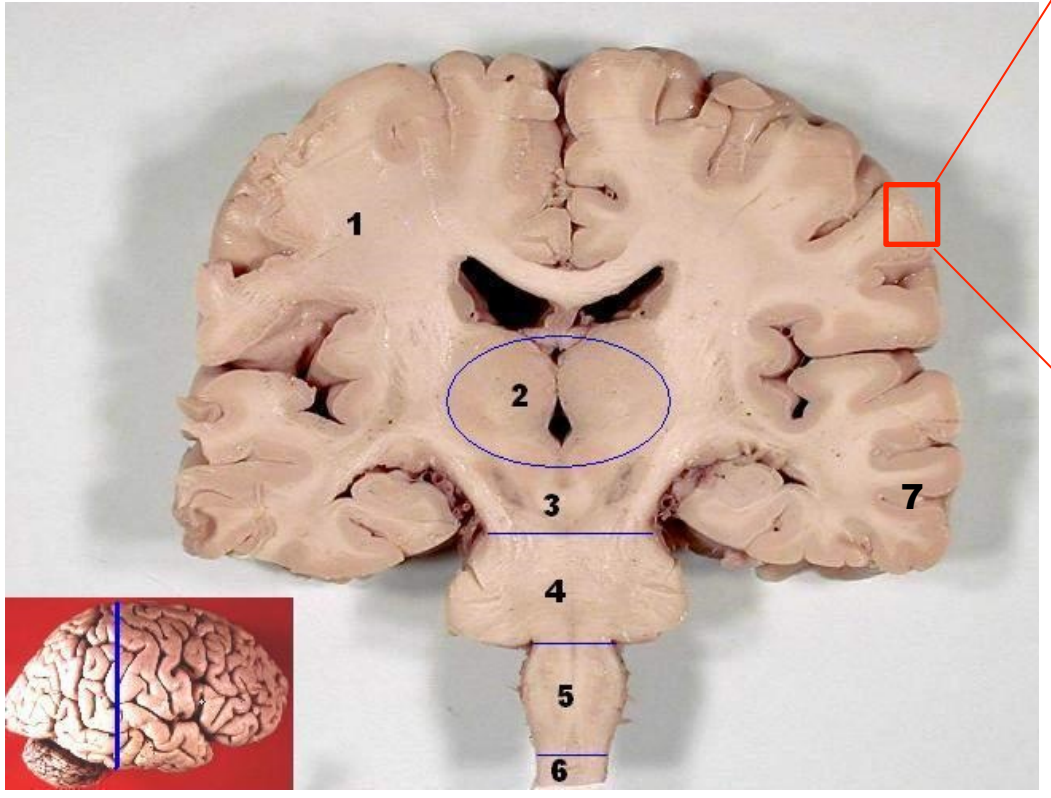




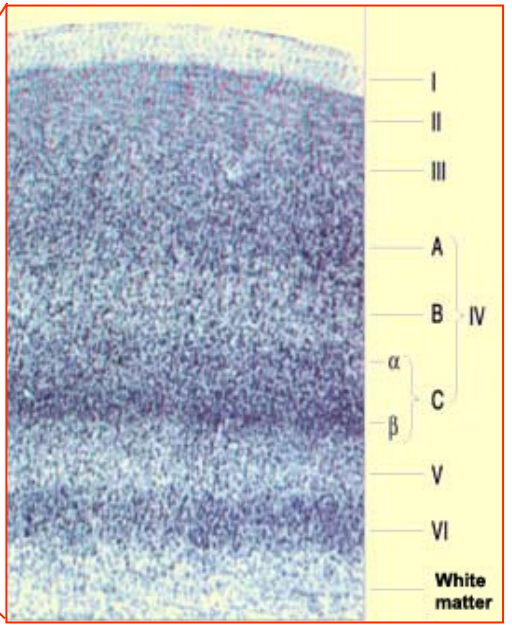


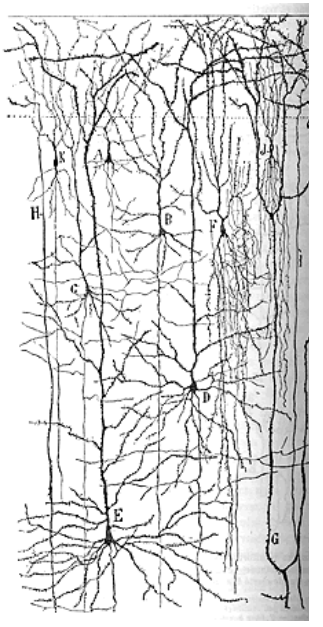
The Cerebral Cortex

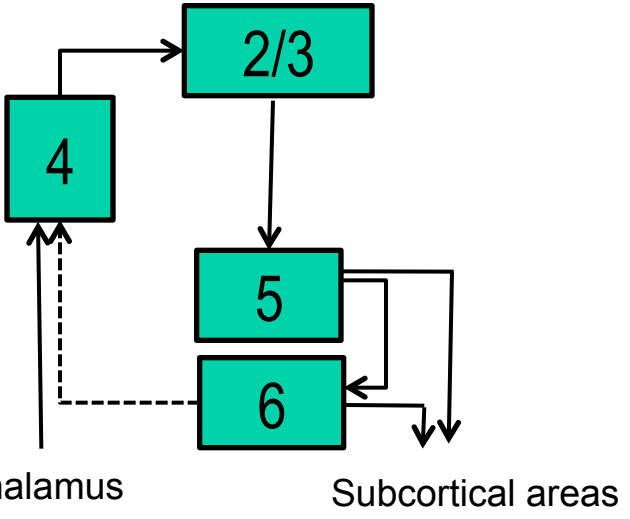
Conscious



Unconscious

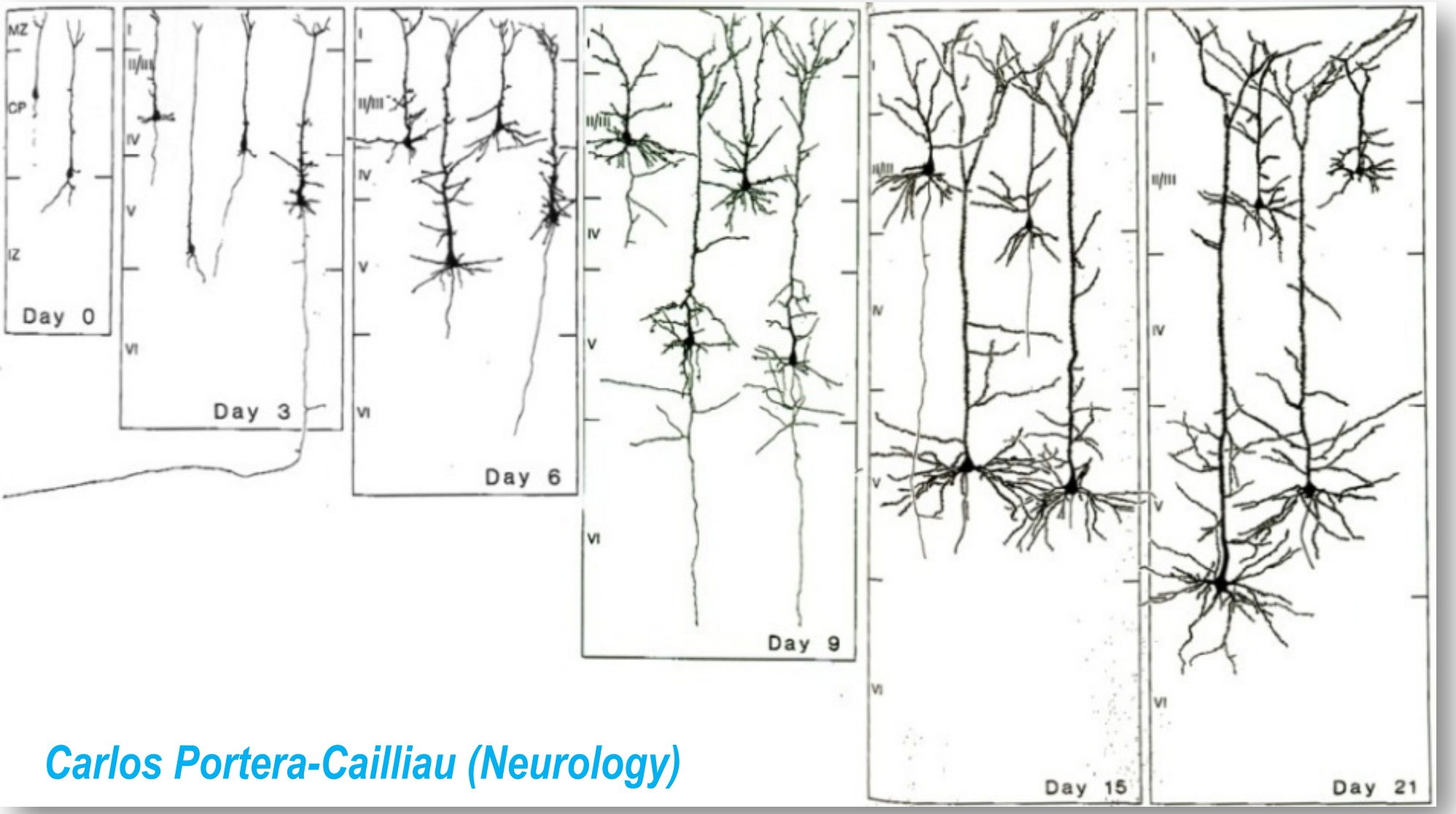






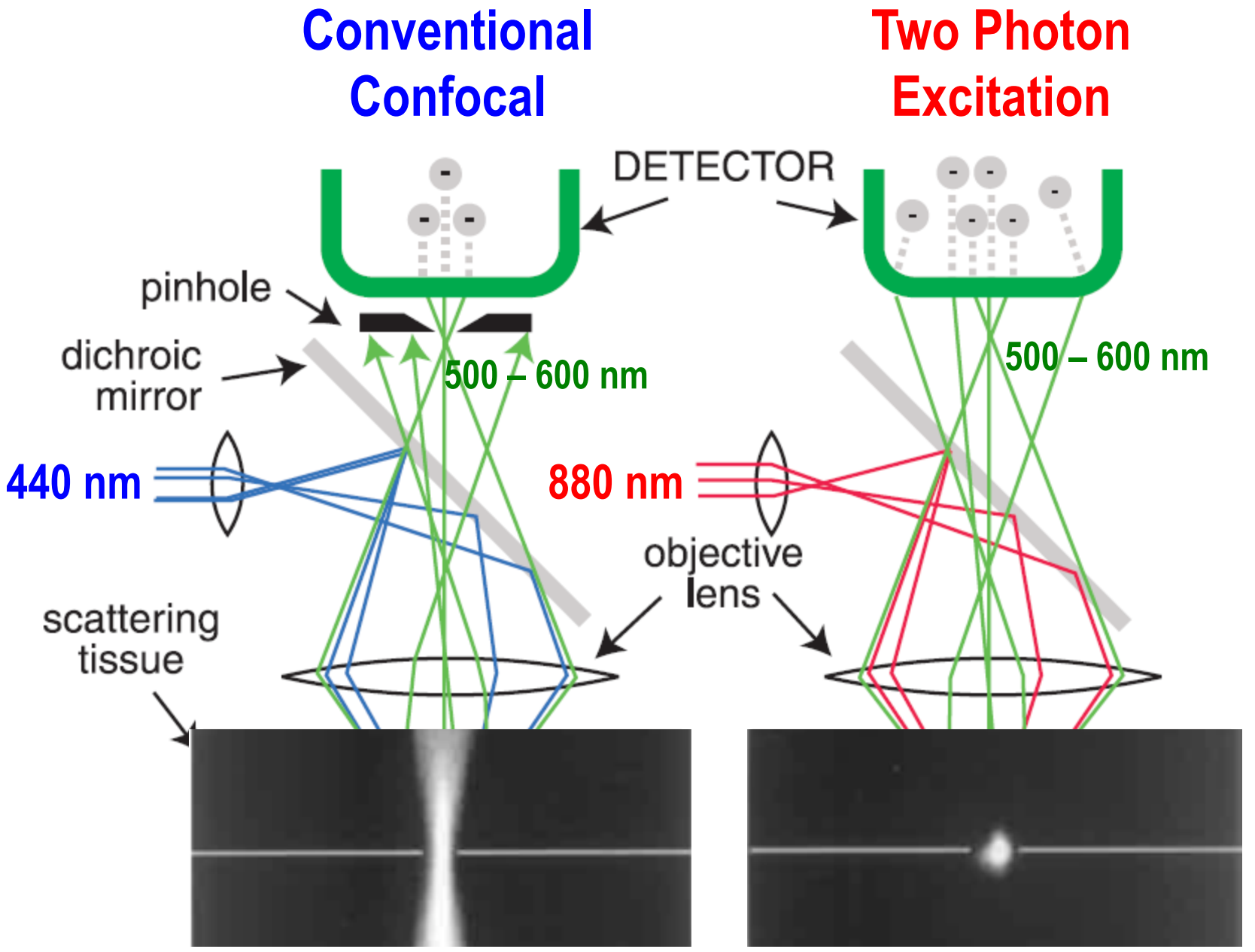
Assembly of rat's cortical circuits during development

How/when do neurons establish networks? → *Symmetry Breaking*



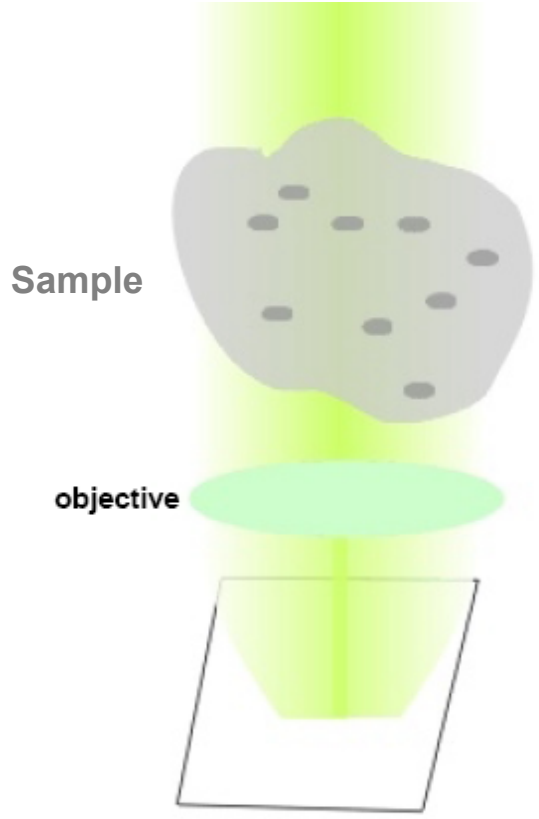
Carlos Portera-Cailliau (Neurology)

Mutiphoton Microscope



Principle of High-speed Bio Imaging

Wide Field

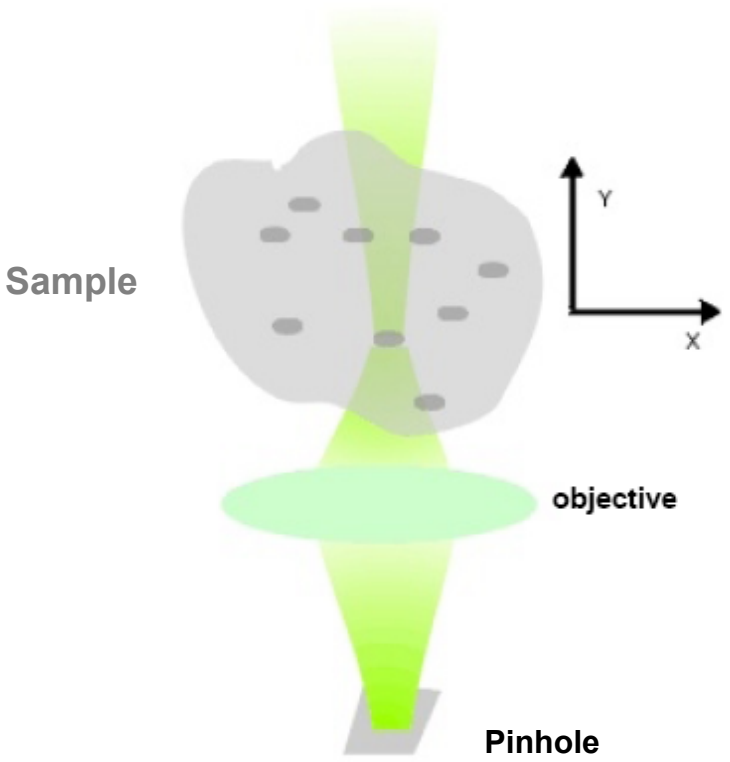


CCD + FADC (10 – 50 MHz)

⇩

CMOS [FADC (50 MHz) * 100]

Confocal

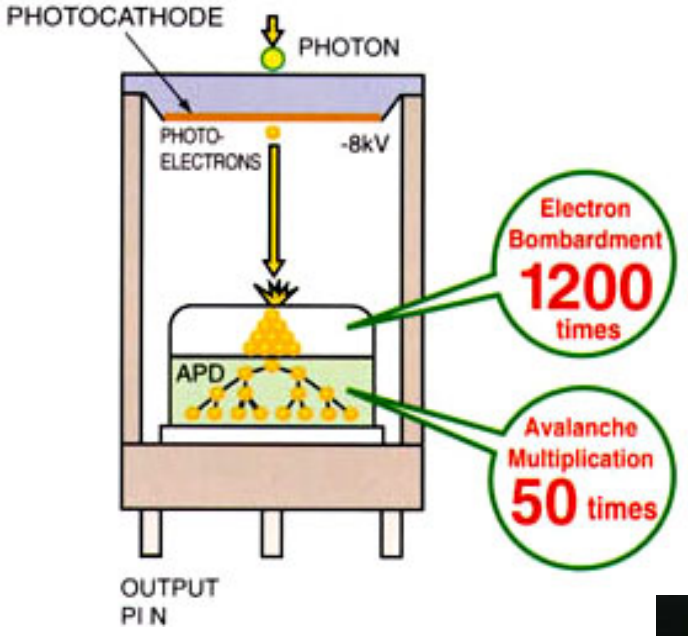


PMT + FADC (10 – 50 MHz)

⇩

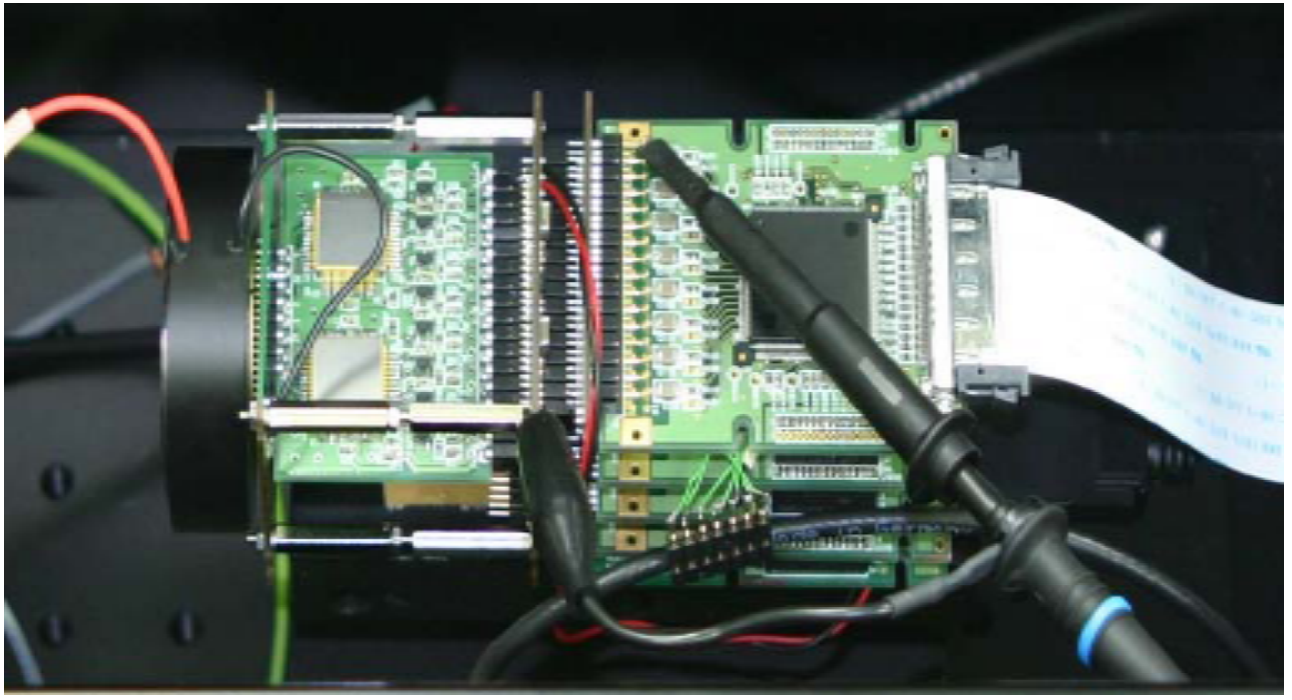
[HAPD + FADC (1 GHz)] * 64

Hamamatsu Hybrid APD



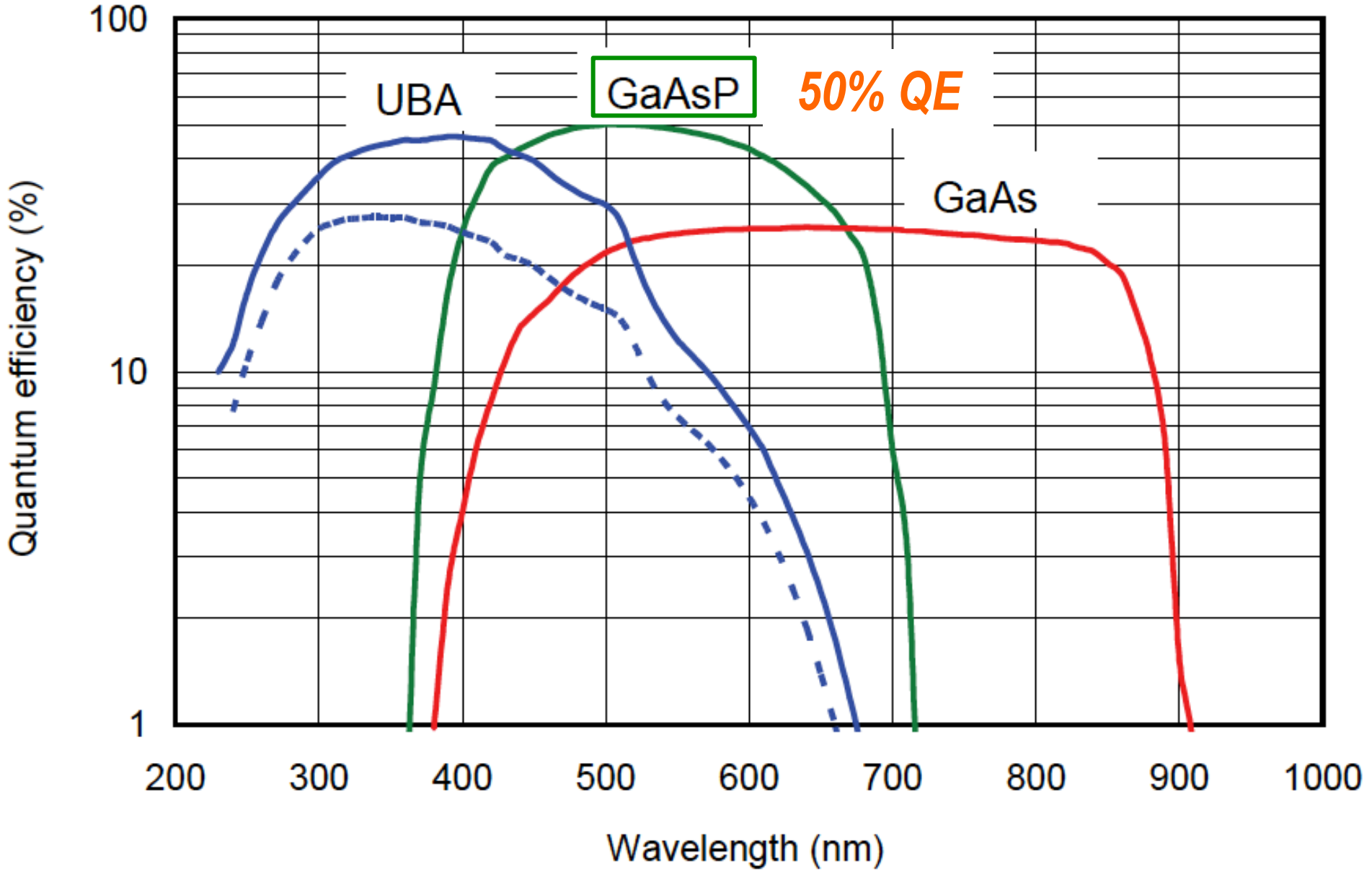
Single Channel HAPD

64 Channel HAPD + Readout

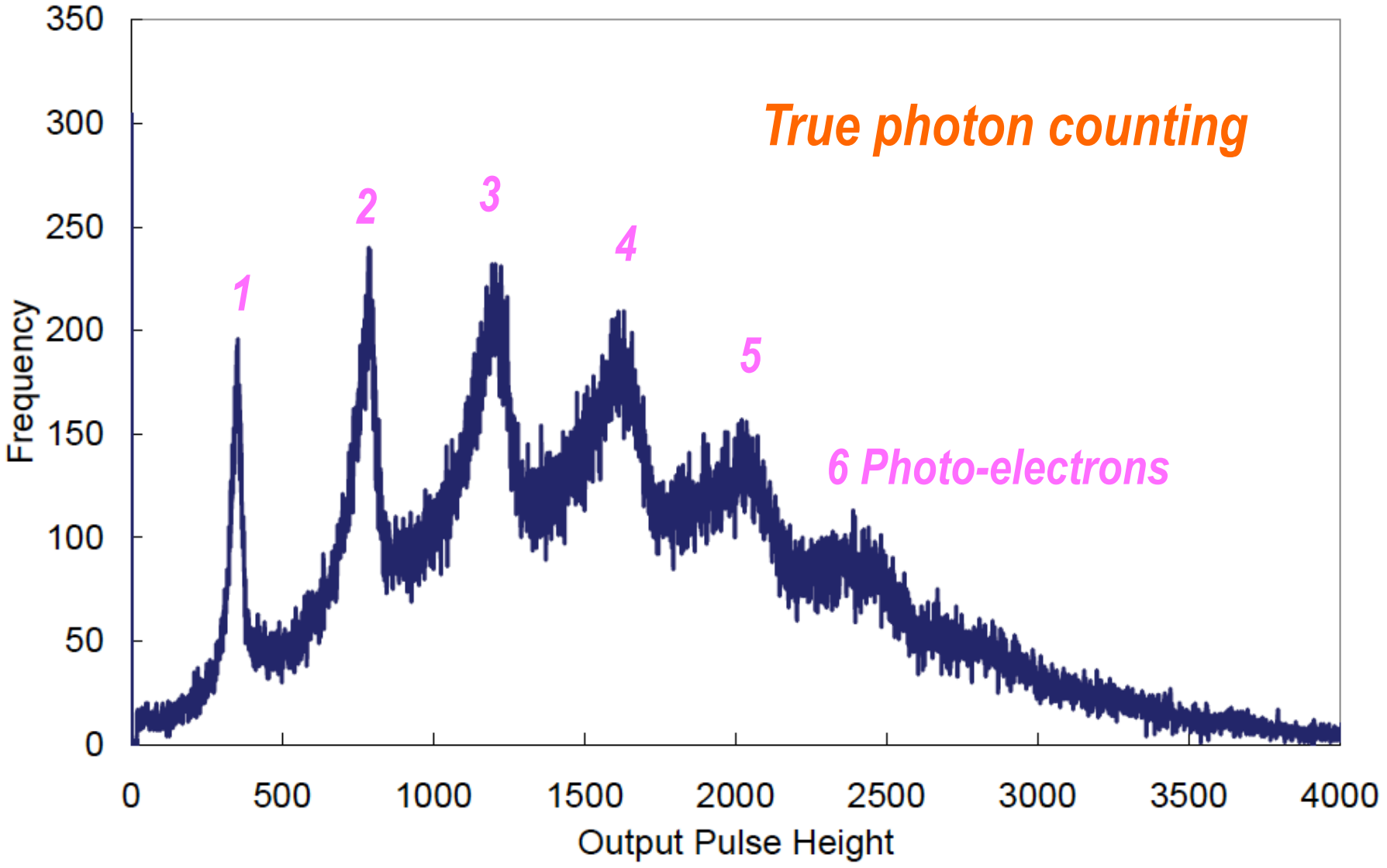


Motohiro Suyama (Hamamatsu)
Xavier Michalet
Shimon Weiss (Chemistry)

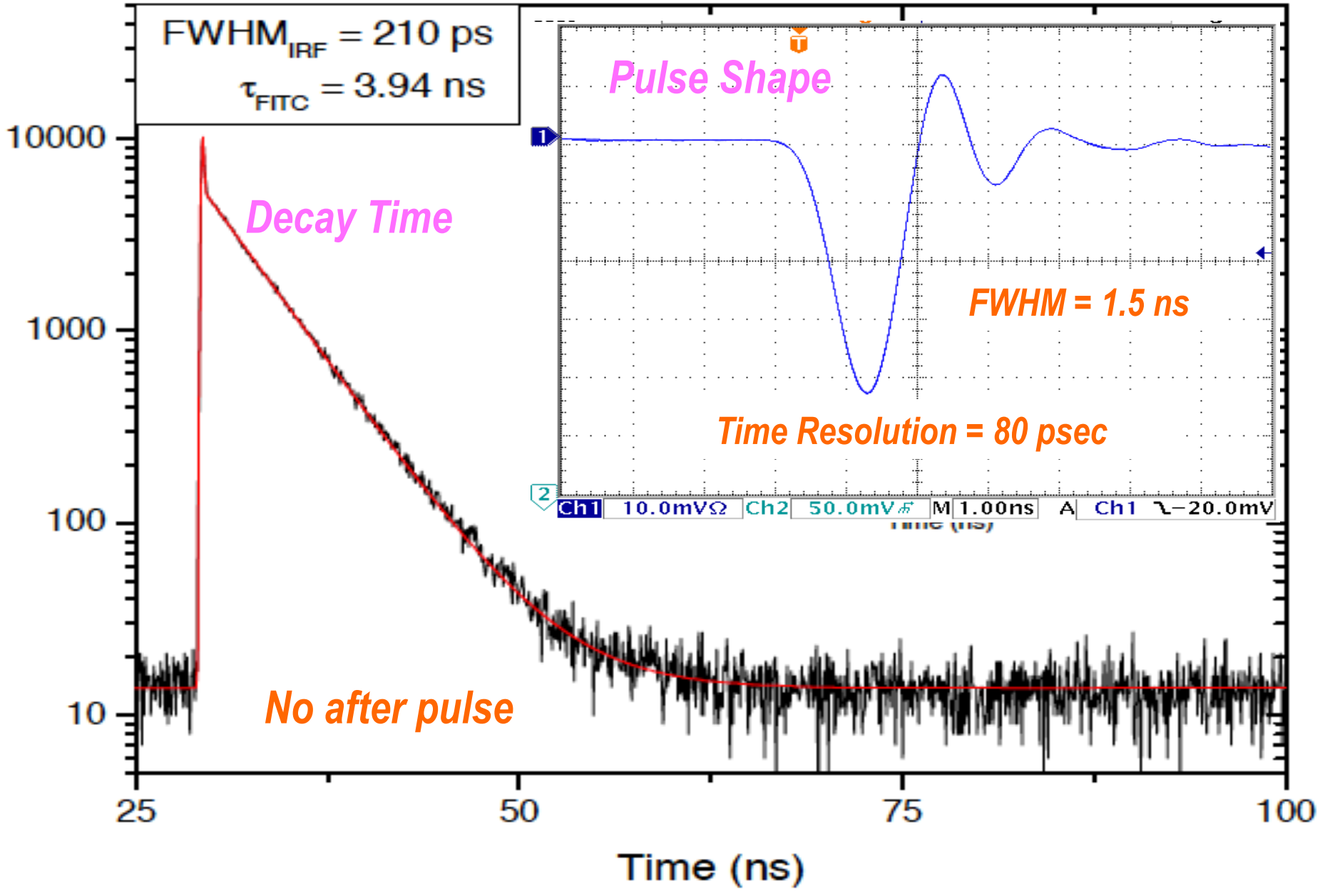
Quantum Efficiency of UBA, GaAsP and GaAs



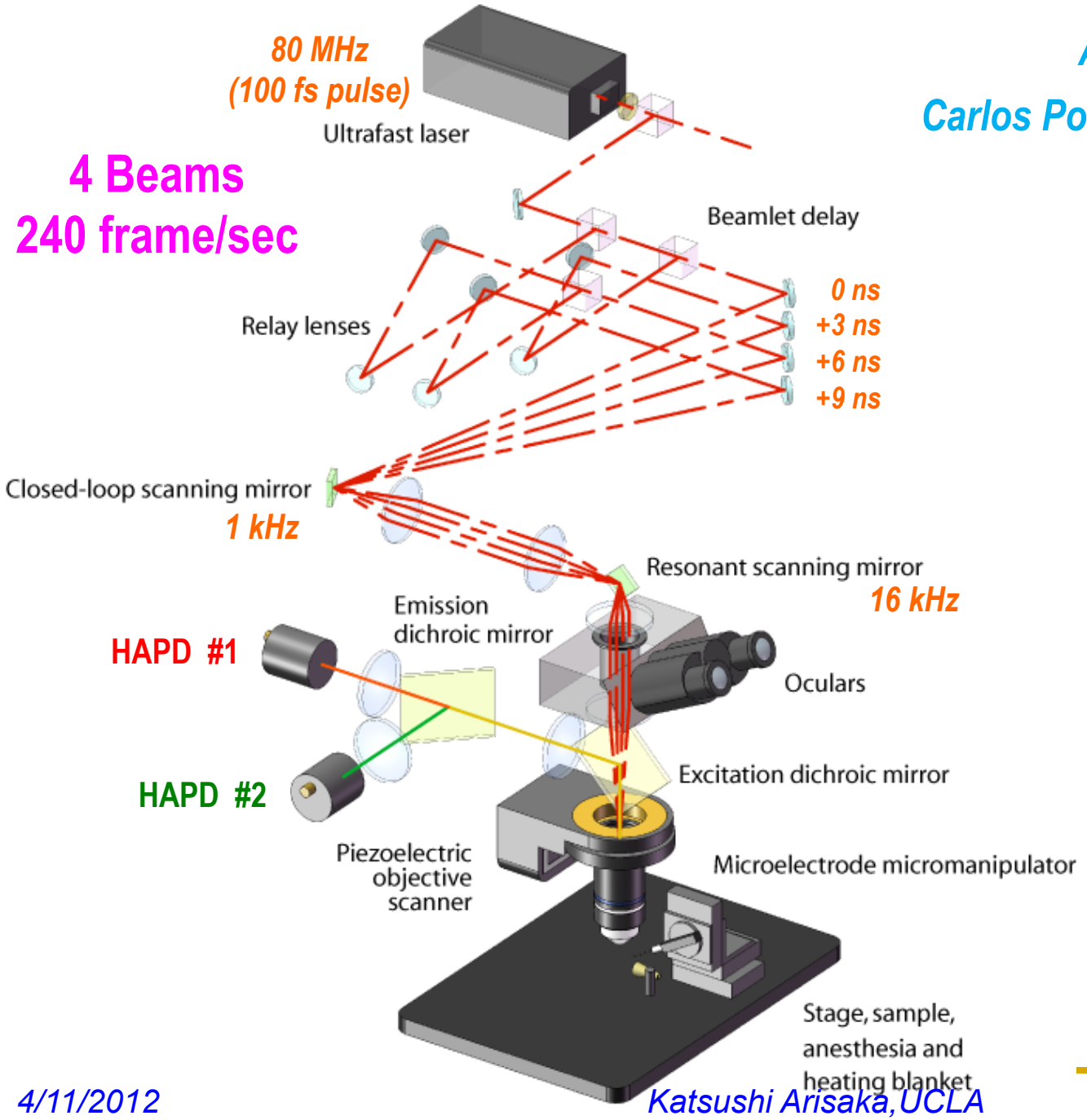
1, 2, 3 … Photo-electron Distribution



Decay Time Measurement by HAPD

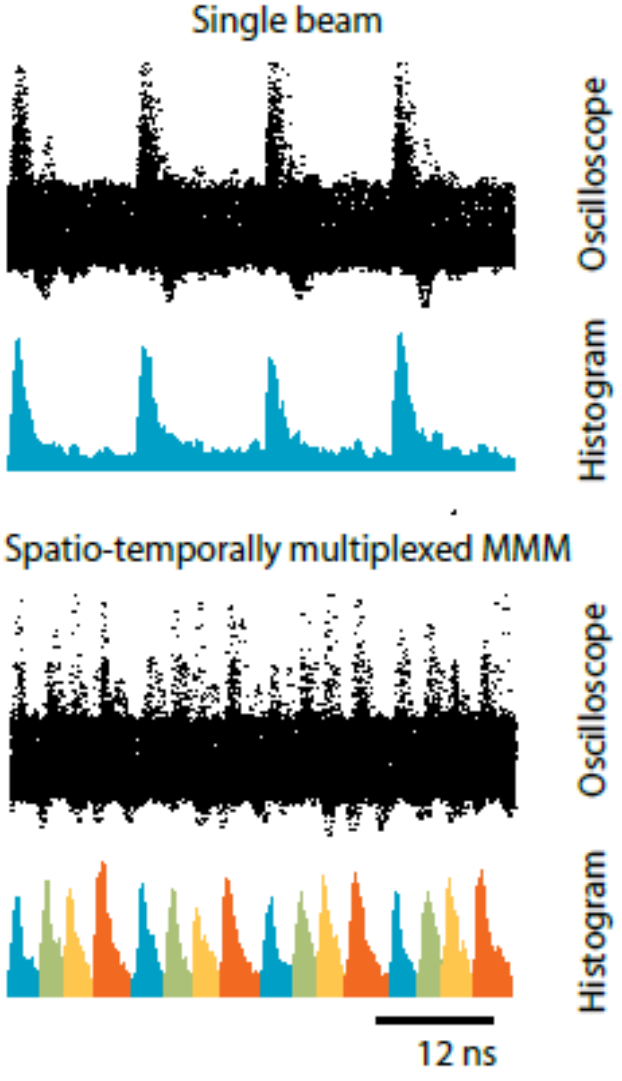


Spatio-Temporal Excitation-Emission Multiplexing (STEM) Microscope

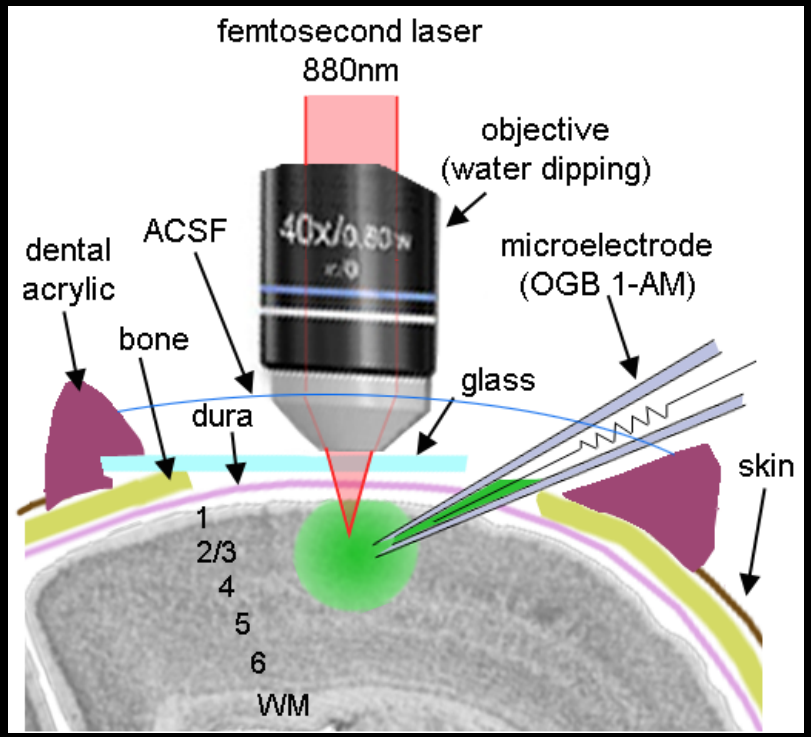


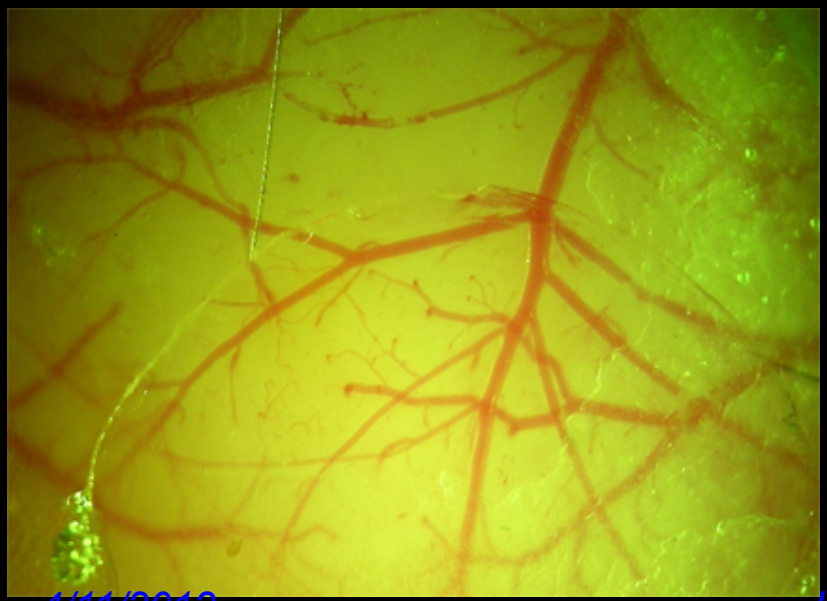
Adrian Cheng (Physics)

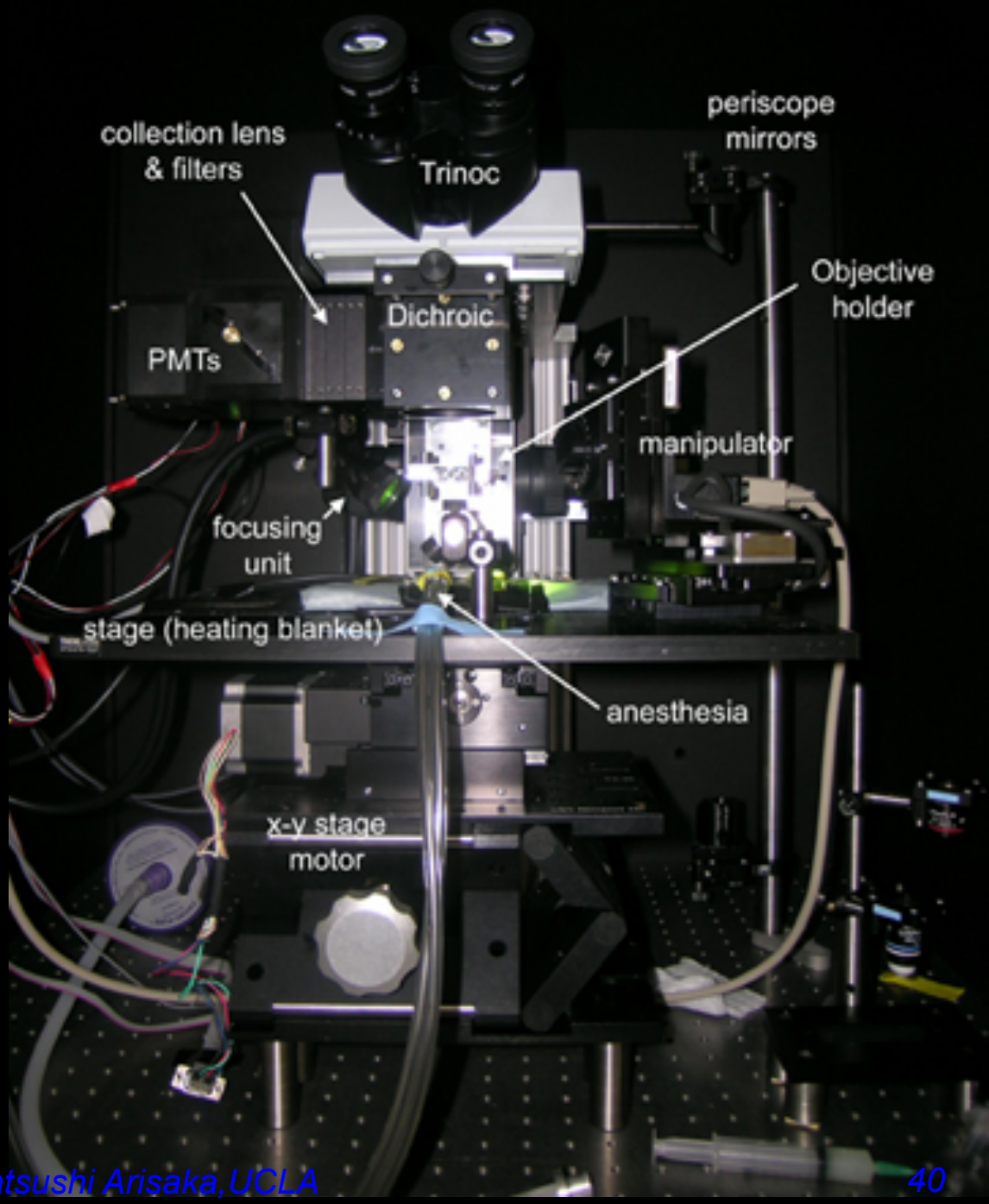
Carlos Portera-Cailliau (Neurology)

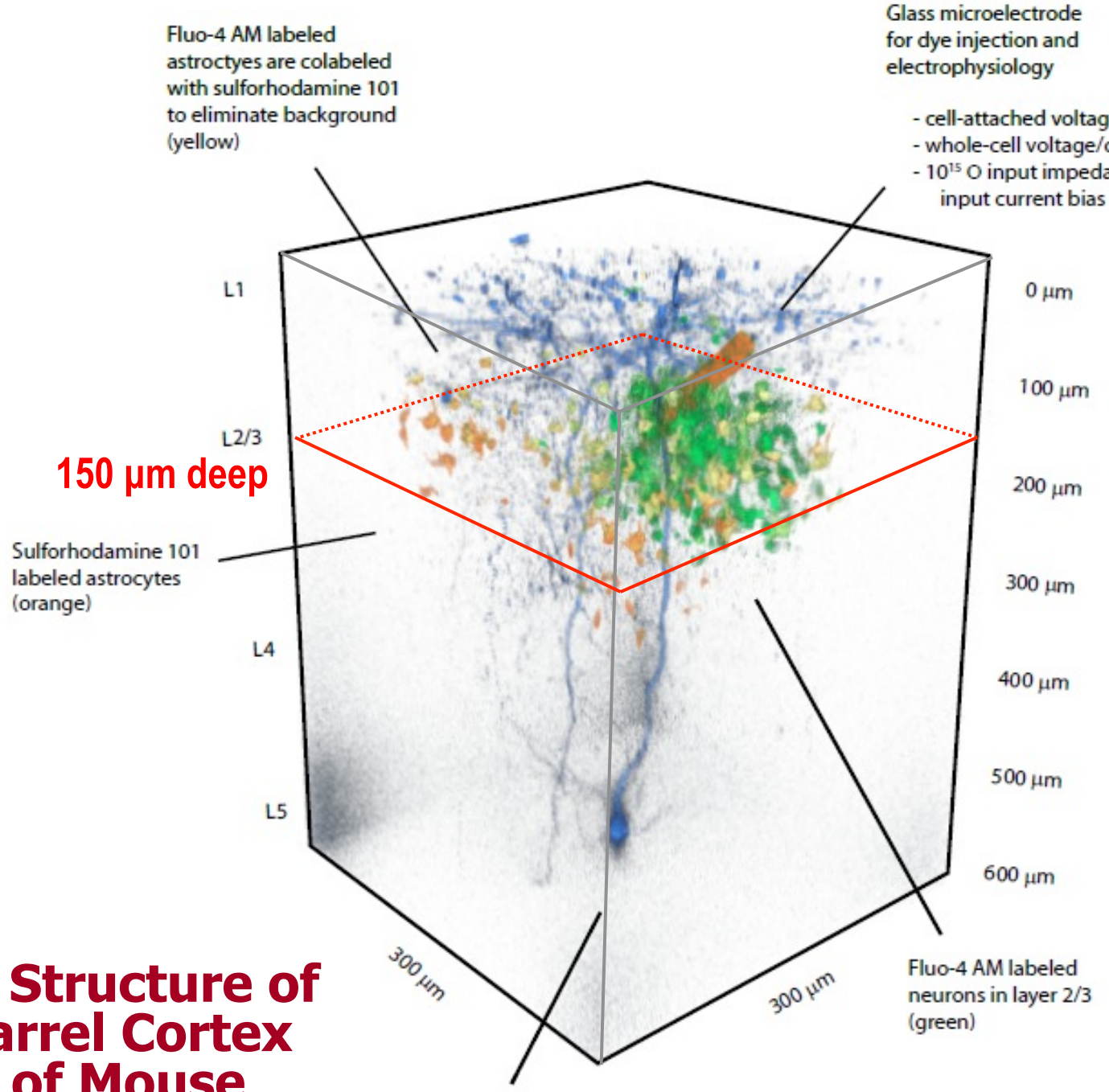


In vivo calcium imaging of neuronal activity









3D Structure of Barrel Cortex of Mouse

Adrian Cheng (Physics)

Tiago Goncalves, Peyman Golshani, Carlos Portera-Cailliau (Neurology)

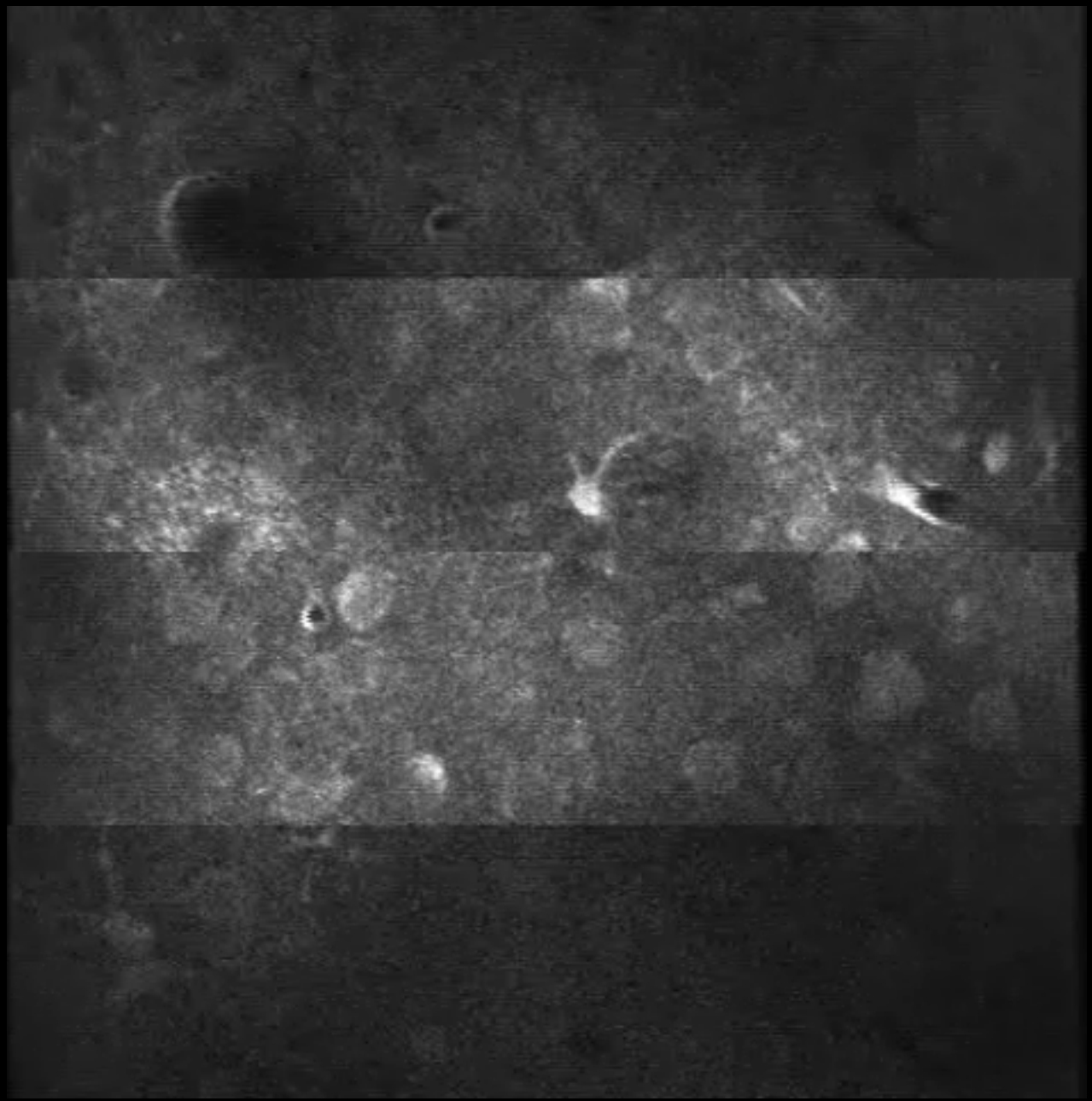
In vivo calcium imaging of Barrel Cortex of Mouse

Barrel Cortex Layer 2/3

150 μm deep

240 fps Raw Data

(x3 faster than real)



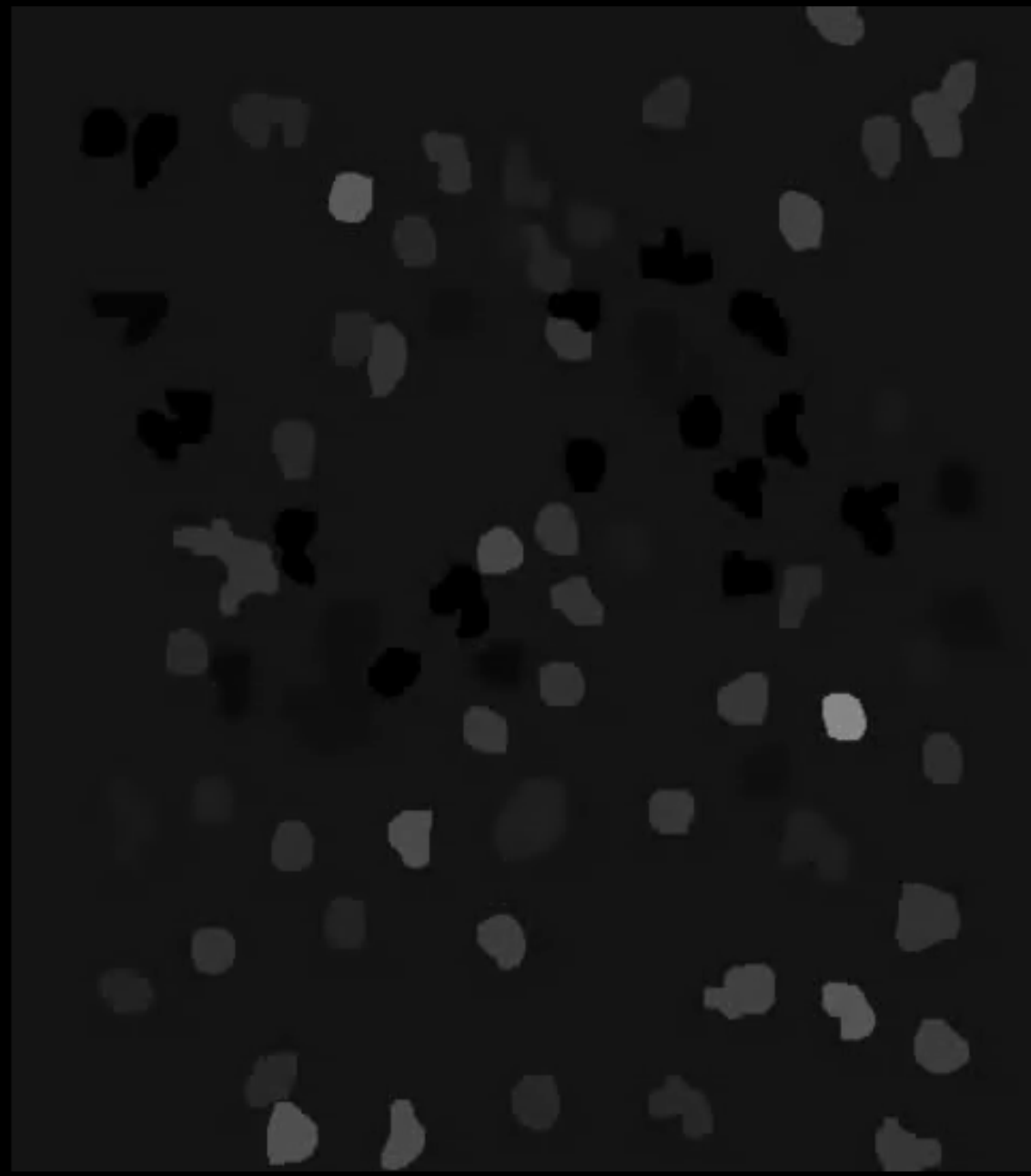
In vivo calcium imaging of Barrel Cortex of Mouse

Barrel Cortex Layer 2/3

150 μm deep

After averaging

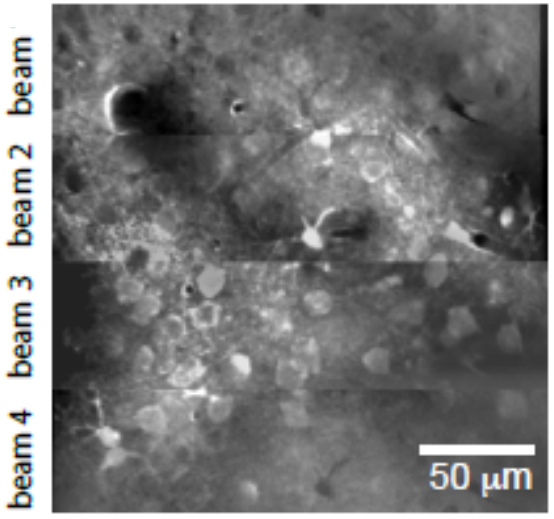
(x3 faster than real)

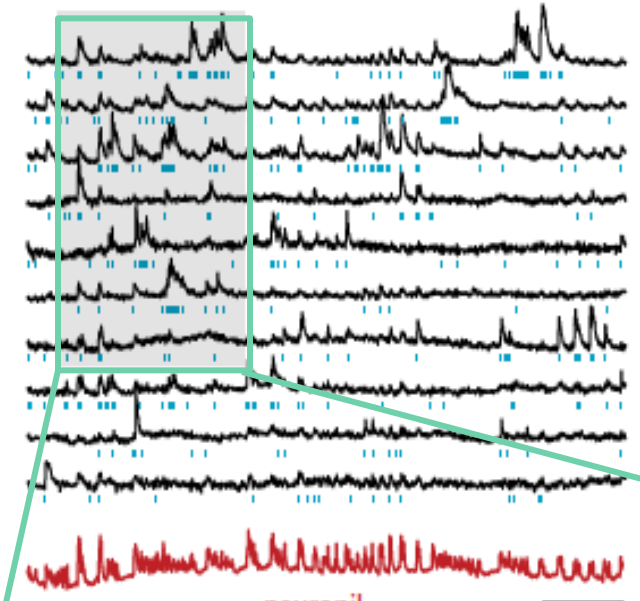


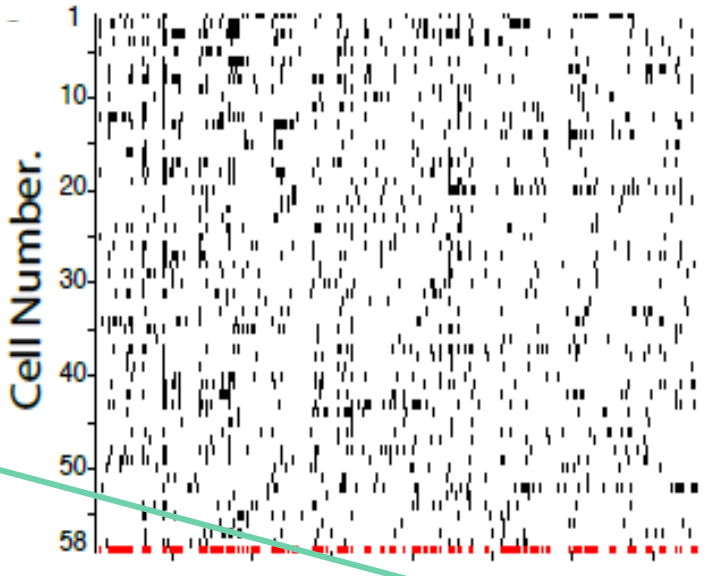
58 neurons

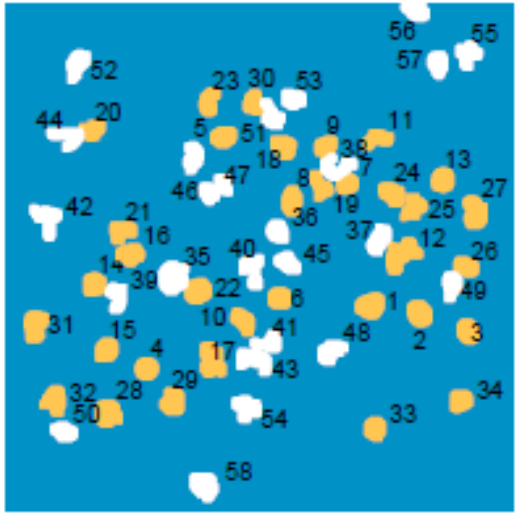
(~100 billons neurons in our brain)

In vivo calcium imaging of layer 2/3 neurons in barrel cortex with STEM

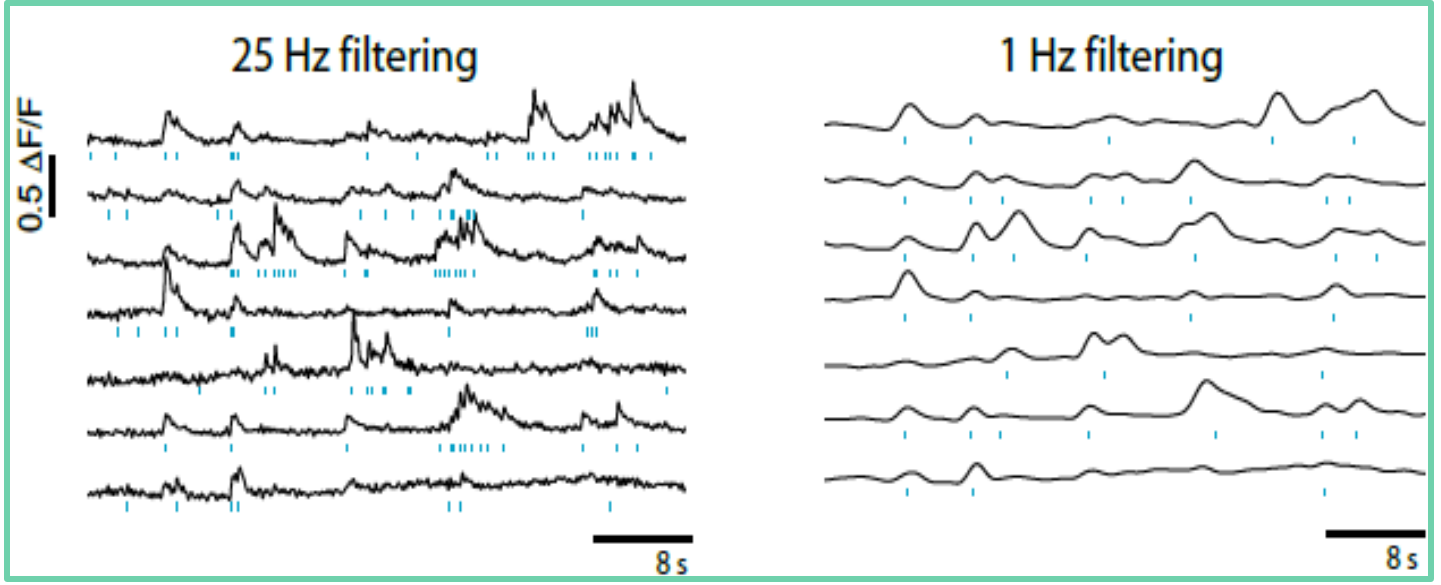


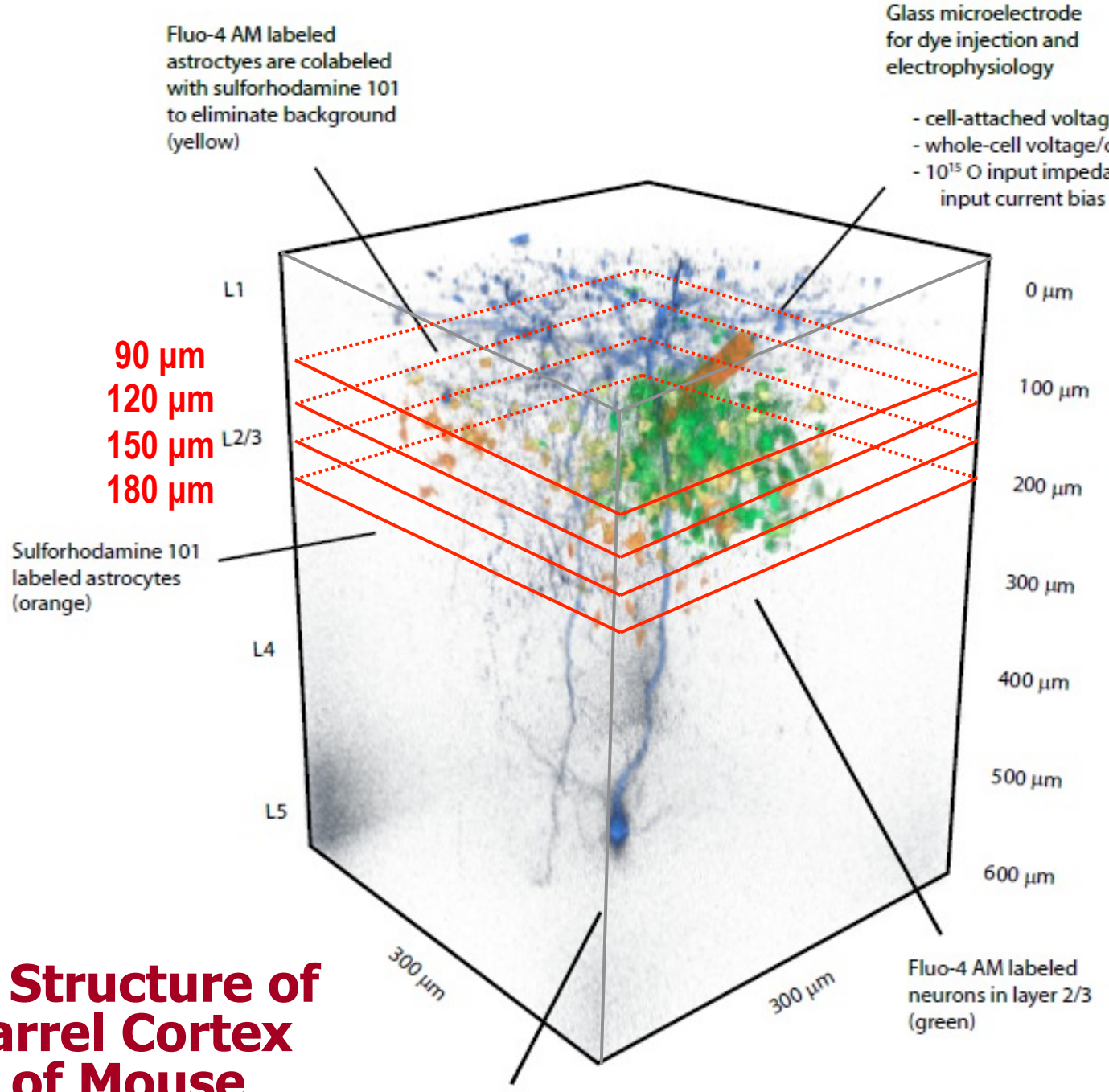






Adrian Cheng (Physics)





3D Structure of Barrel Cortex of Mouse

Adrian Cheng (Physics)

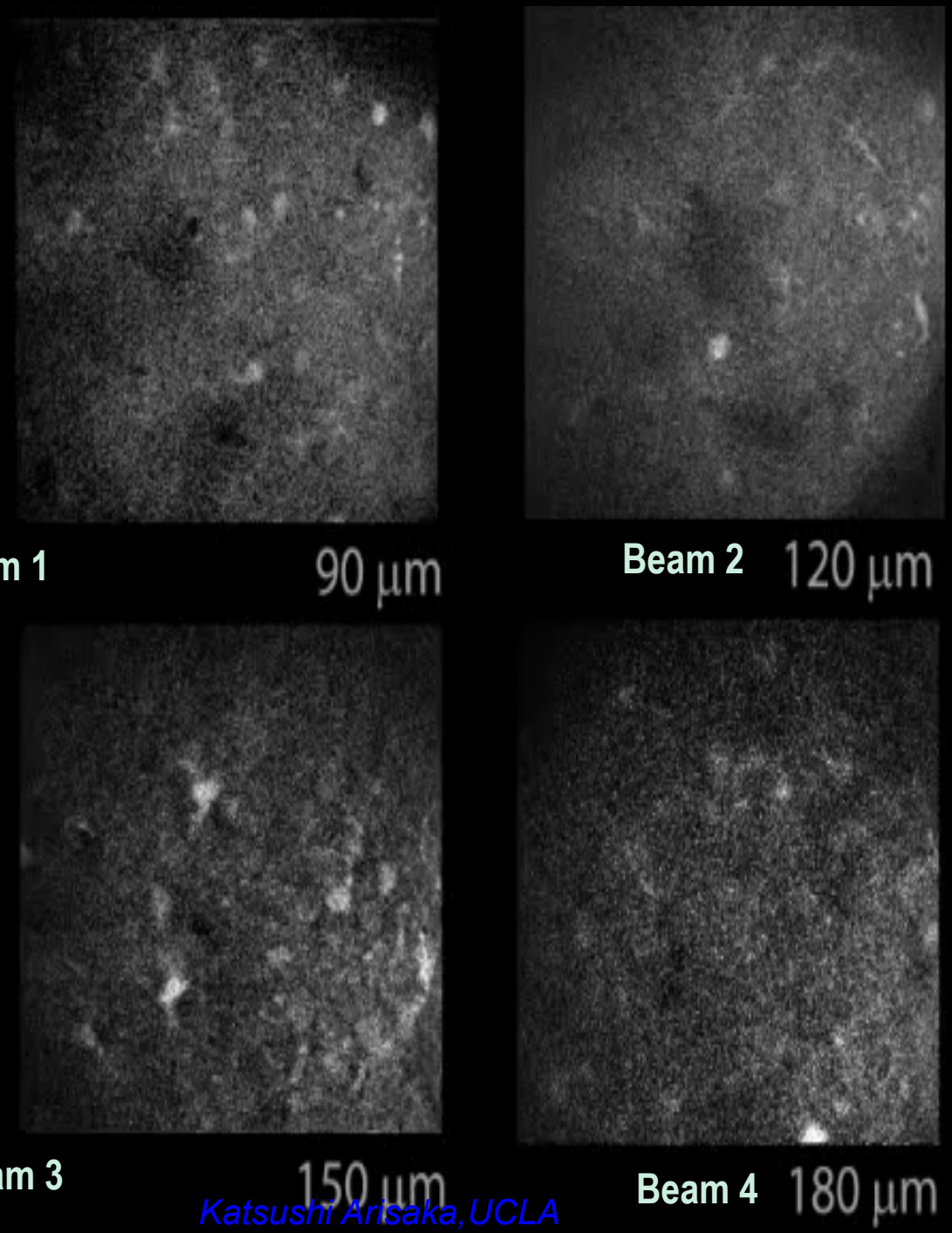
Tiago Goncalves, Peyman Golshani, Carlos Portera-Cailliau (Neurology)

Simultaneous in vivo calcium imaging in 4 axial planes

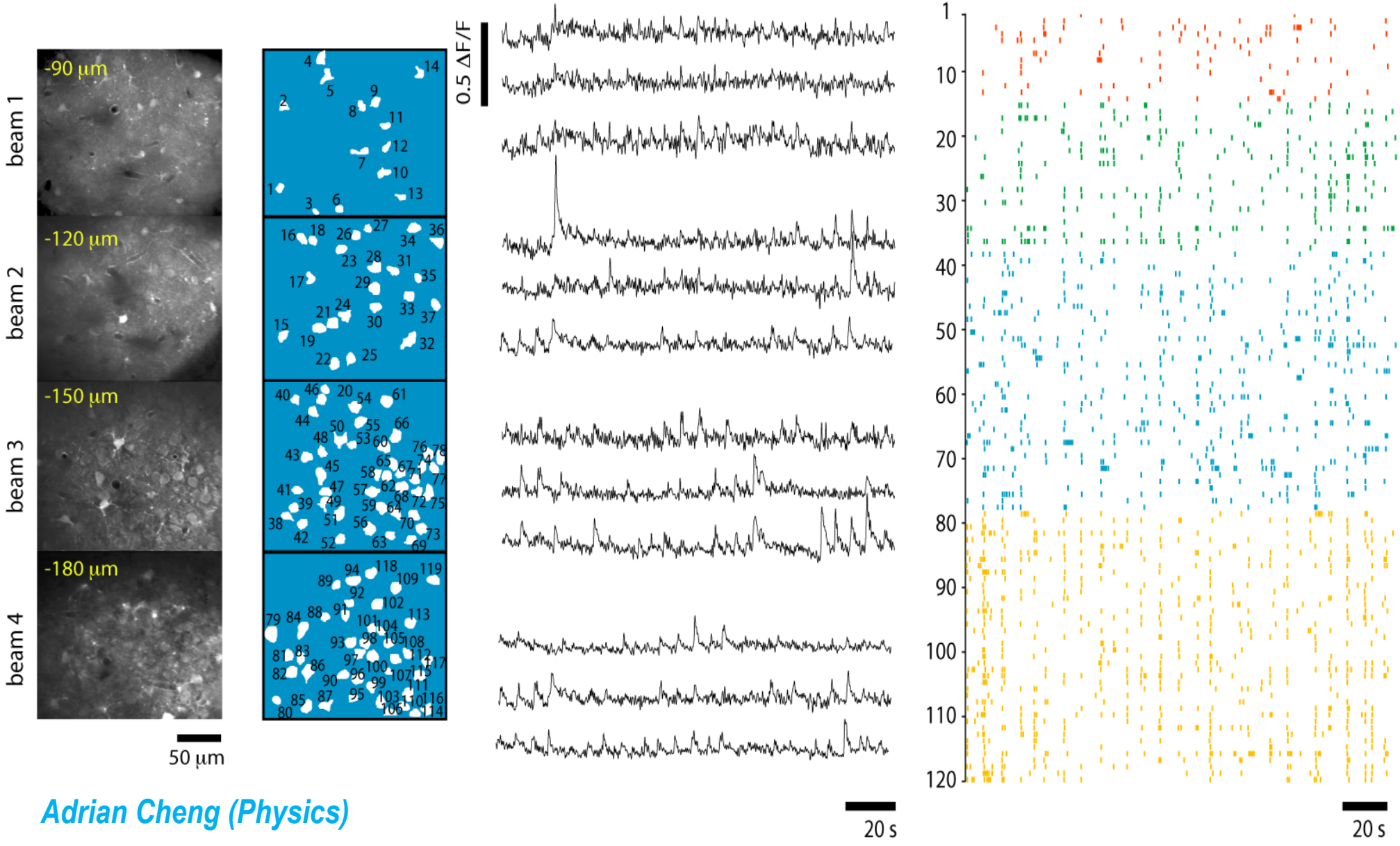
Barrel Cortex Layer 2/3

60 fps

(x3 faster than real)



Simultaneous in vivo calcium imaging of neuronal activity in 4 axial planes with STEM



Adrian Cheng (Physics)

UCLA Newsroom on January 11, 2011

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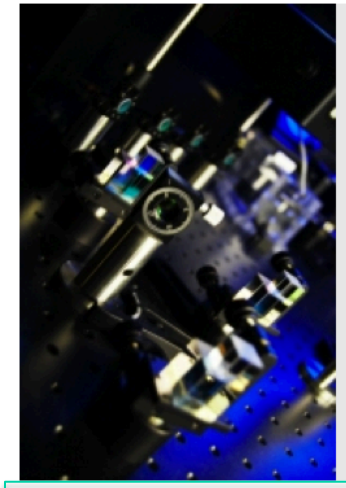
New UCLA-designed microscope records firing of thousands of individual neurons in 3-D

Imaging system could help reveal 'miscommunications' in autism, schizophrenia

By Mark Wheeler | January 11, 2011



Some disorders of the brain are obvious — the massive death of brain cells after a stroke, the explosion in the growth of cells that marks a tumor. Other disorders, such as autism, schizophrenia and mental retardation show no physical signs of damage and are believed to be caused by problems in how brain cells communicate with one another.

To understand the root of the problem of these latter diseases, visualizing brain activity is key. But even the best imaging devices available — fMRIs and PET scans — can only give a "coarse" picture of brain activity.

UCLA neuroscientists have now collaborated with physicists to develop a non-invasive, ultra–high-speed microscope that can record in real time the firing of thousands of individual neurons in the brain as they communicate, or miscommunicate, with each other.

"In our view, this is the world's fastest two-photon excitation microscope for three-dimensional imaging *in vivo*," said UCLA physics professor Katsushi Arisaka, who designed the new optical imaging system with UCLA assistant professor of neurology and neurobiology Dr. Carlos Portera-Cailliau and colleagues.

Their research appears in the Jan. 9 edition of the journal Nature Methods.

Because neuropsychiatric diseases like autism and mental retardation often display no physical brain damage, it's thought they are caused by conductivity problems — neurons not firing properly. Normal cells have patterns of electrical activity, said Portera-Cailliau, but abnormal cell activity as a whole doesn't generate relevant information that brain can use.

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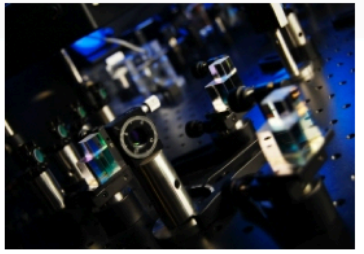
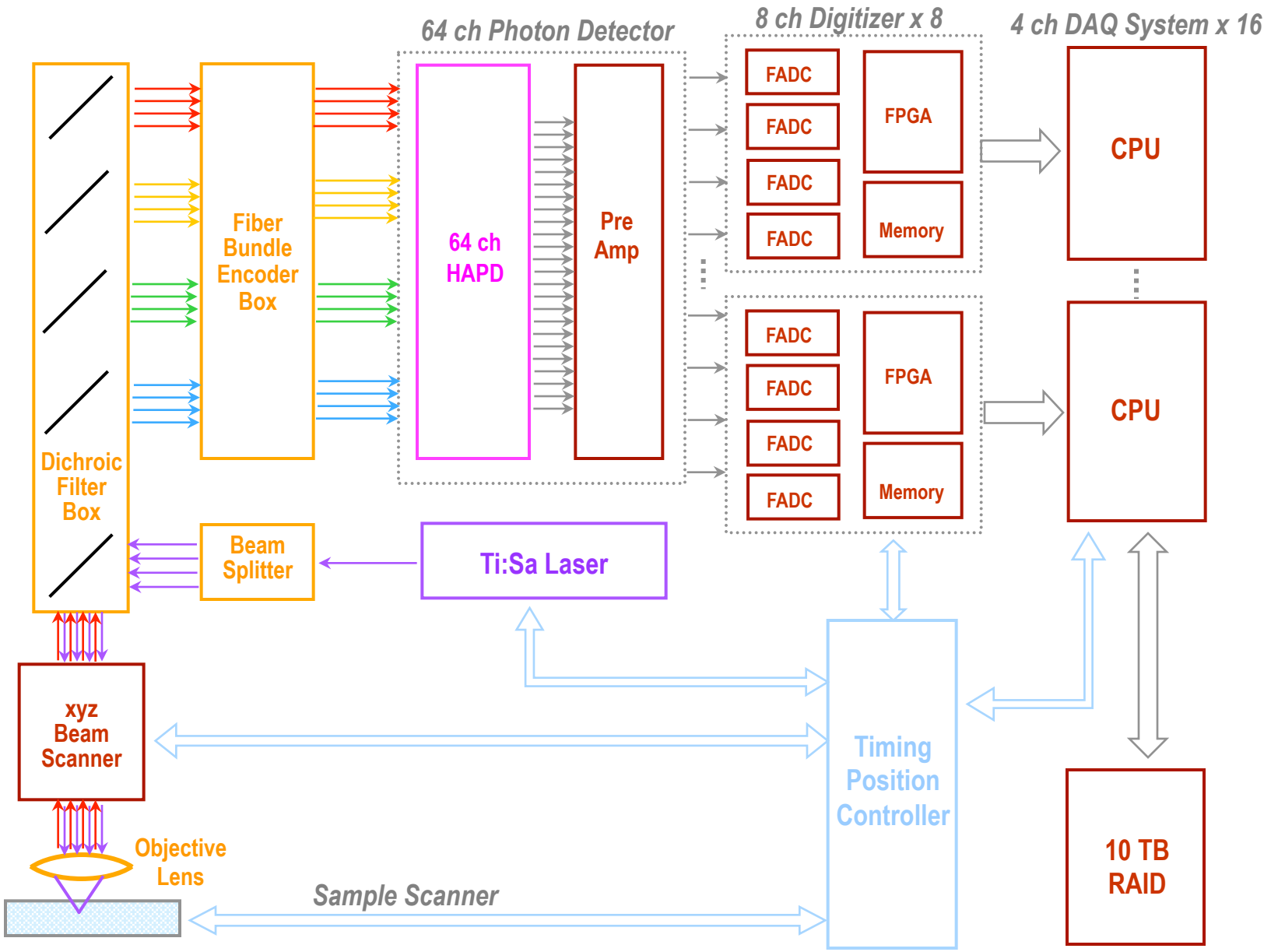


STEM microscope designed at UCLA

View All Images

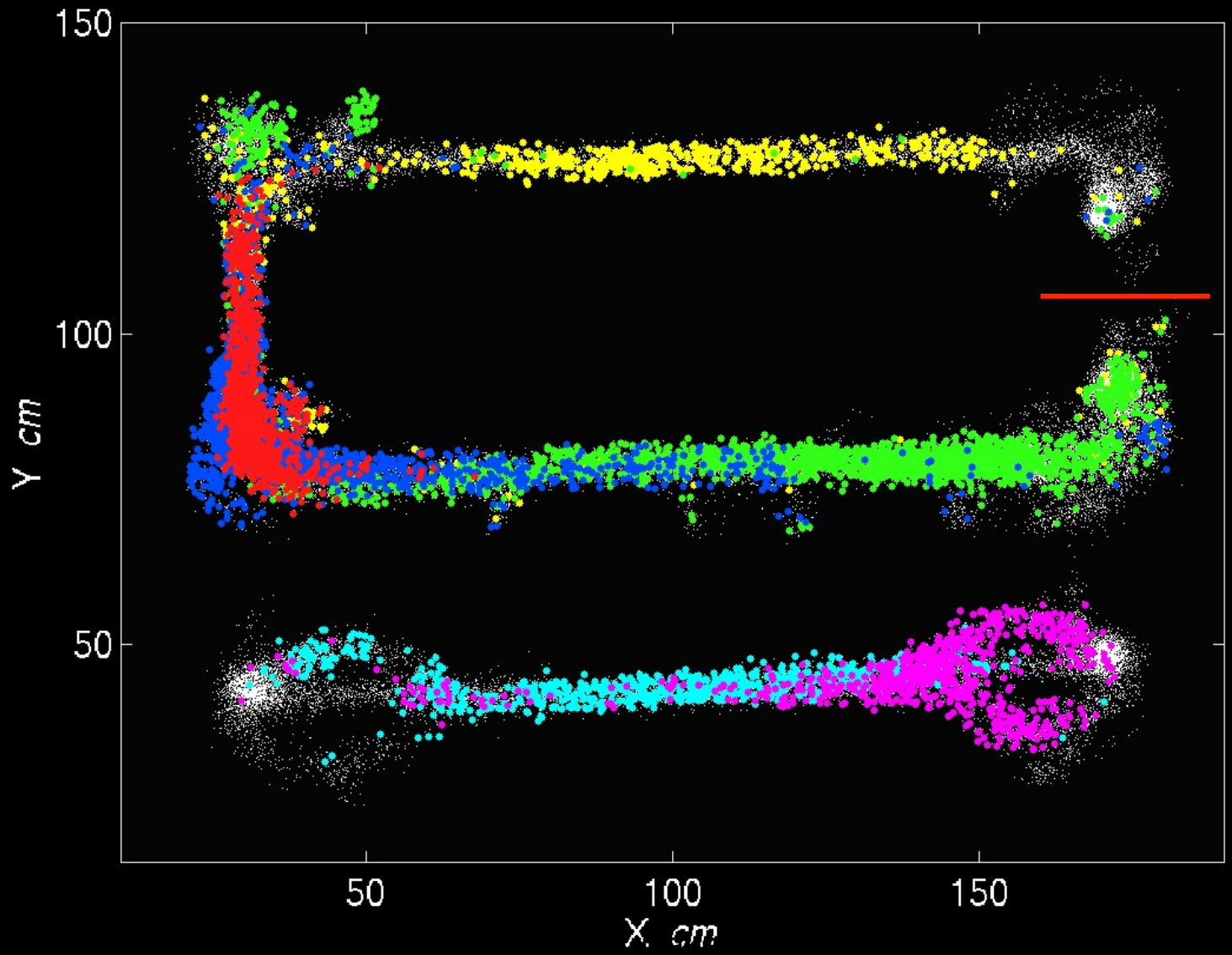
Block Diagram of Multi-beam Confocal Microscope



Future Directions
- Virtual Reality -

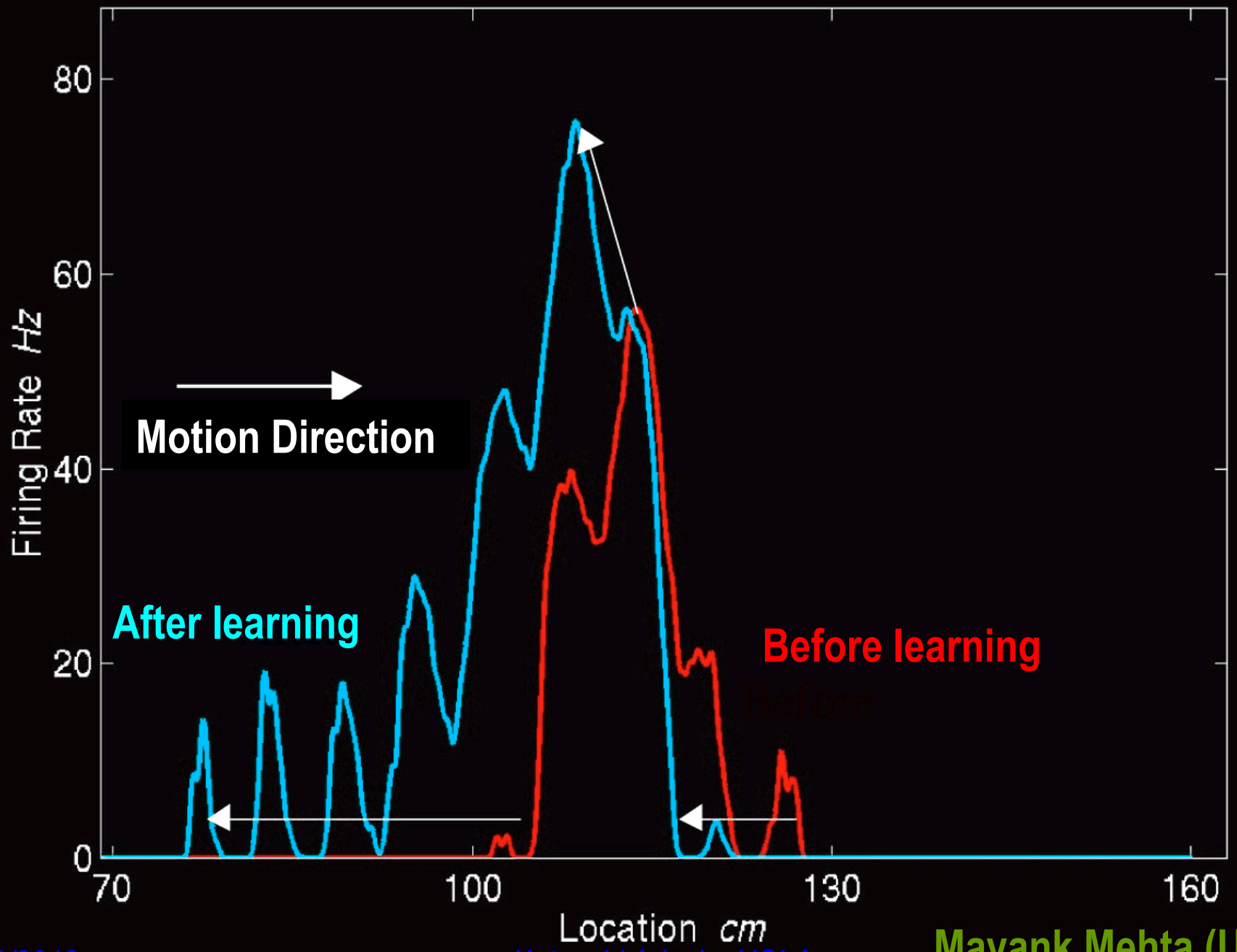
Activity of (excitatory) pyramidal neurons in CA depends on rat's position: place cells

Mayank Mehta (Physics, Neurology)



Hippocampus has a cognitive map of space

Learning and Memory by Hippocampus

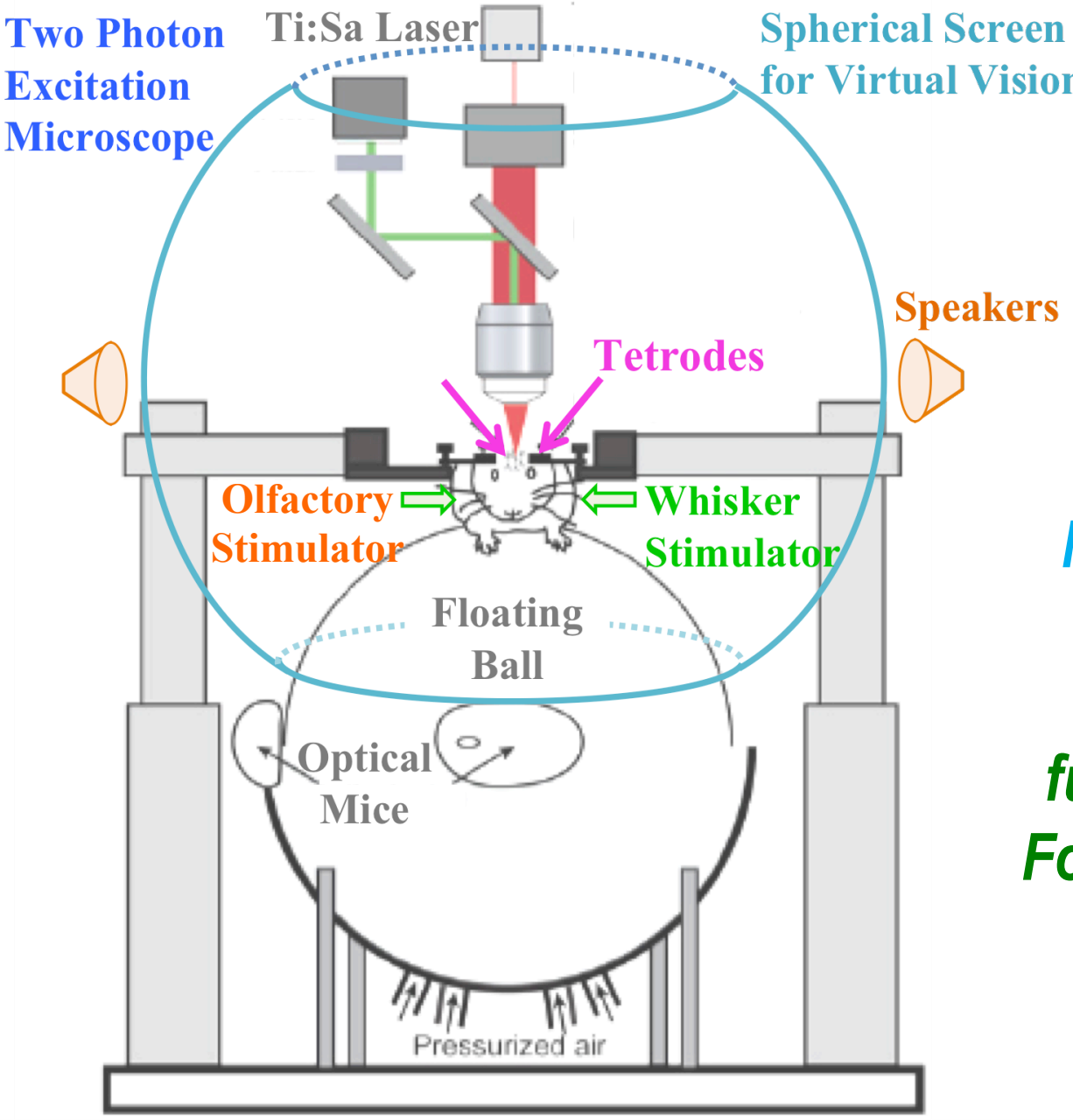


Mayank Mehta (UCLA)

Origin of the Brain

- Brains were evolved for animals to predict necessary motions for survival.
  - Find preys
  - Escape away from predators
  - Find mates for sex
- A brain "consciously" makes the best decision at a given time.
- Complex activities of brains are the results of evolution of life.

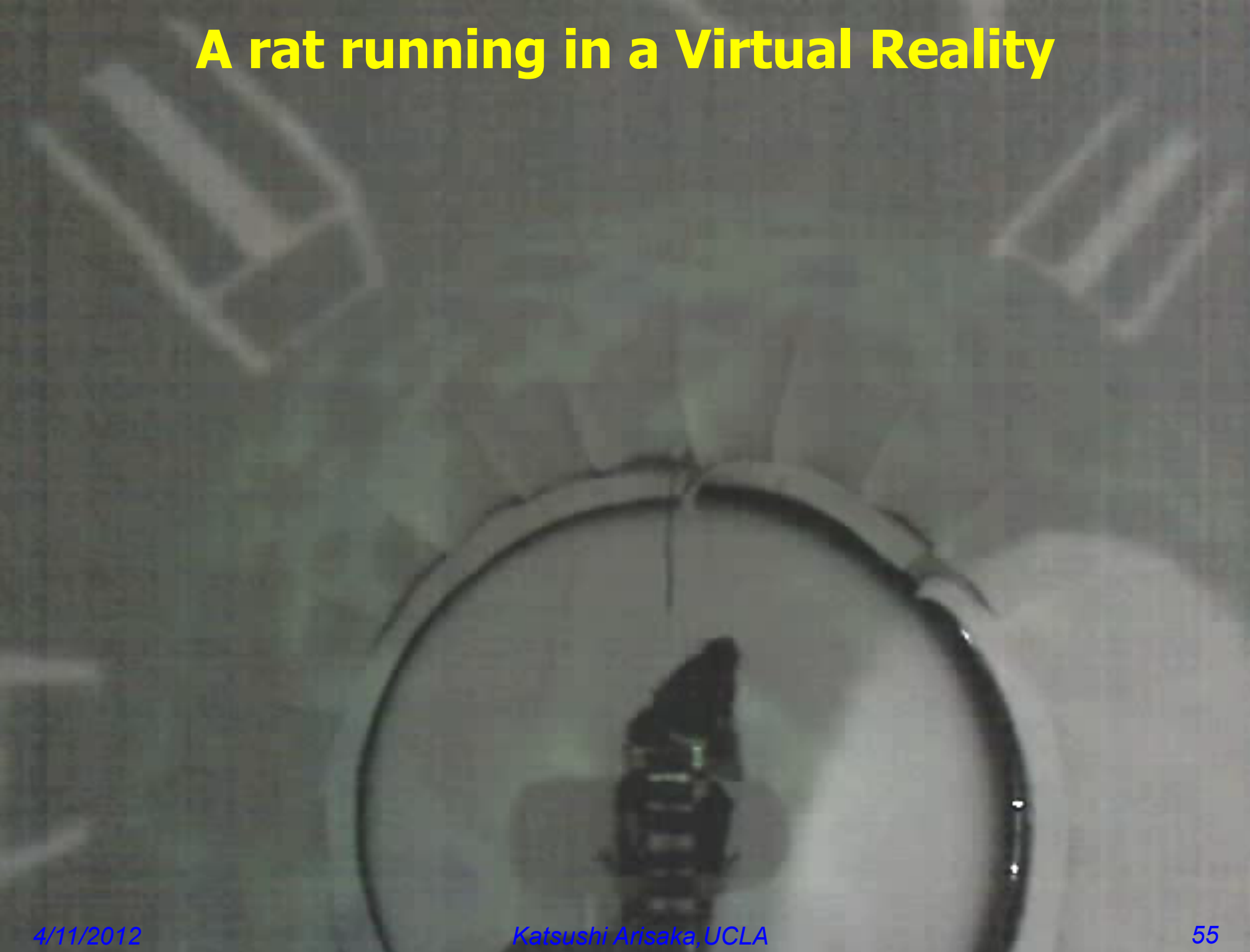
Virtual Reality Experiment on Awake Rats



Mayank Mehta (Physics)

funded by Keck Foundation ($1M)

A rat running in a Virtual Reality

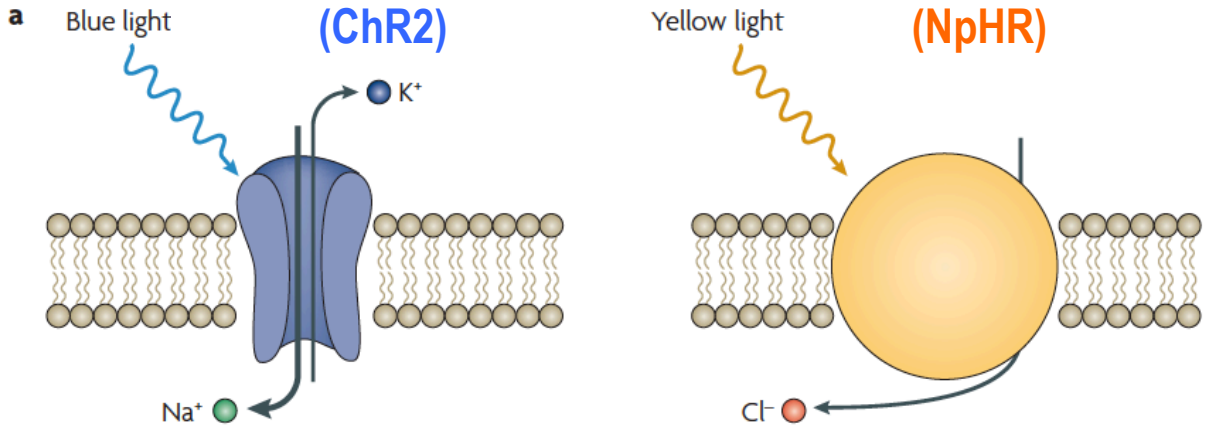


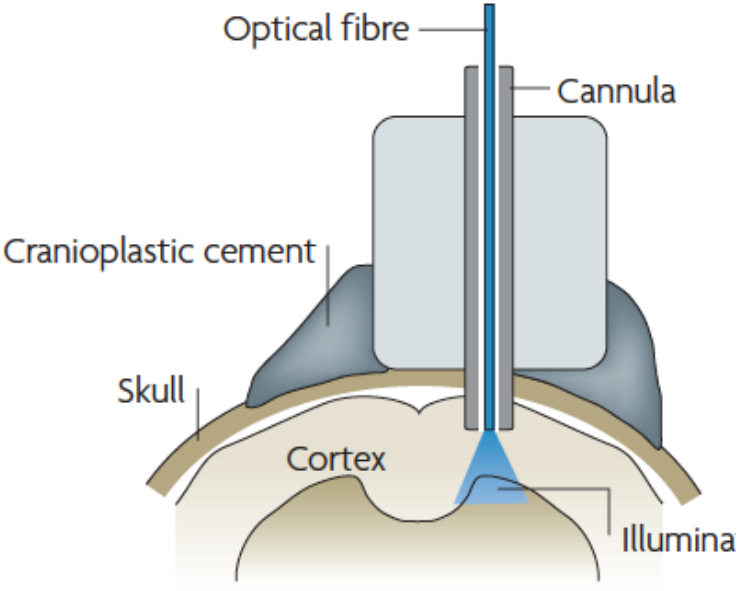
Optogenetic Excitation of Neurons

Karl Deisseroth (Stanford)

Excitation by Channelrhodopsin-2 (ChR2)

Inhabitation by Halorhodopsin (NpHR)





Outer world vs. Inner word

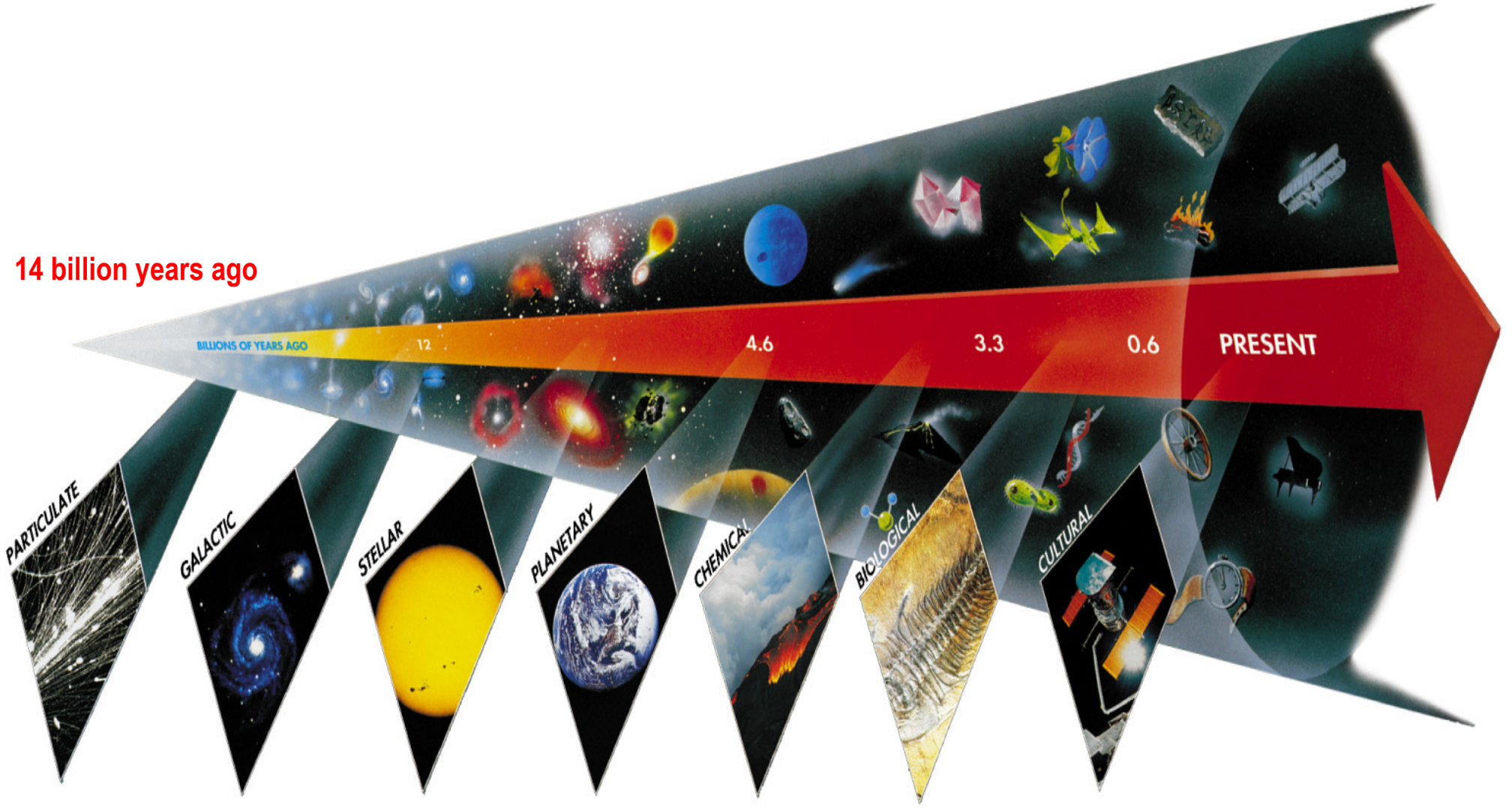
- Outer world : Five senses → Manipulate by Virtual Reality
  - Vision
  - Sound
  - Touch
  - Smell
  - Taste
- Inner world → Manipulate by Photo Excitation of single neurons
  - Neural network in brain
- Establish direct link between Inner world & Outer world
  - Control outer world – Virtual reality
  - Control inner world – Neural reality

The Origin of Consciousness

- Our brains are making enormous parallel processing "*unconsciously*" all the time.
  - Image processing
  - Language
  - Recognition of space-time
- "*Consciousness*" is merely the outcome of the decision making processes which have been performed unconsciously.
  - Language and logics are just left-over from the past.
  - We realize what we said only after we spoke.

Summary

Seven Phases of Cosmic Evolution



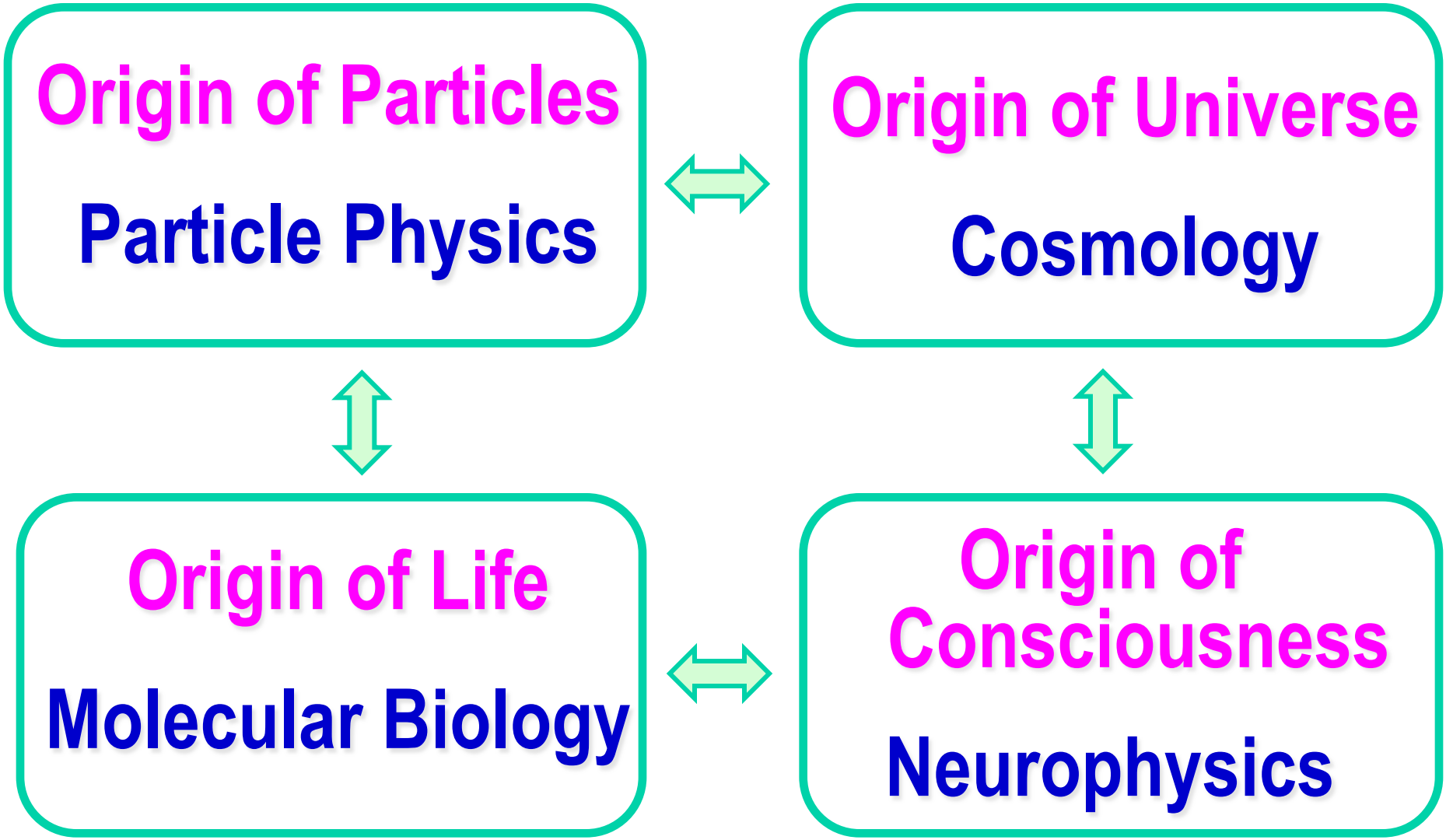
Origin of Particles

Origin of Structure

Origin of Life

Origin of Consciousness

Four Major Science



Future of Ultra High-speed Bio Imaging

- **Origin of Life:**
  - Networks of molecules in/on a cell
  - Competition against Brownian : 10 – 100 nm / 1 msec
- **Origin of Consciousness:**
  - Neural networks
  - Action potentials: 1 msec

- **> 1,000 frame/sec with nano second time stamp.**
  - Gated Image Intensified CMOS
  - Super-PIAS (GHz Photon-counting Imager)
  - 6D Imaging by Streak-CMOS Camera

Concluding Remarks

- "Life" is a complex system in 4 dimensional space-time.
  - Emergent property
  - Strongly interacting
- Countless "spontaneous symmetry breakings" during the evolutional and developing process of life
- Fully controlled experiments by "Virtual Reality" under way.
  - Outer world (environment) vs. Inner world (brain)

- "Ultra high-speed optical imaging" may reveal the fundamental principle of the brain function such as consciousness.