Exploring the Origin of Consciousness by high-speed Optical Microscopes

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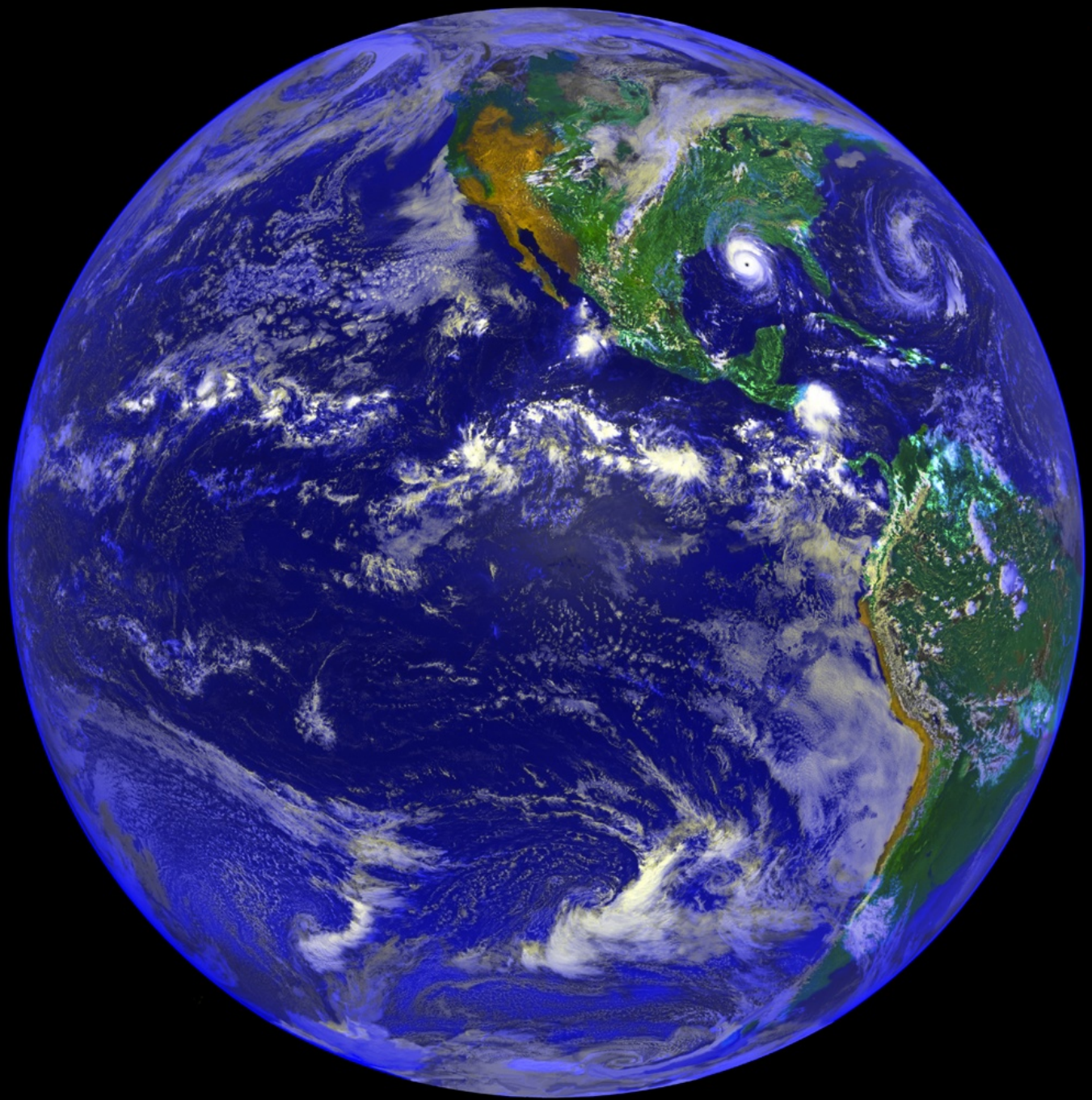
Department of Physics and Astronomy

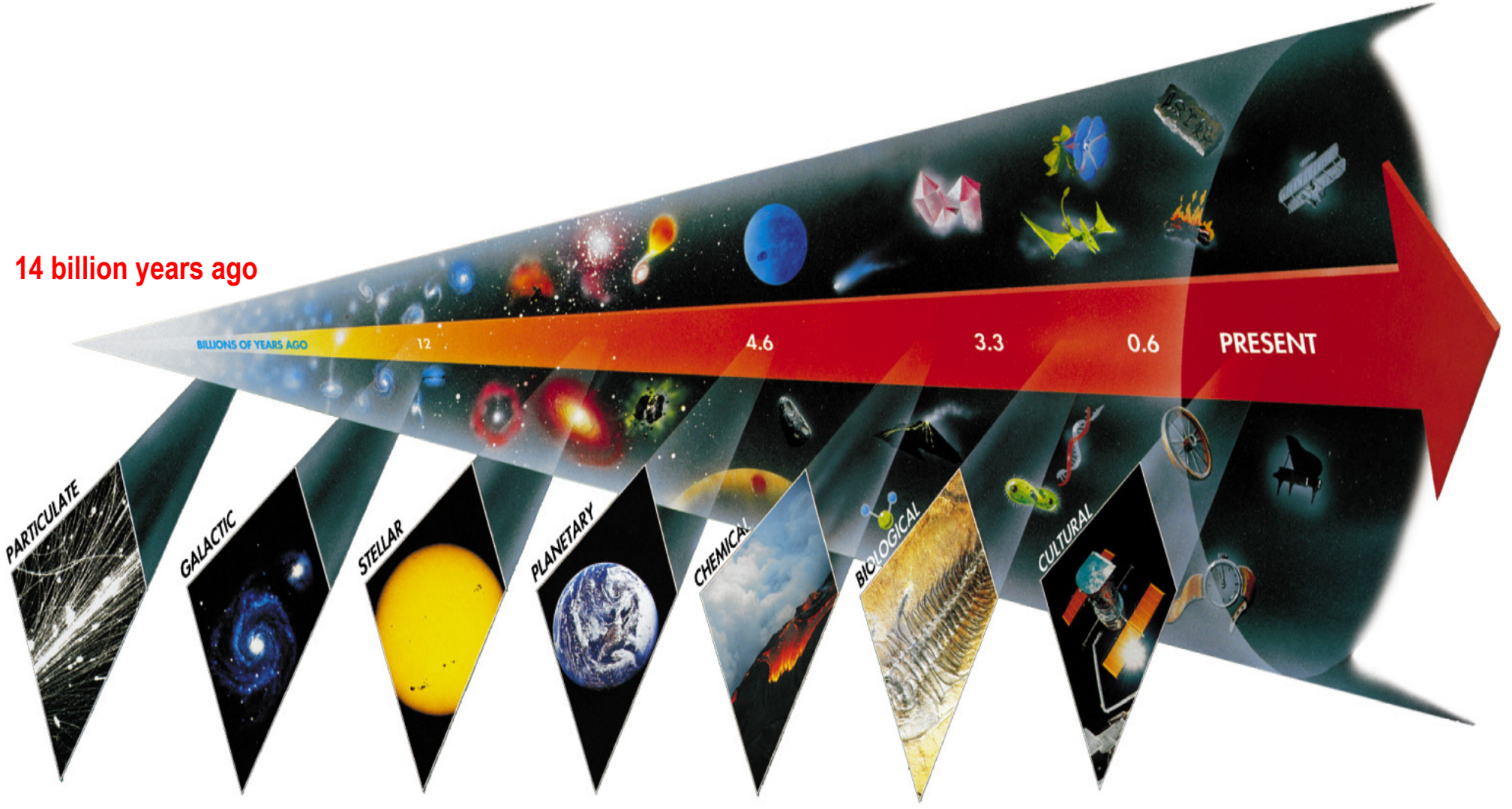
Talk Outline

- **Today: Bio-imaging and Neuro-physics**
  - Part I ~30 min.
    - Introduction to High-speed Bio-imaging
    - Single Molecule: Origin of Life
  - Part II ~30 min.
    - Neurophysics: Origin of Consciousness
- **Next week : Particle Physics & Cosmology**
  - Part I ~30 min.
    - Introduction to Cosmology: Origin of Universe
    - CMS at CERN: Origin of Particles
  - Part II ~30 min.
    - Detection of Dark Matter: Origin of Structure in Universe
  - Lab Tour ~10 min.



Why are we here?

Seven Phases of Cosmic Evolution



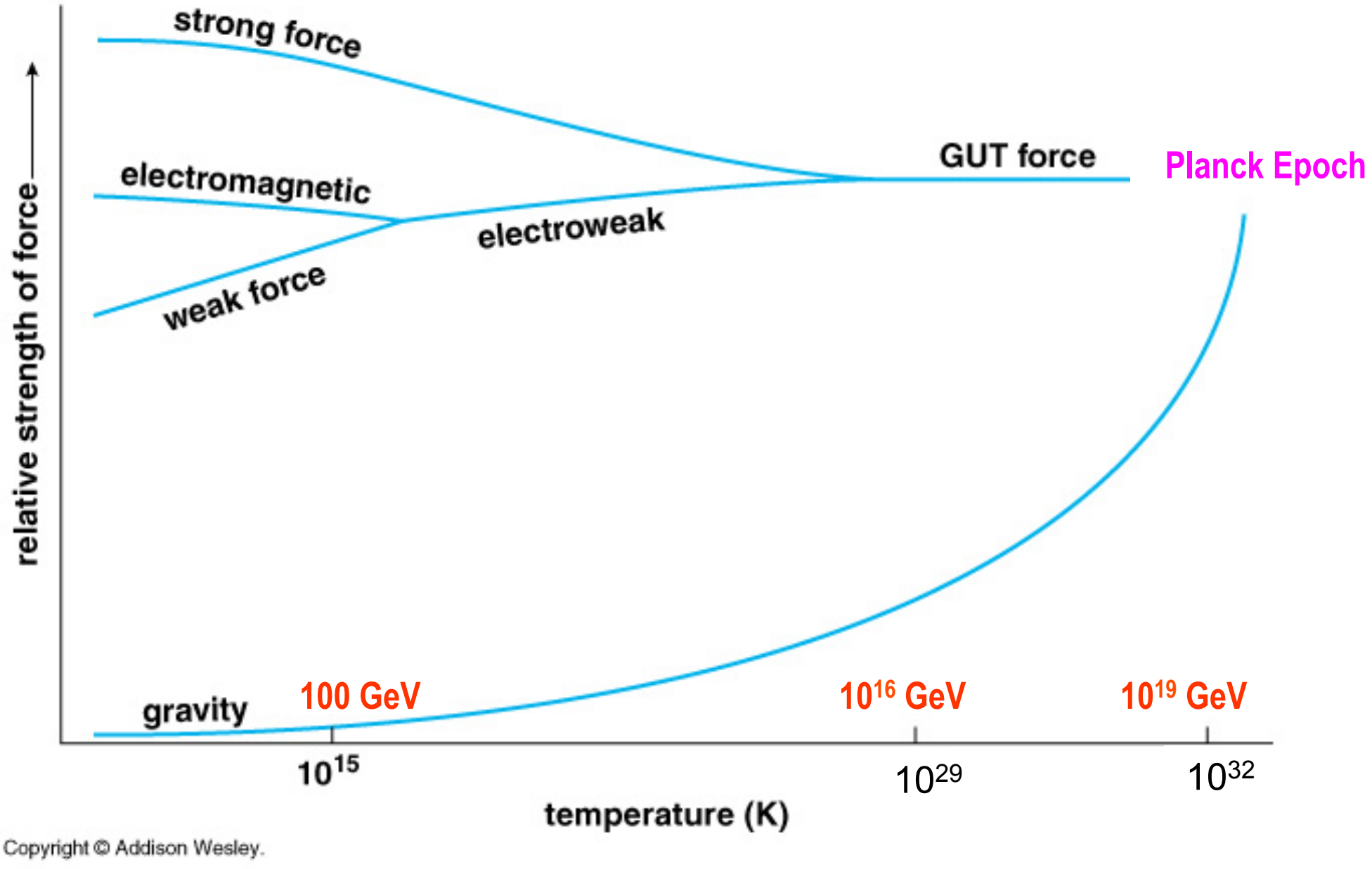
Origin of Particles

Origin of Structure

Origin of Life

Origin of Consciousness

Unification of Forces



Physicists' View of Early Universe

Fiat lux

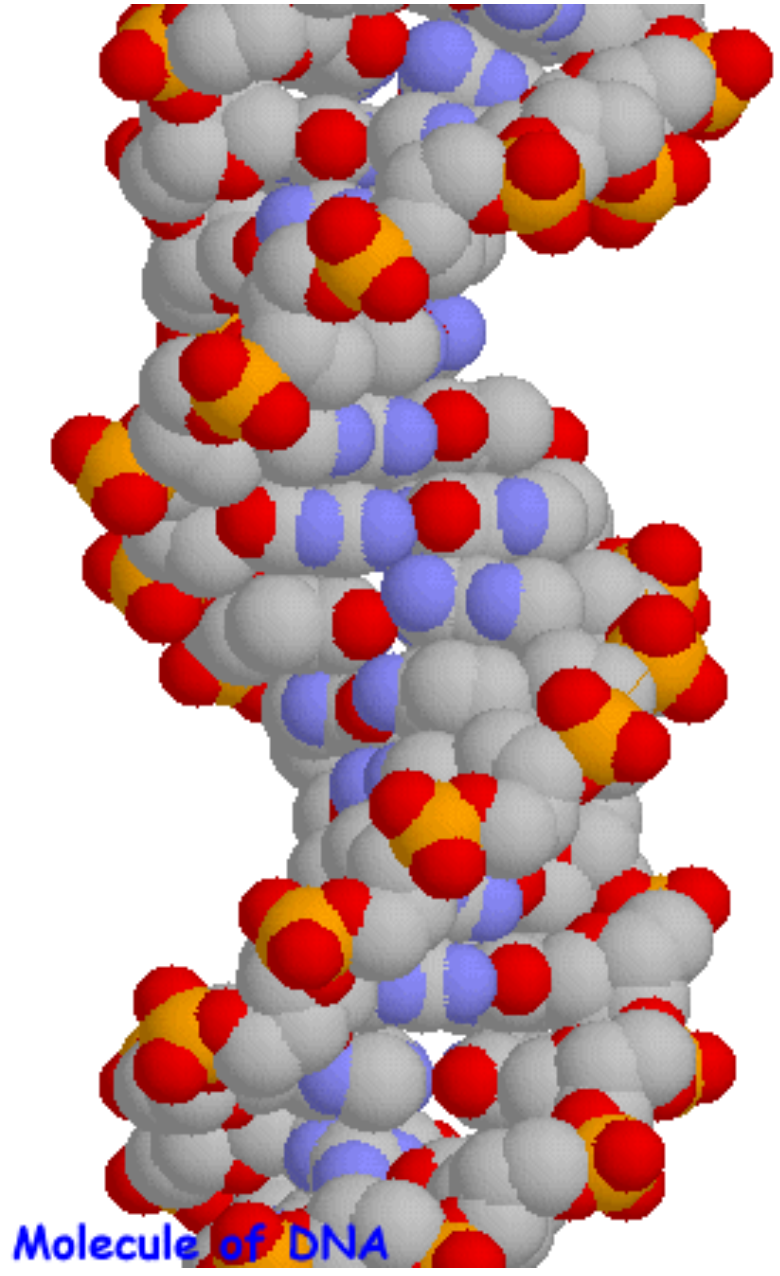
Let there be light

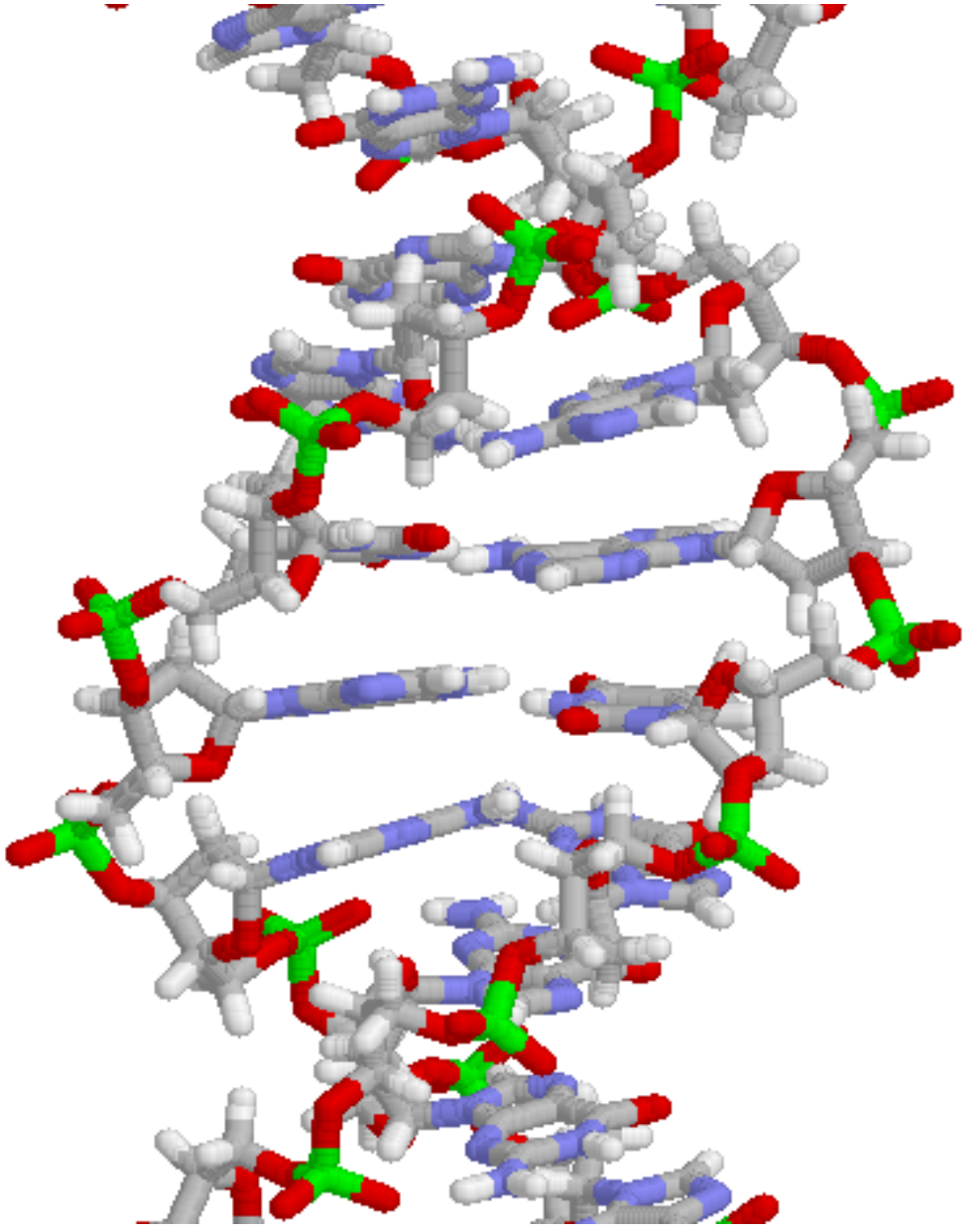
Physicists' View of Early Universe

Lorentz Invariance

Local Gauge Invariance

Structure of DNA



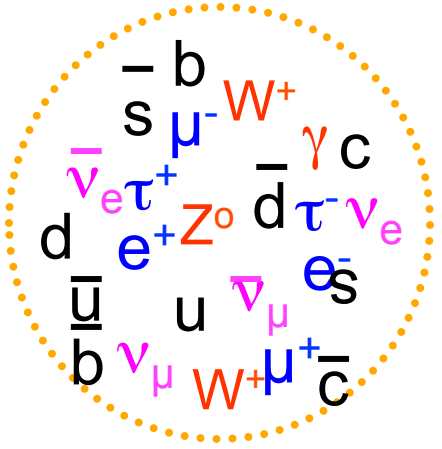


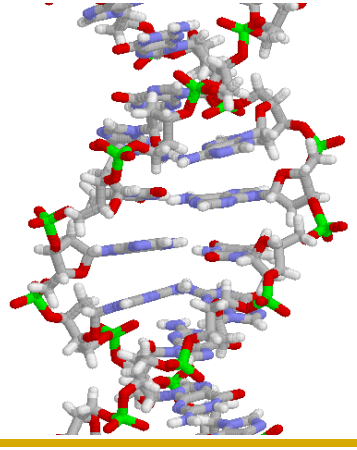
Symmetry Breaking

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

Simple

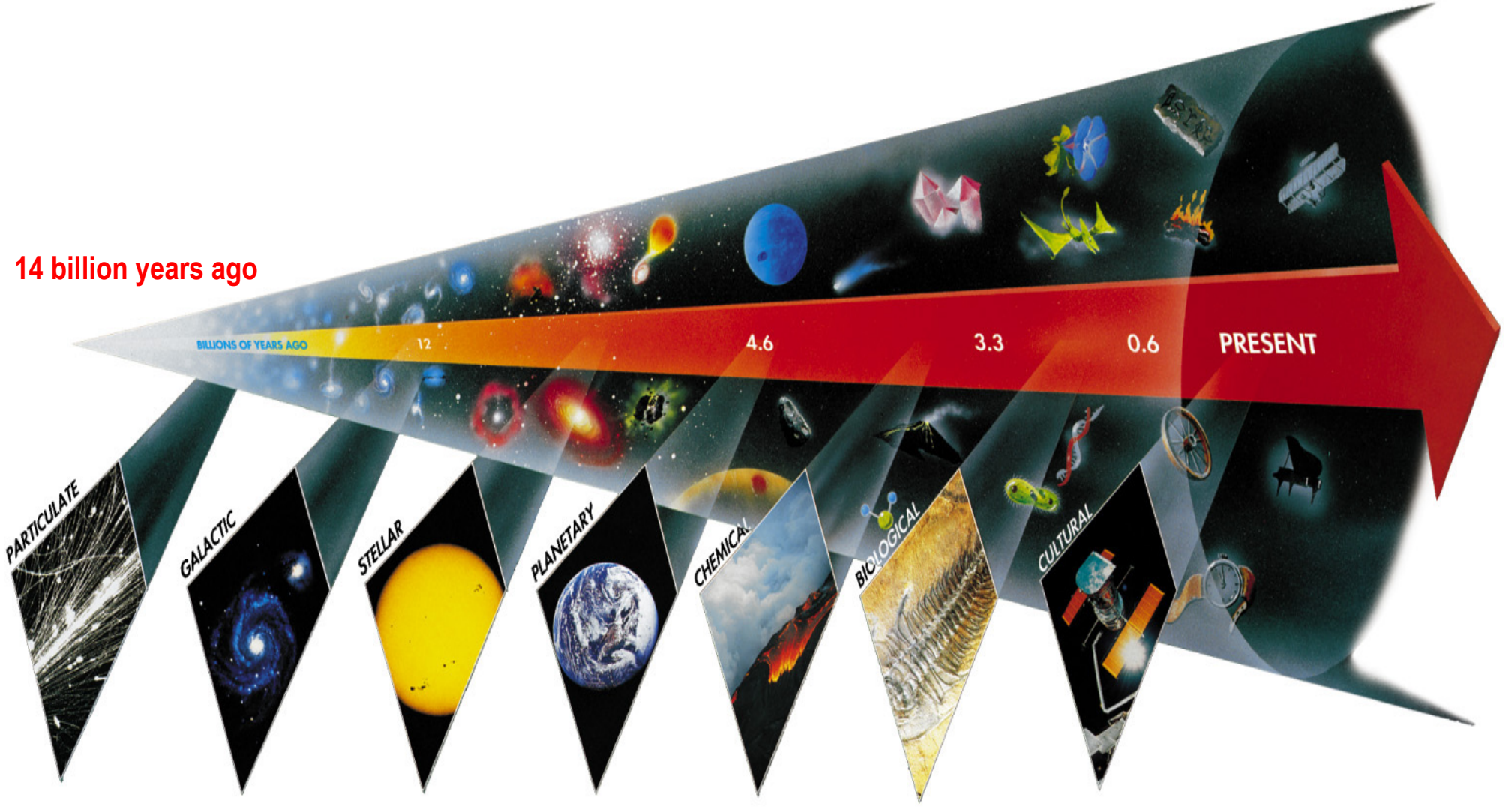
Symmetry Break Down





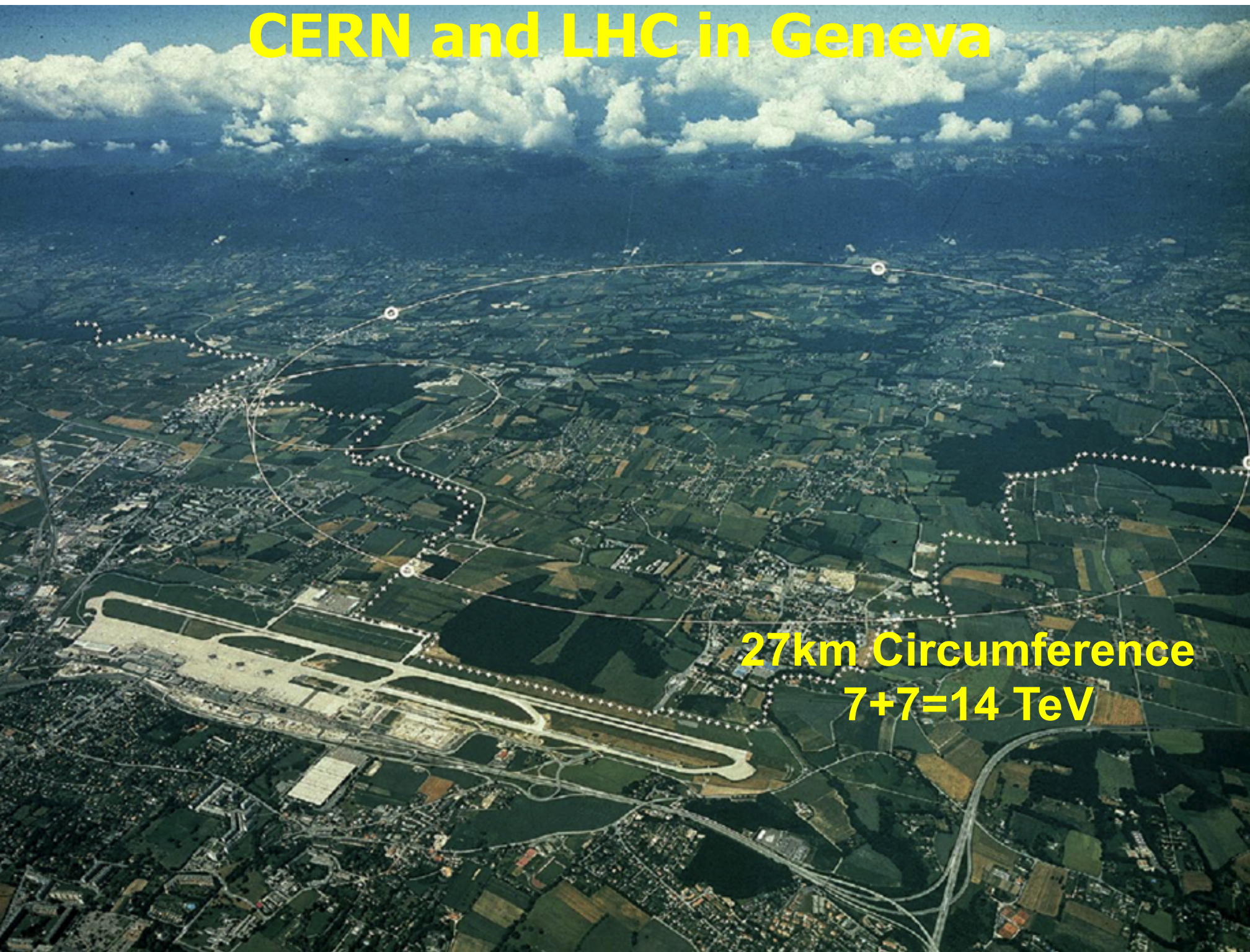
Complex

Seven Phases of Cosmic Evolution

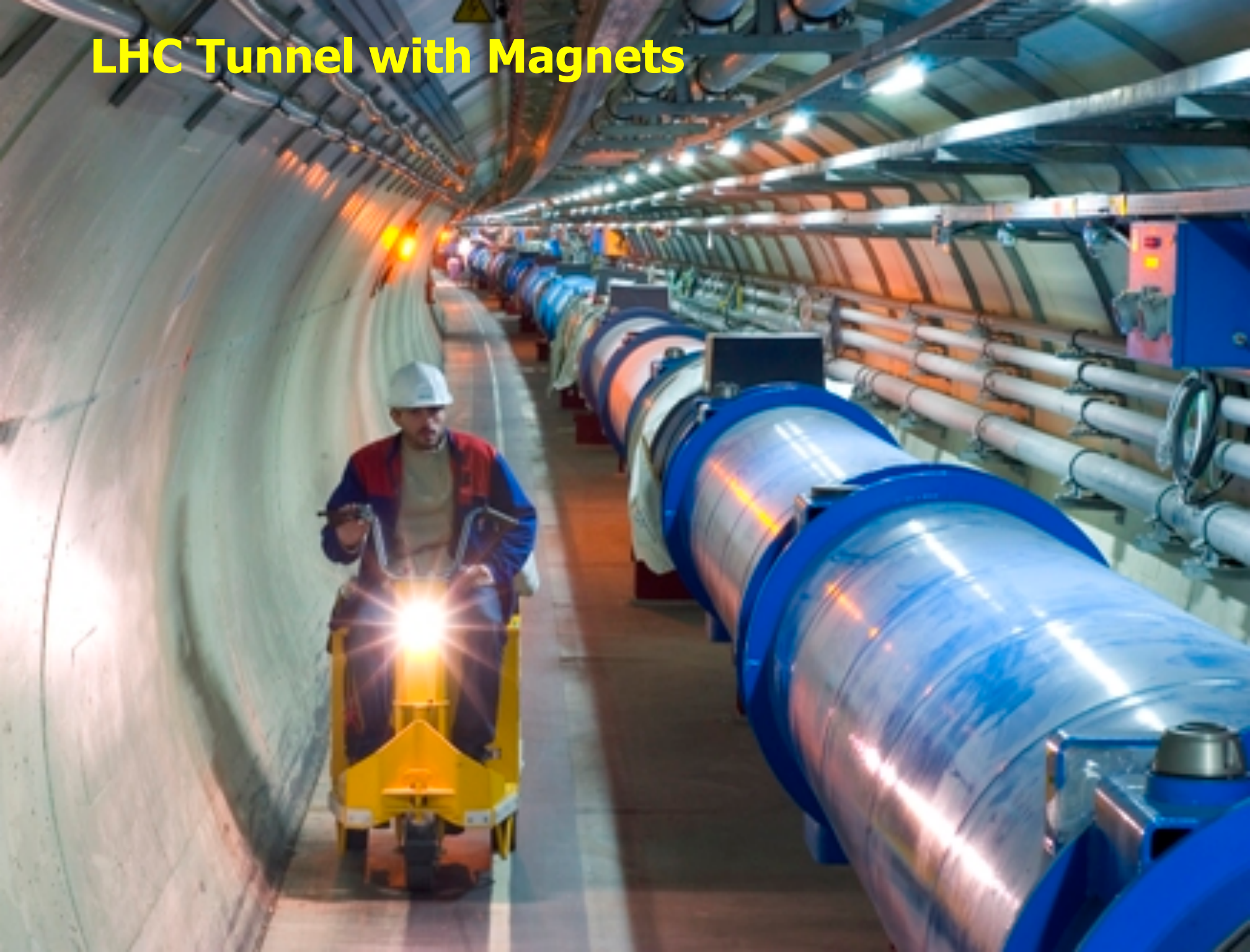


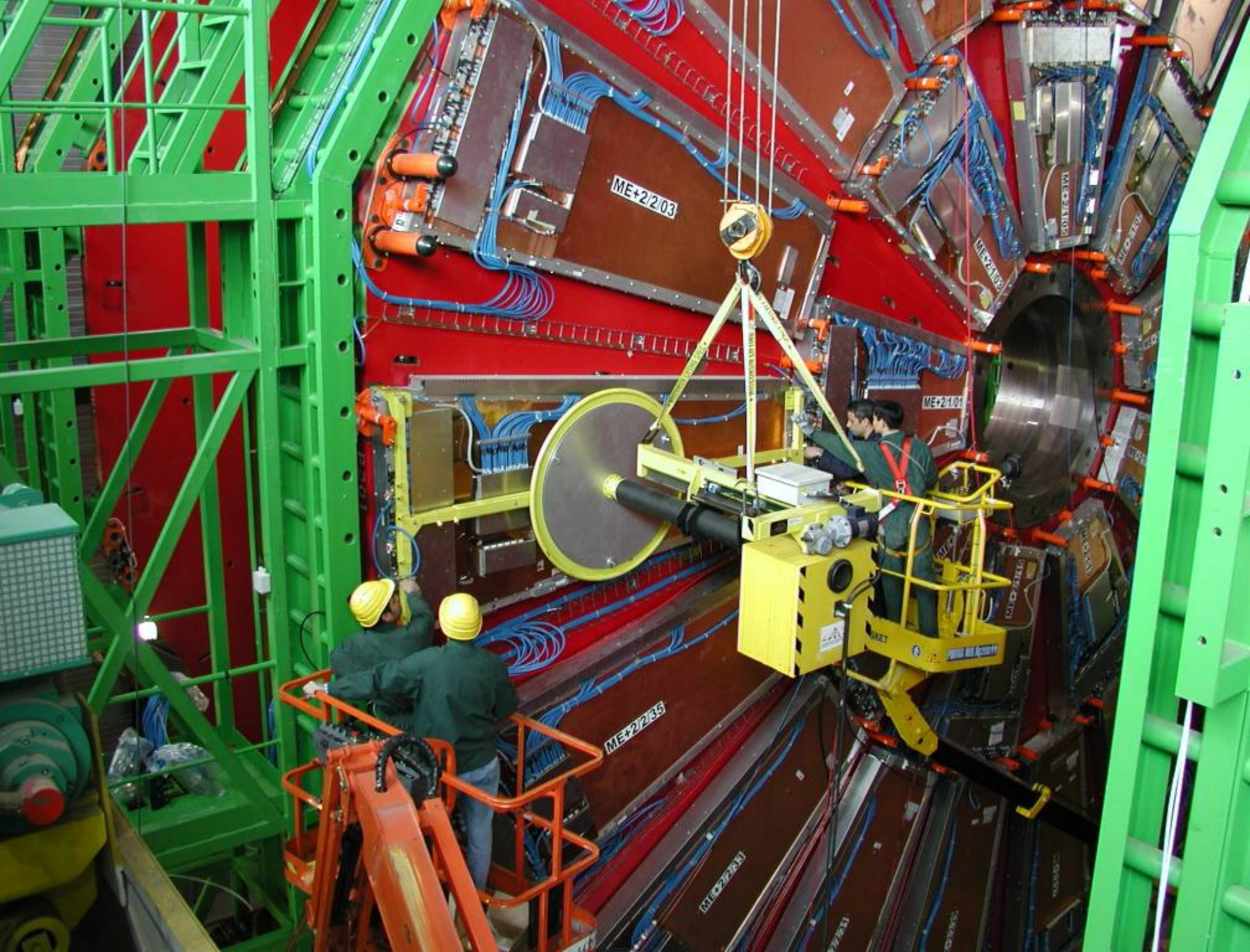
Origin of Particles

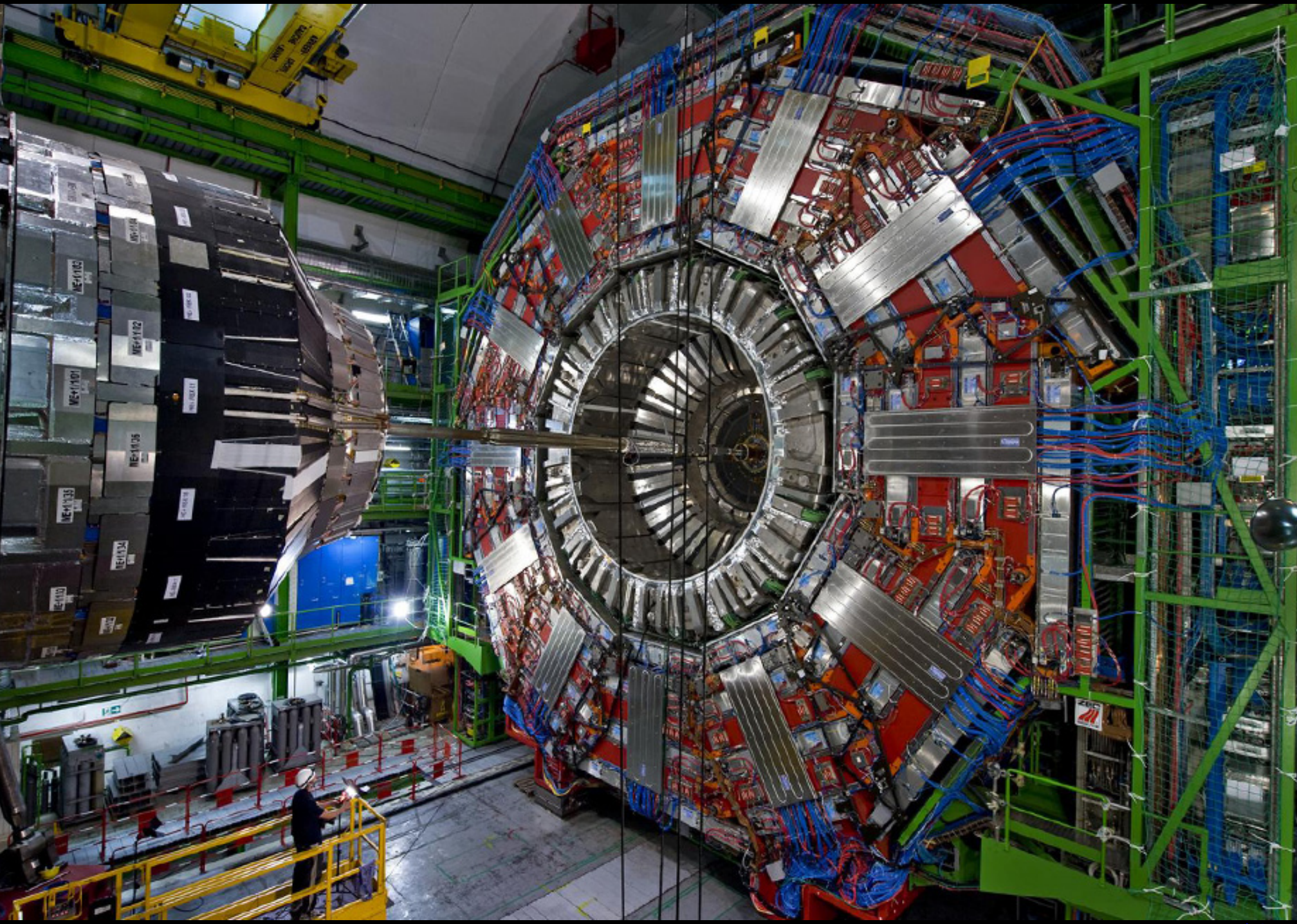
CERN and LHC in Geneva



LHC Tunnel with Magnets



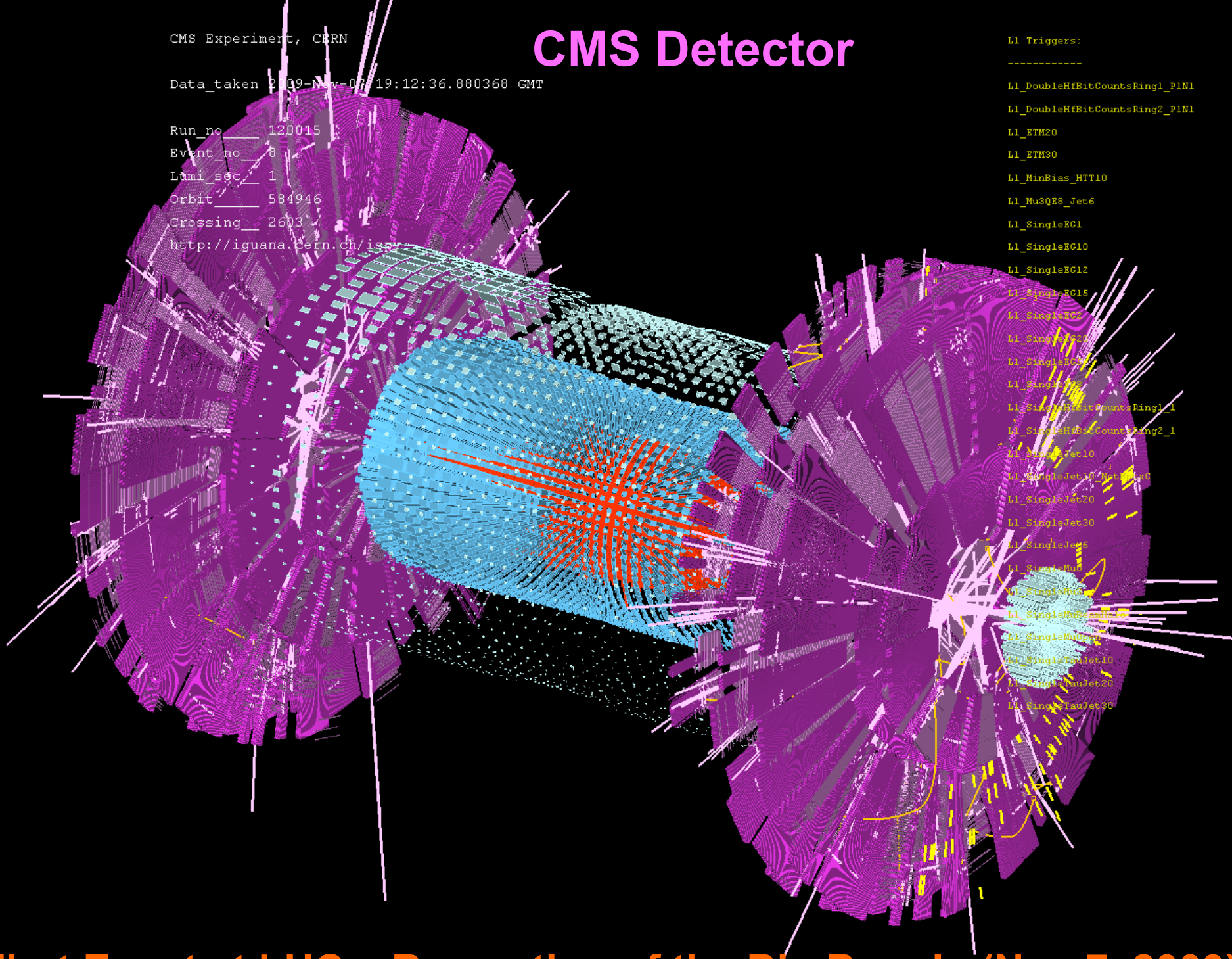

ME+2/2/03
ME+2/1/01
ME+2/2/35



Sept 15, 2008

CMS End-cap Muon Chamber made at Westwood in 1999 - 2005

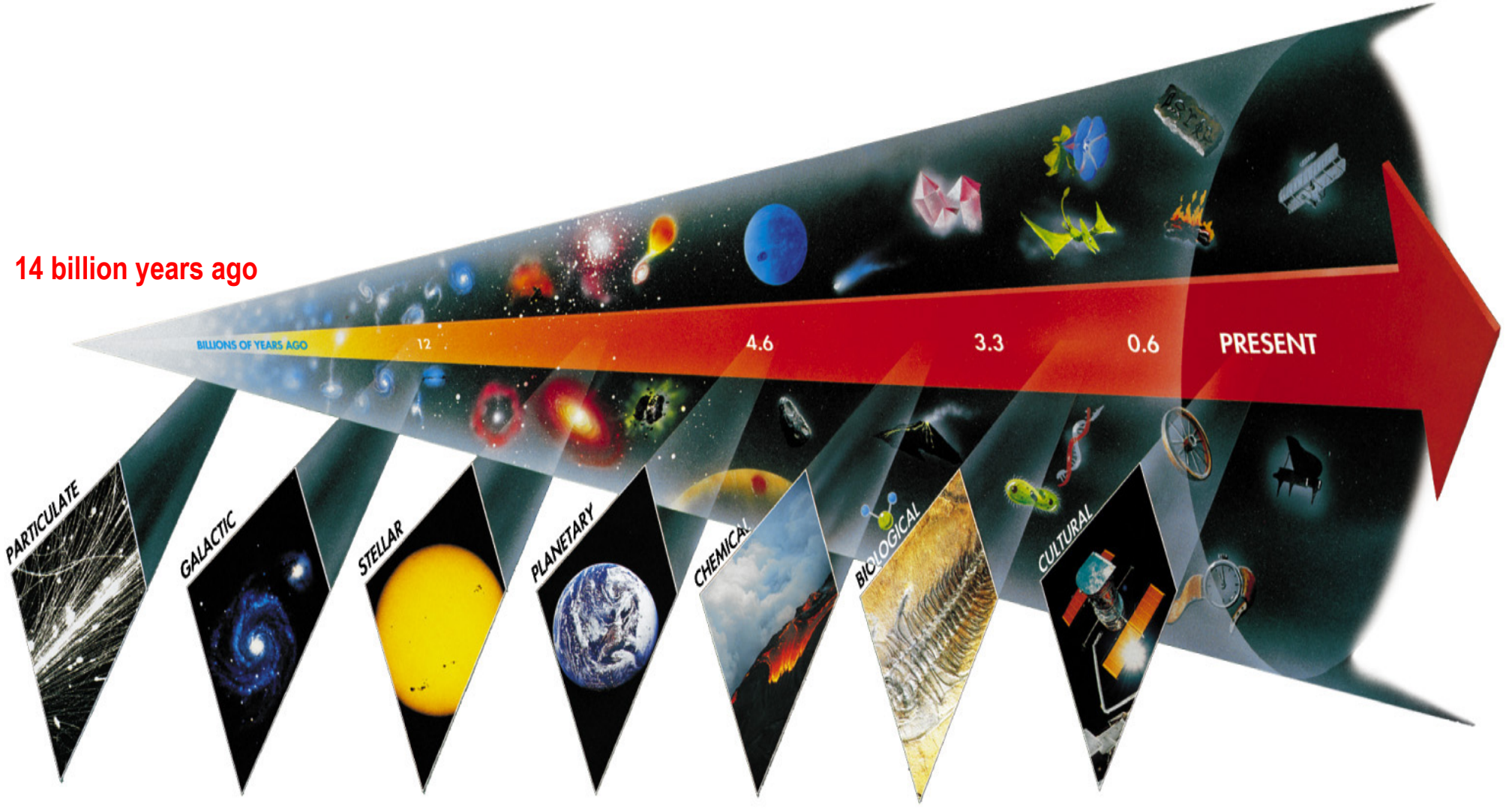
CMS Detector



First Event at LHC – Recreation of the Big Bang! (Nov 7, 2009)

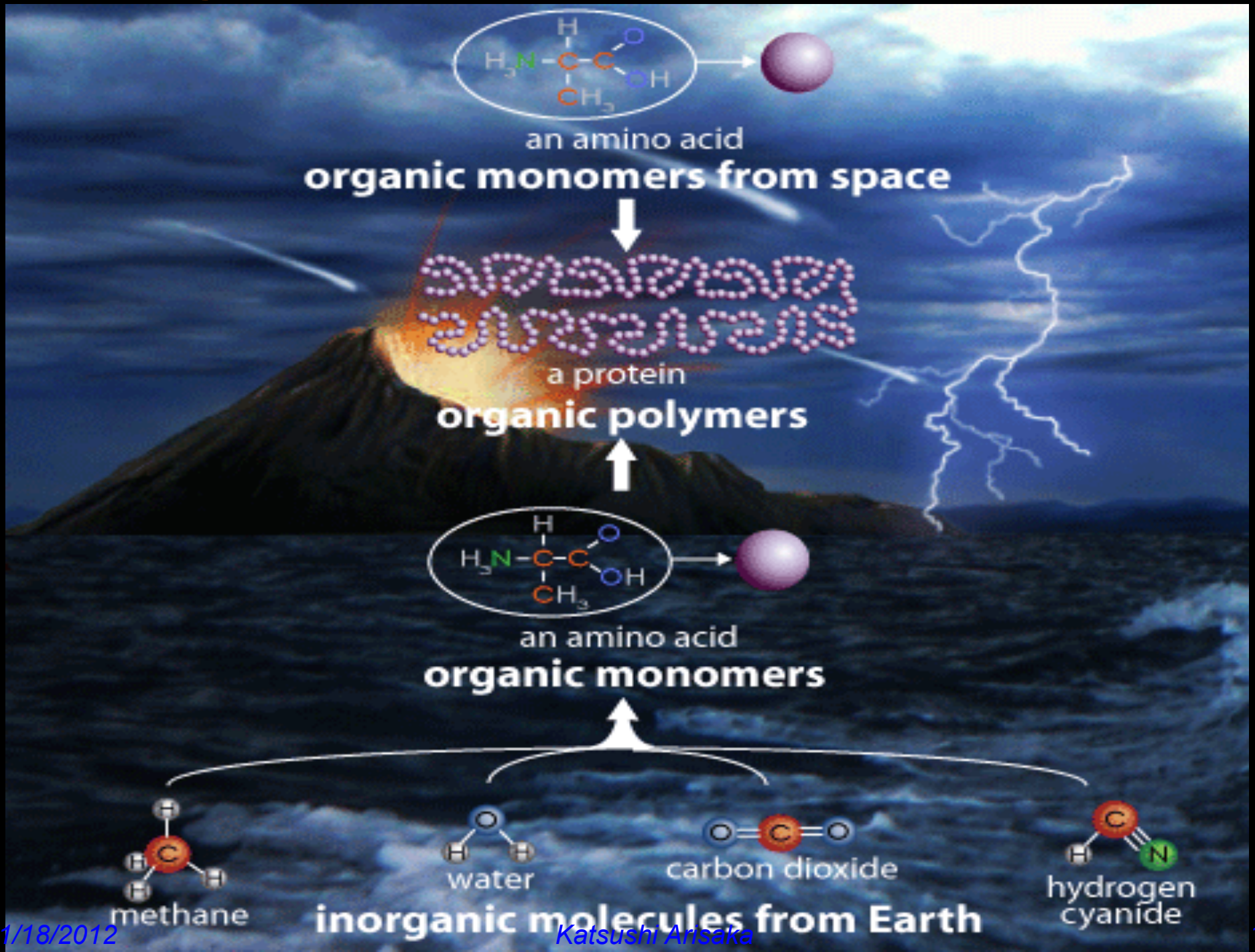
Origin of Life

Seven Phases of Cosmic Evolution

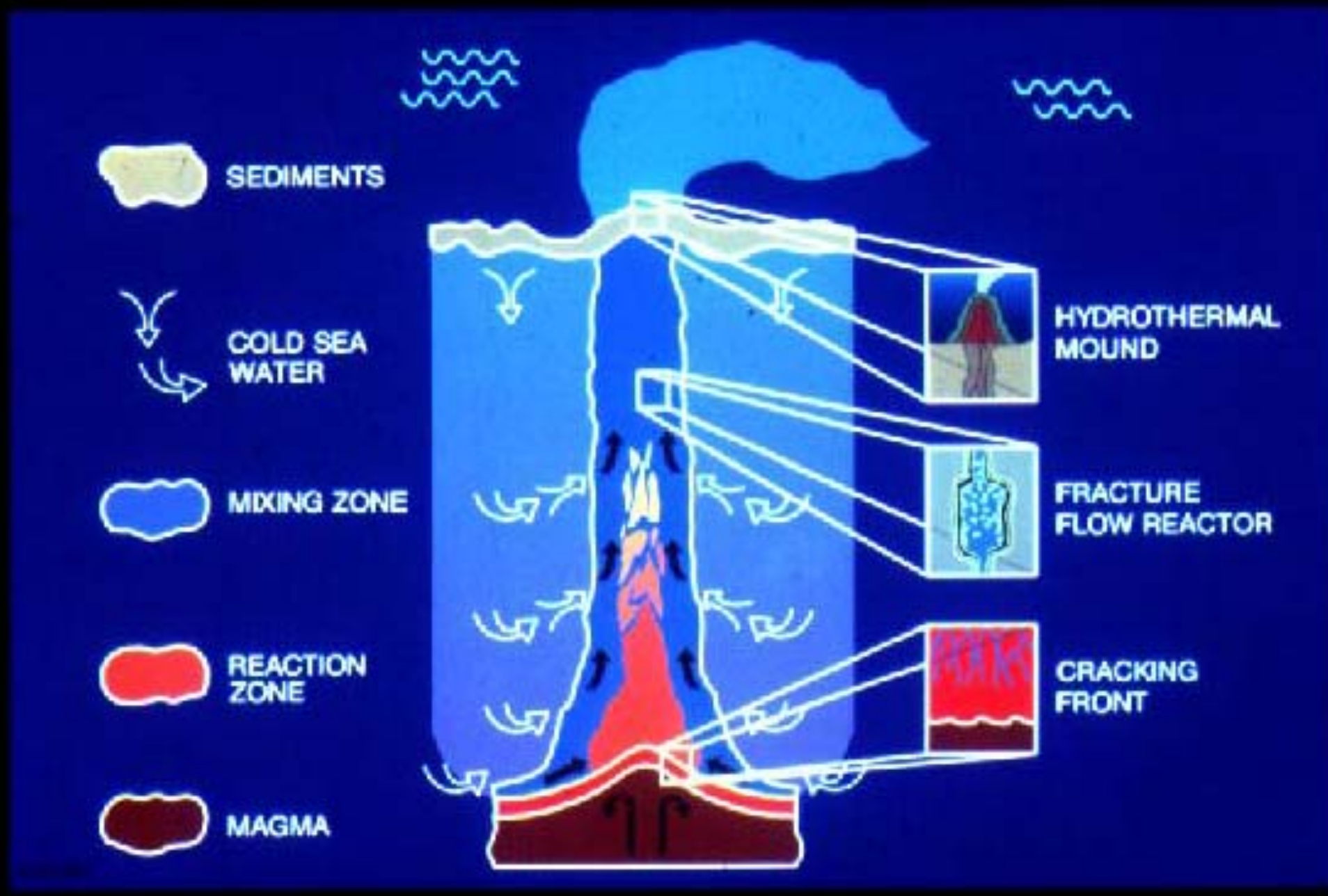


Origin of Life

Organic Polymers (4.5B → 4B years)



Volcano under deep ocean



Deviation from Thermal Equilibrium

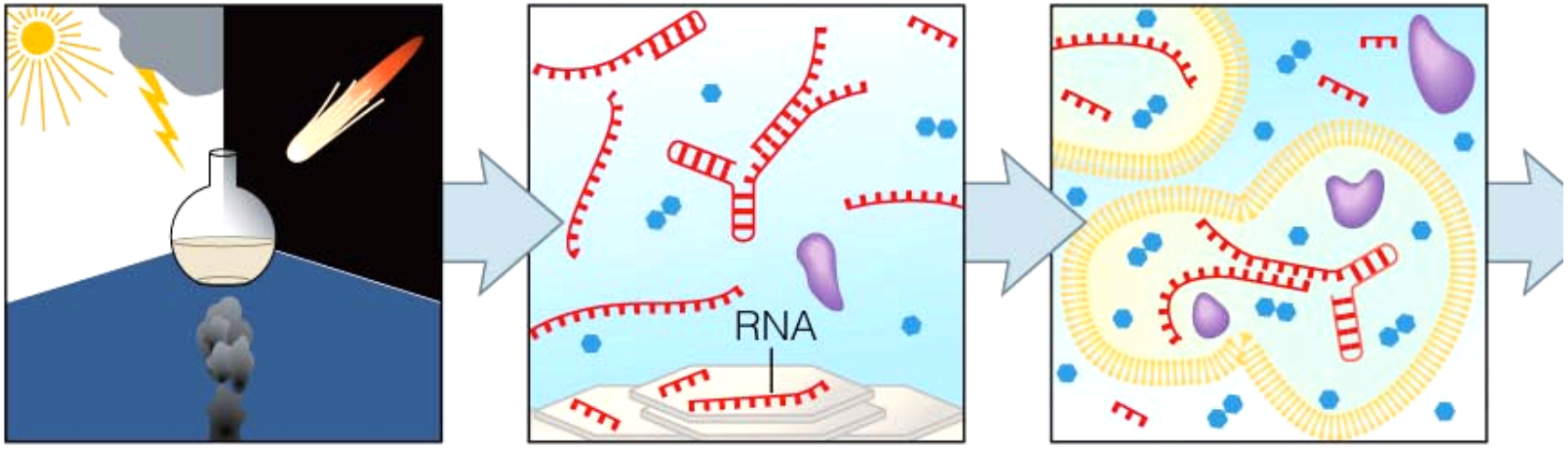
- **Particles — Quark, Leptons…**
  - Spontaneous Symmetry Breaking (Higgs Mechanism)
- **Atoms — Carbon, Oxygen, Iron …**
  - Explosion of Supernova
- **Organic Molecules — Ammonia, Amino Acid …**
  - Evolution of molecules in outer space by UV
- **Origin of Life — RNA, Protein, DNA**
  - Volcano under deep ocean

RNA Word (4B → 3.5B years ago)

1. Organic precursor molecules appear.

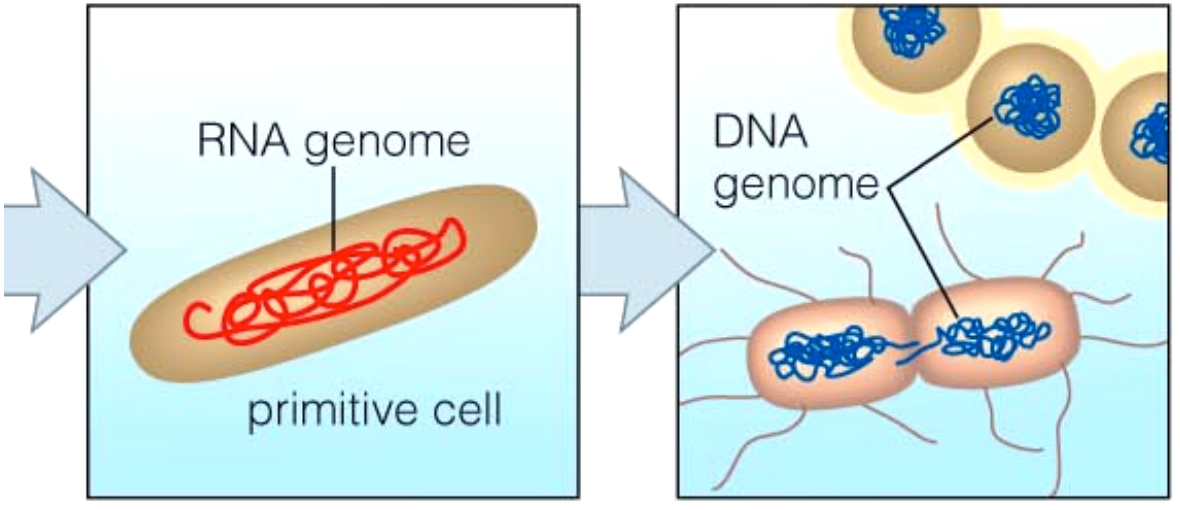
2. RNA molecules become self-replicating.

3. Membrane-enclosed pre-cells arise.



4. True cells with RNA genome appear.

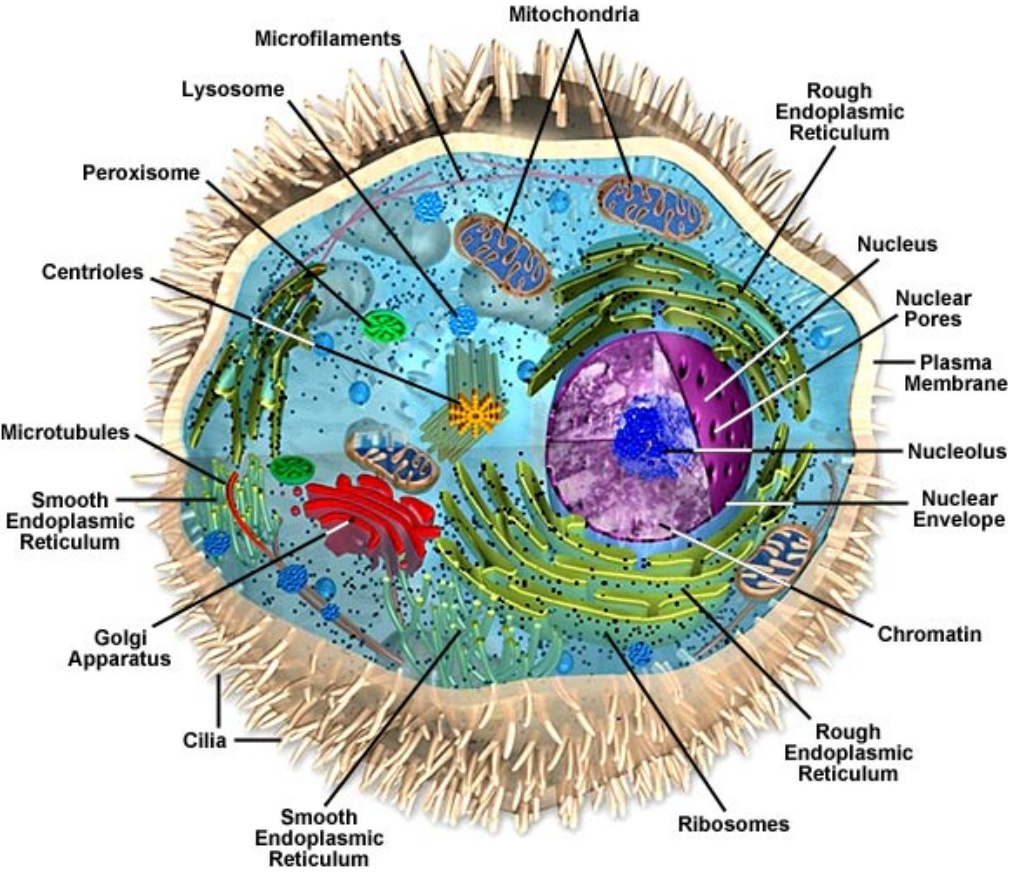
5. Modern cells with DNA genome evolve.



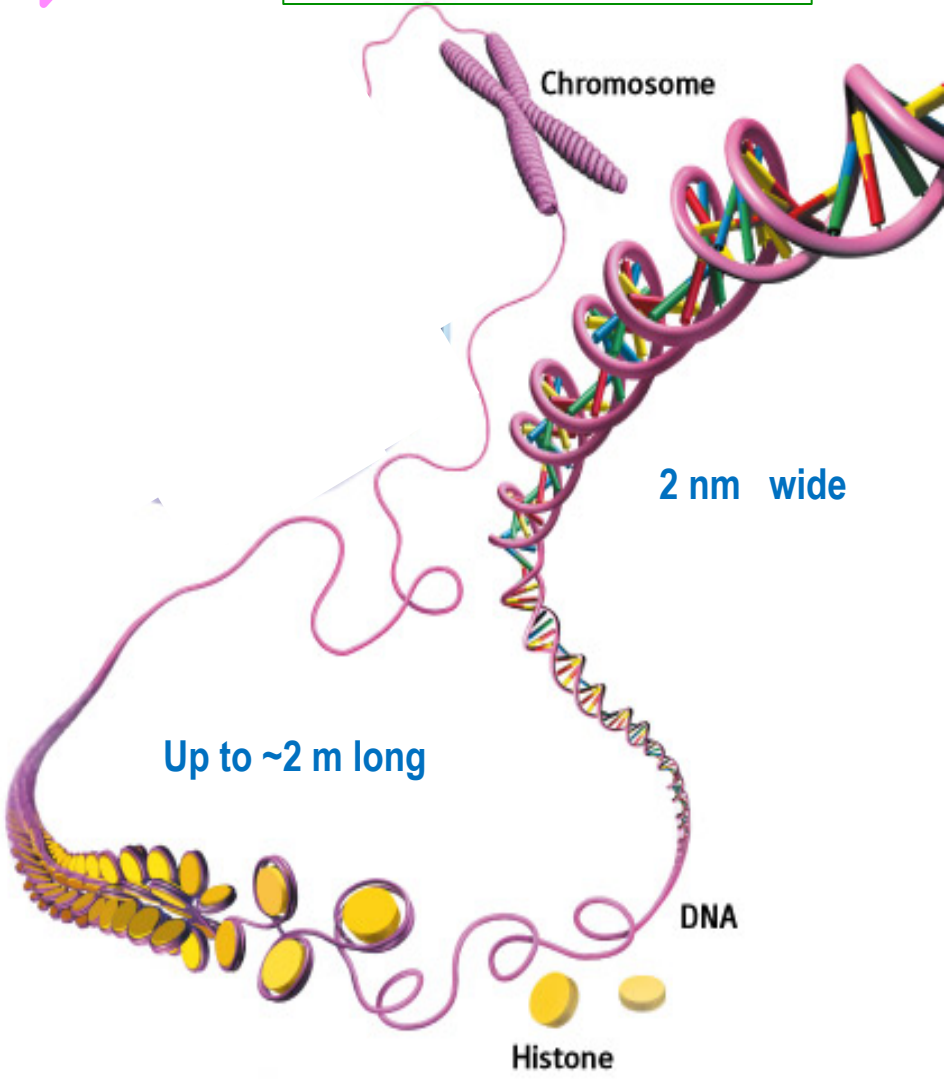
Eukaryote (~2B years ago)

Symmetry breaking

Cell made by proteins ⟺ **Gene made by DNA**



10 – 50 μm



Photosynthesis and Breathing

Spontaneous Symmetry Breaking

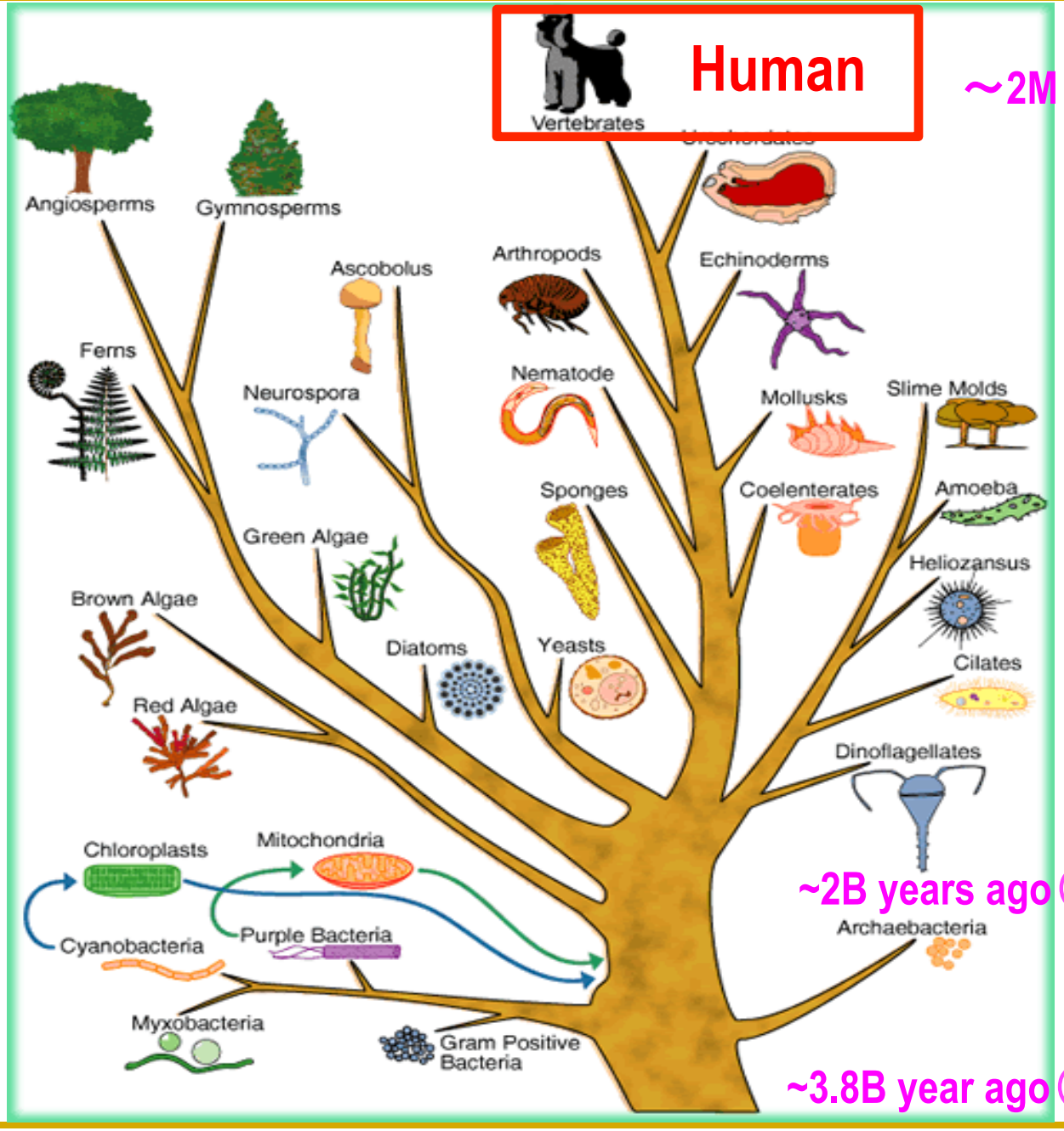
Plants	⟺	Animals
Chloroplast		Mitochondria

Photosynthesis

$$6CO_2 + 12H_2O \rightleftarrows C_6H_{12}O_6 + 6H_2O + 6O_2$$

Breathing

Tree diagrams of evolution



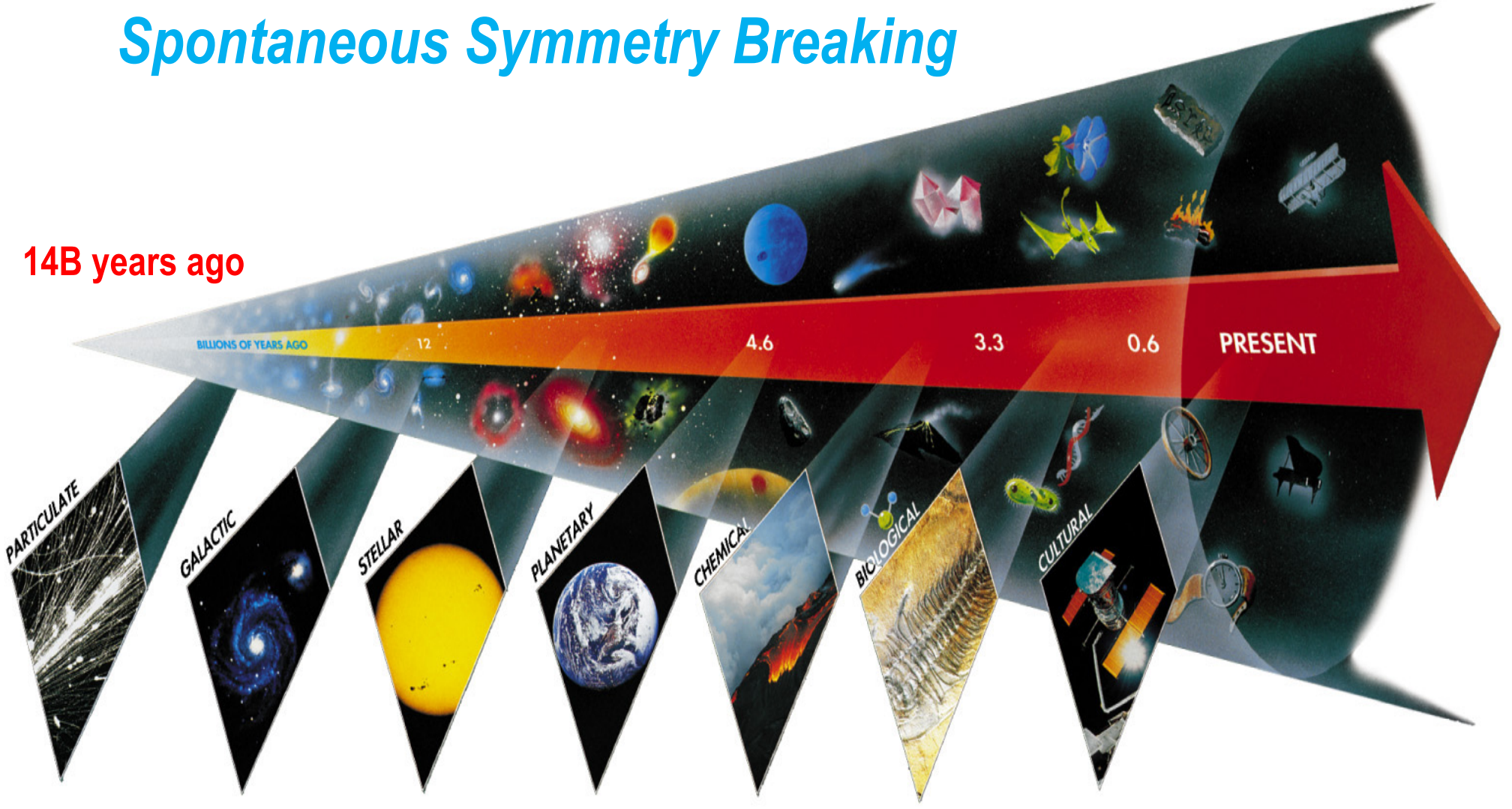
What is Life?

- **Emergent Property**
  - Strong-interacting, complex system
  - ~10^4 of different proteins in one cell
  - ~10^{14} cells in one life
- **Continuous, countless "symmetry breaking" towards coherent states**
  - Origin of life
  - Evolution of life
  - Growth from a single cell to a multi-cell body
  - Learning and memory

High-speed Bio-imaging

Seven steps of cosmic evolution

Spontaneous Symmetry Breaking



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

How to observe the Life and Consciousness ?

- We must look for "Live Life"
- Exactly the same way as we look for the "Origin of Universe"

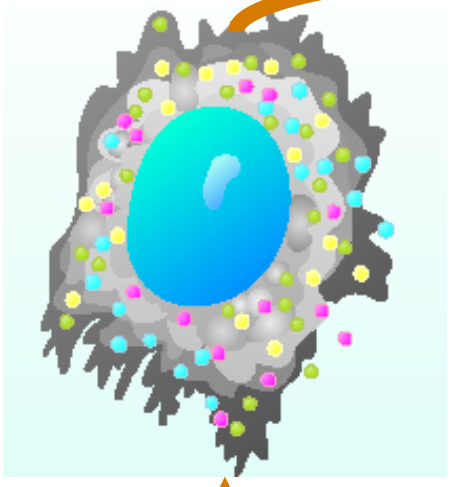
  Telescope ↔ Microscope

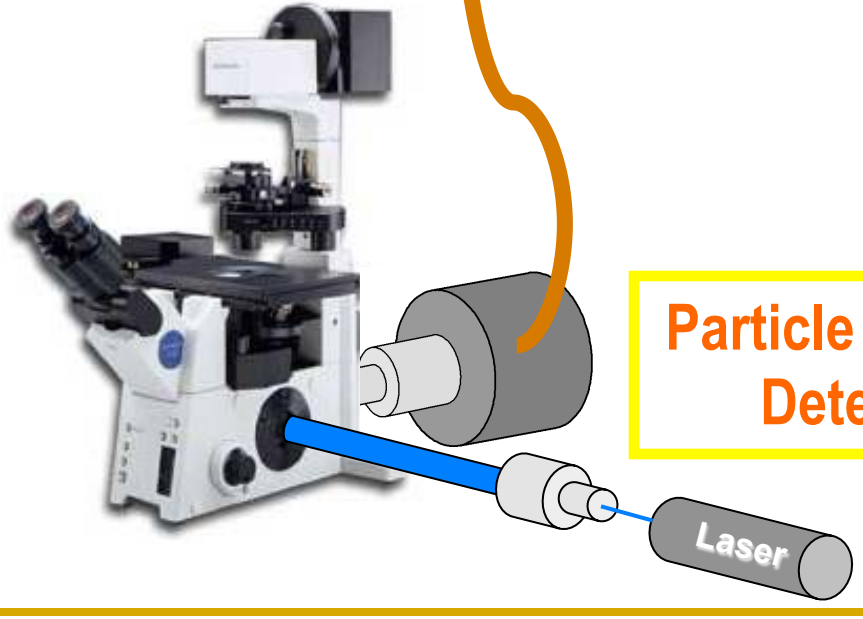
- Take advantages of the state of art "Photon Detectors" in particle physics.

Single Molecule Imaging

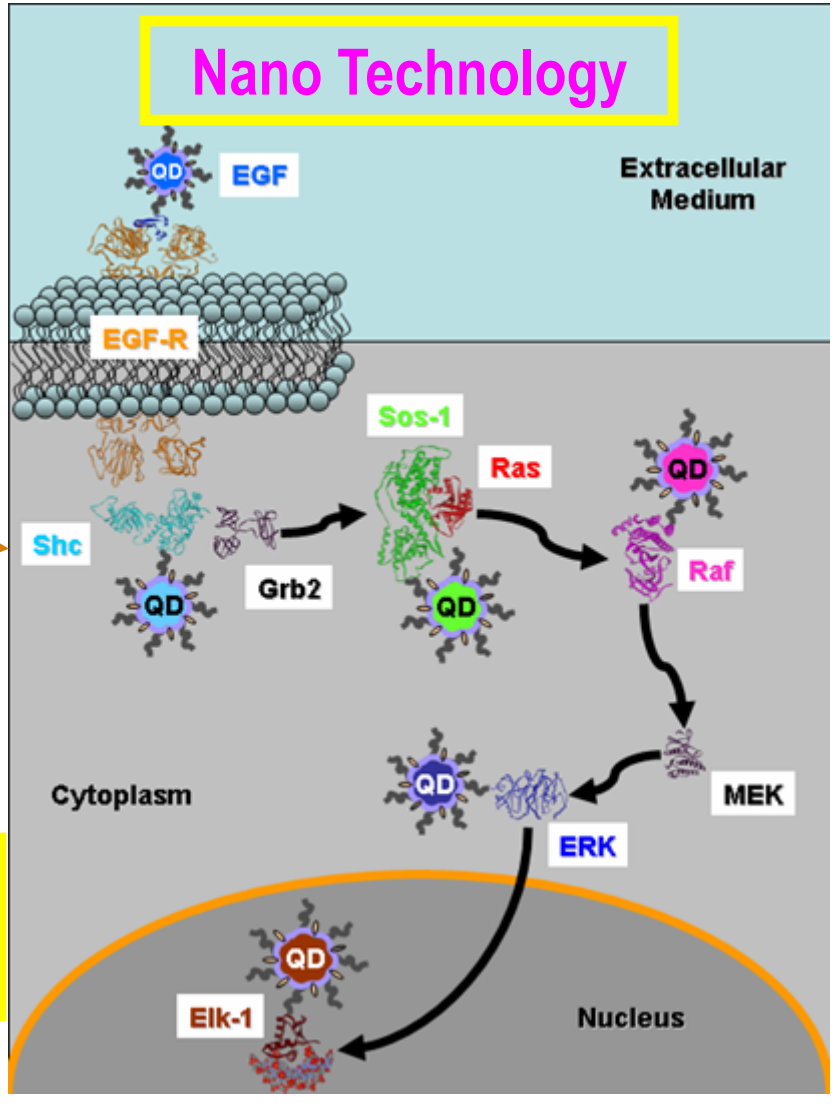
January 2006

Shimon Weiss (Chemistry)





Particle Physics Detector



How to speed up microscopes

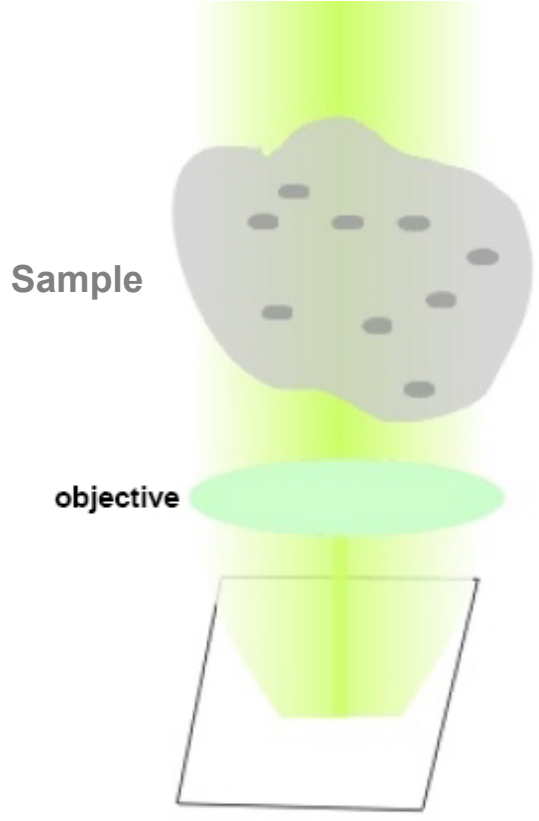
- All the existing microscopes are limited by the narrow bandwidth of readout.
  - Just one channel of FADC (Flash Analog to Digital Converter) running at 10 – 50 MHz
  - So-called Video Rate (30 frame/sec)

- 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

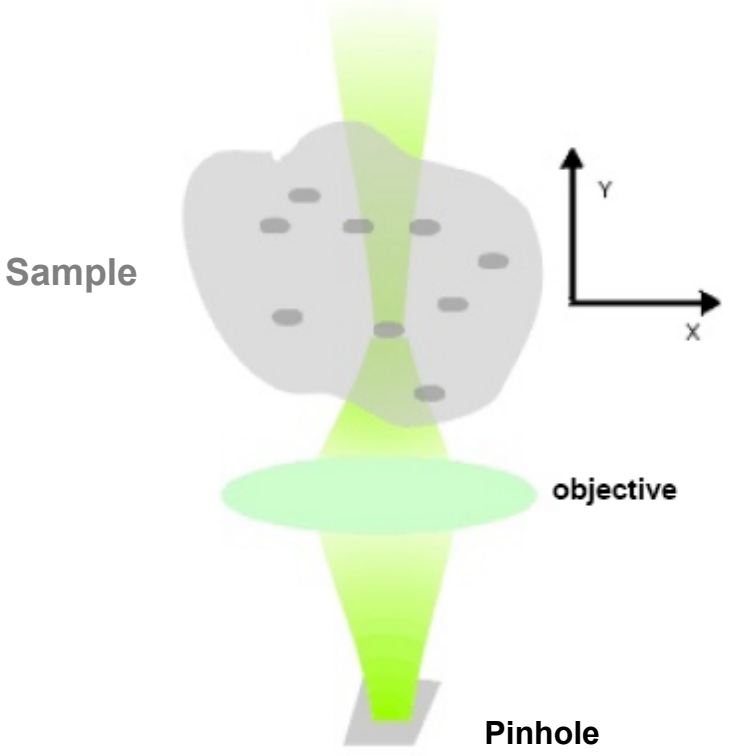


CCD + FADC (10 – 50 MHz)

⇩

CMOS [FADC (50 MHz) * 100]

Confocal

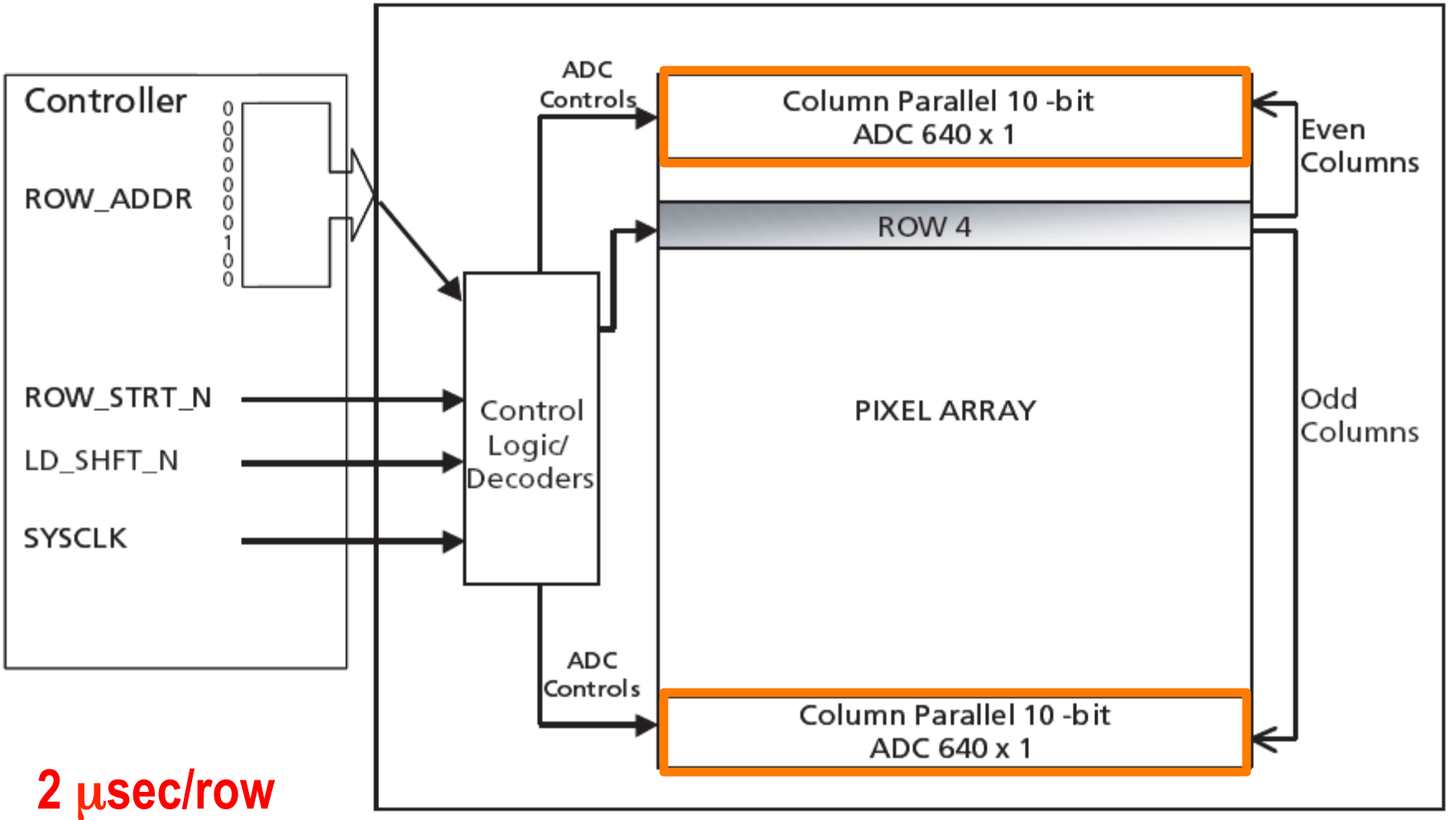


PMT + FADC (10 – 50 MHz)

⇩

[HAPD + FADC (1 GHz)] * 64

Micron 1.3M-Pixel CMOS Sensor



2 μsec/row
2 msec/frame

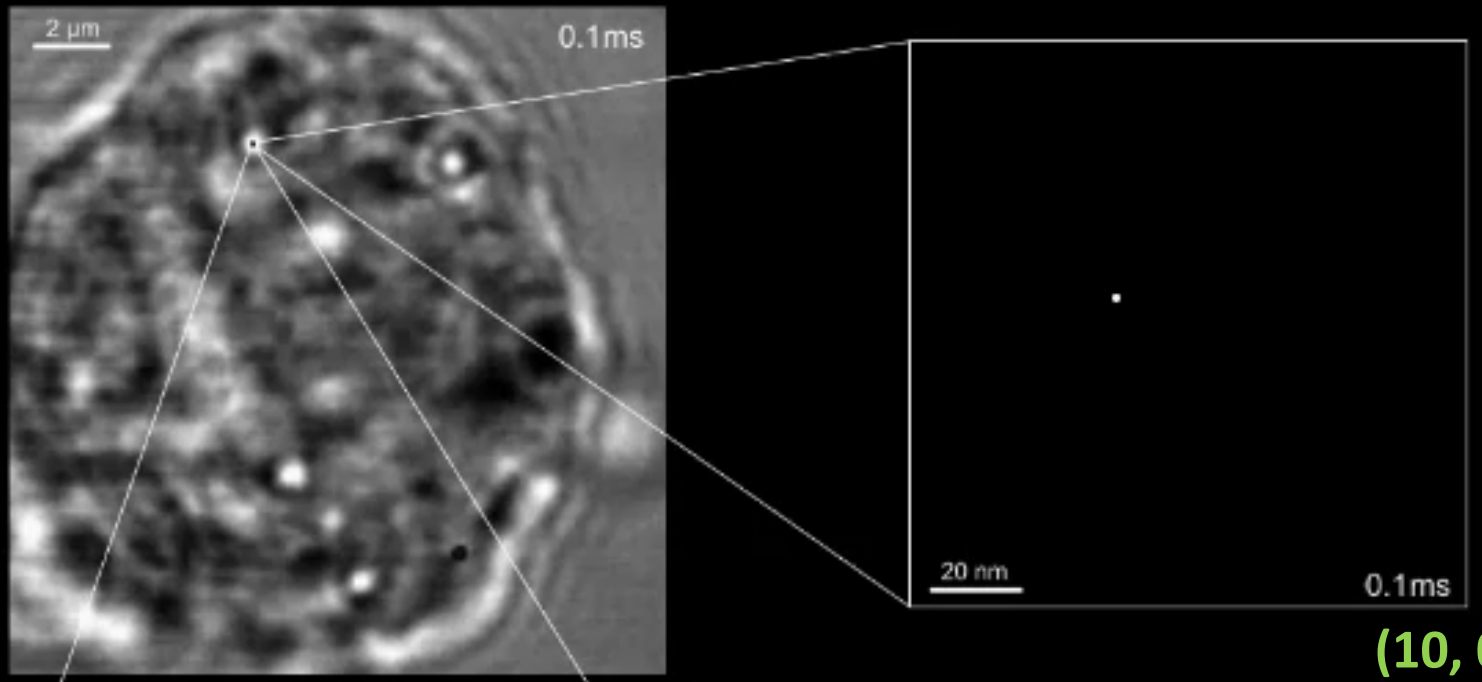
(10 bits, 66MHz)

Photron SA-5 CMOS Camera

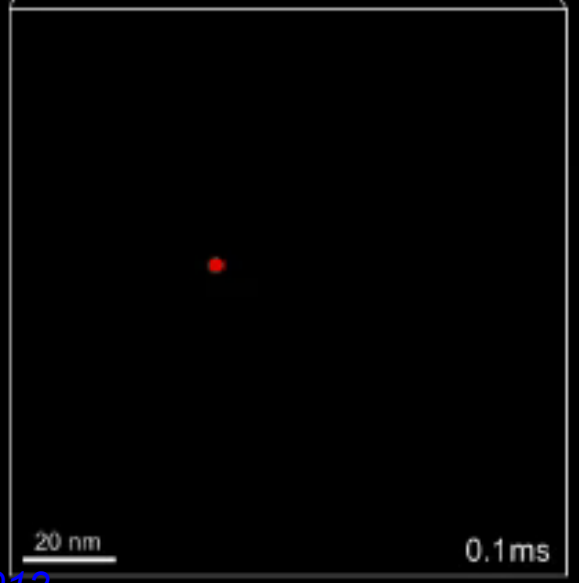
FRAME RATE (fps)	MAXIMUM RESOLUTION Horizontal	Vertical
1,000	1,024	1,024
2,000	1,024	1,024
4,000	1,024	1,024
5,000	1,024	1,024
7,000	1,024	1,024
7,500	1,024	1,000
9,300	1,024	800
10,000	1,024	744
15,000	960	528
20,000	832	448
30,000	768	320
50,000	512	272
75,000	320	264
100,000	320	192
150,000	256	144
300,000	256	64
420,000	128	64
525,000	128	48
775,000	128	24
930,000	128	16
1,000,000	64	16

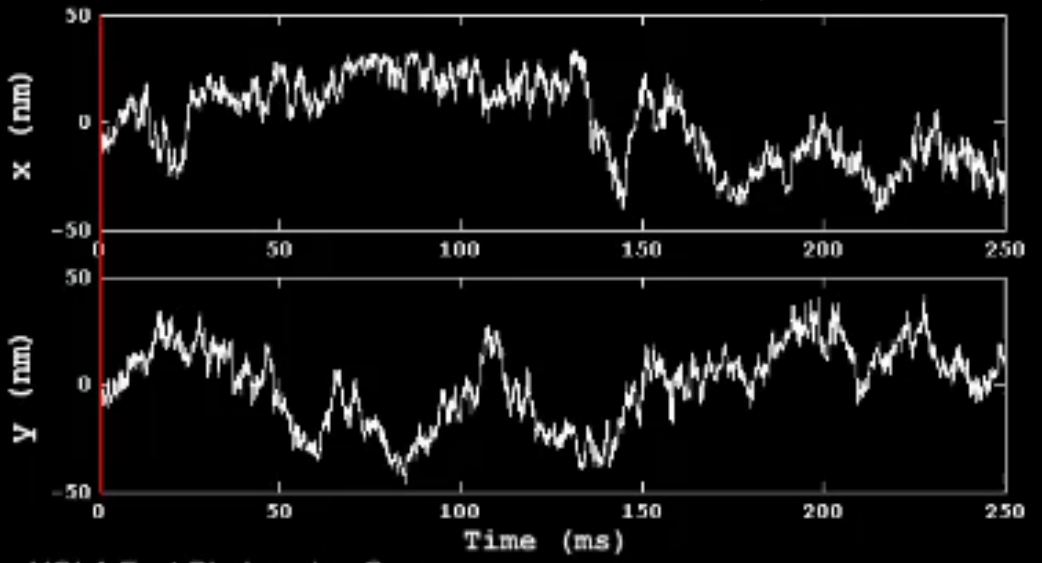
Gold nano particle (40nm) attached to Transferrin Receptor (TfR) on Cancer Cell

Prof. Manuel Penichet (Oncology)



(10, 000 frame/sec)

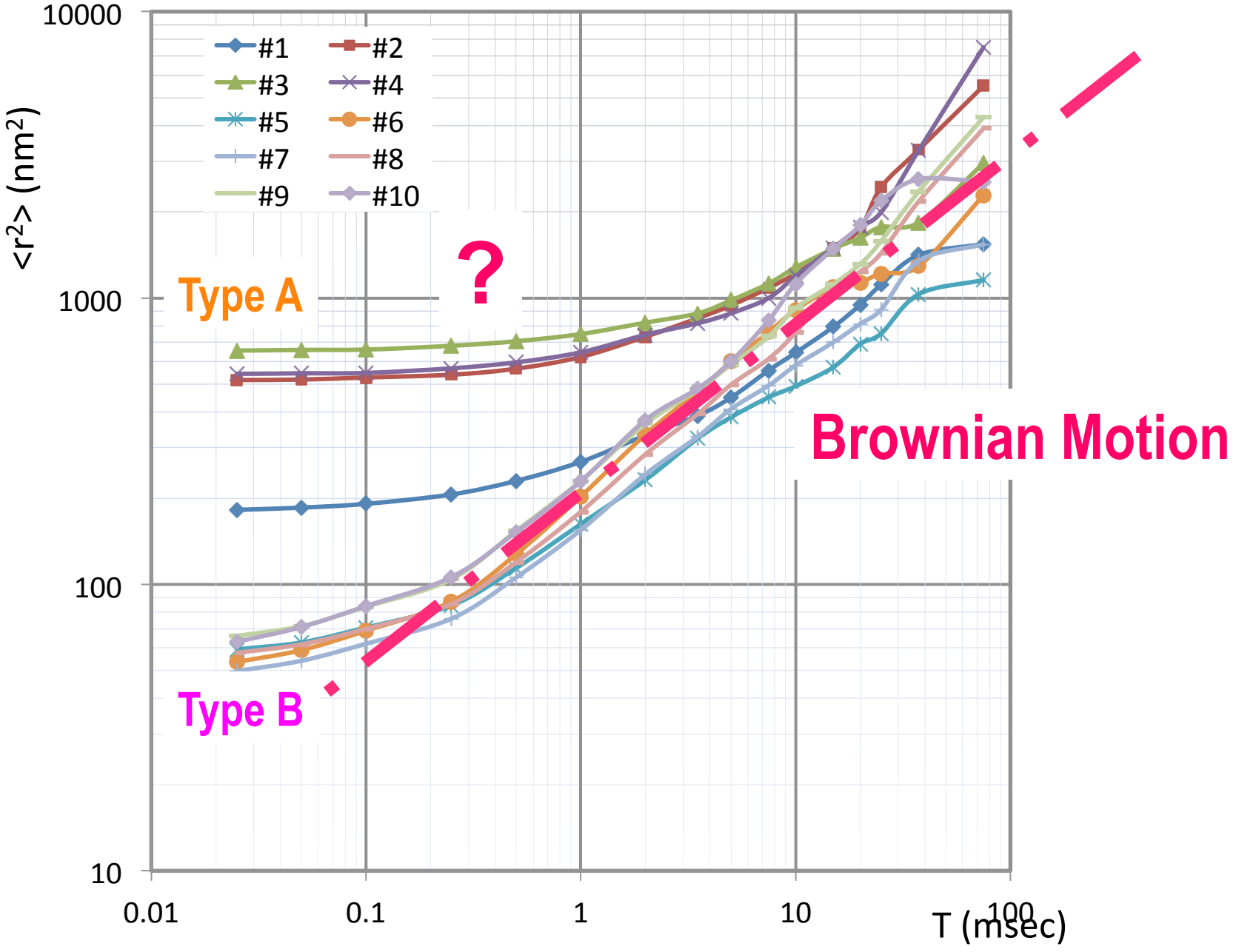




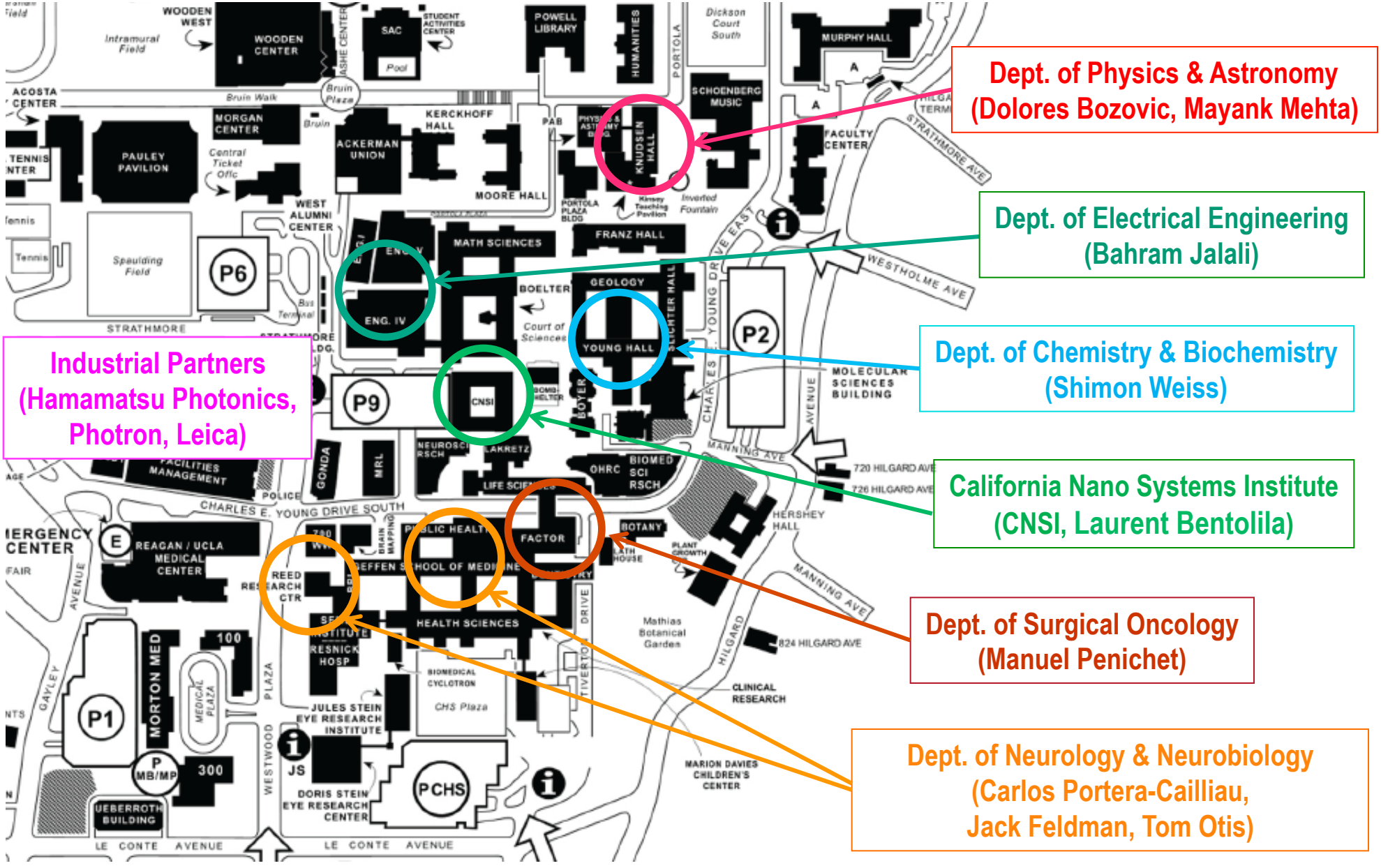
UCLA Fast Bio-Imaging Group

L. Fredrickson, H. Pandya, A. Cheng, K. Jewhurst, J. Miao, K. Arisaka

Mean Squire Displacement <r^2> of TfR on a Human Multiple Myeloma Cell vs. Time



Arisaka's Campus-wide Collaborations on High-Speed Bio-imaging



Dept. of Physics & Astronomy
(Dolores Bozovic, Mayank Mehta)

Dept. of Electrical Engineering
(Bahram Jalali)

Dept. of Chemistry & Biochemistry
(Shimon Weiss)

California Nano Systems Institute
(CNSI, Laurent Bentolila)

Dept. of Surgical Oncology
(Manuel Penichet)

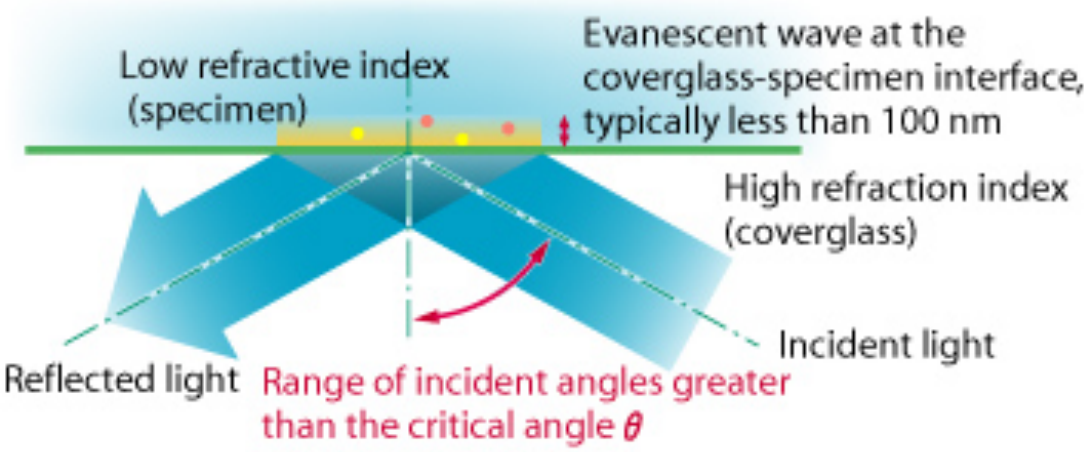
Dept. of Neurology & Neurobiology
(Carlos Portera-Cailliau,
Jack Feldman, Tom Otis)

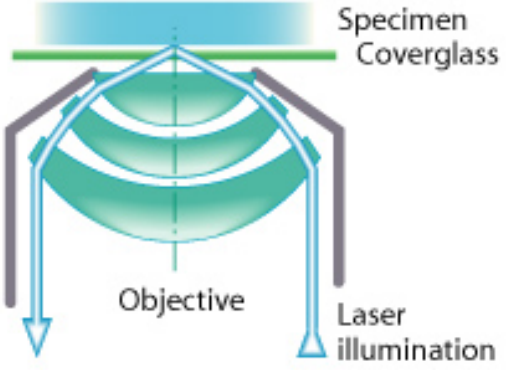
Industrial Partners
(Hamamatsu Photonics,
Photron, Leica)

User-shared Core Facility of High-speed Microscopes at CNSI

4D Nano Biophysics

Nikon Microscope TE200E with TIRF at CNSI



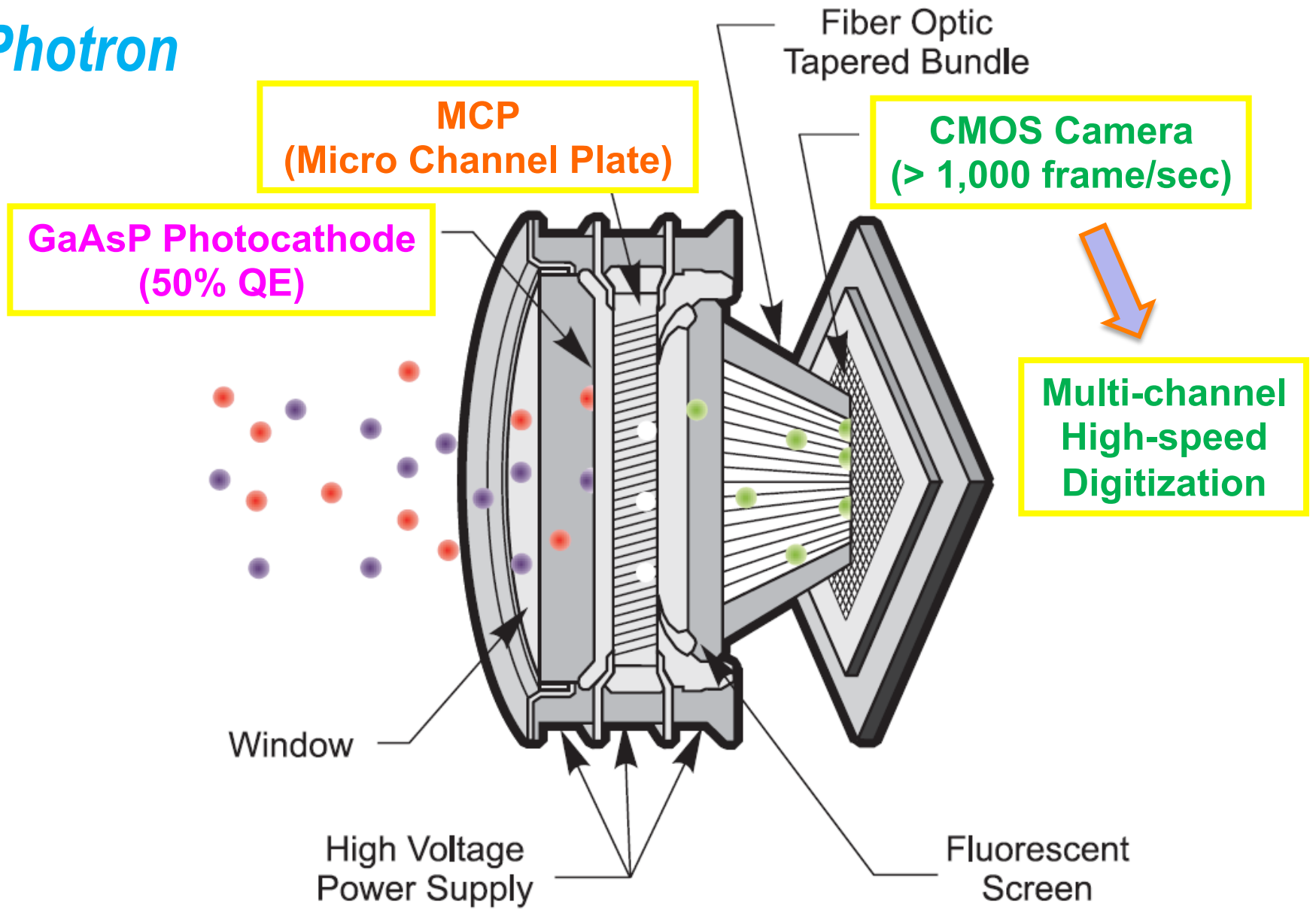


Laurent Bentolila (CNSI)

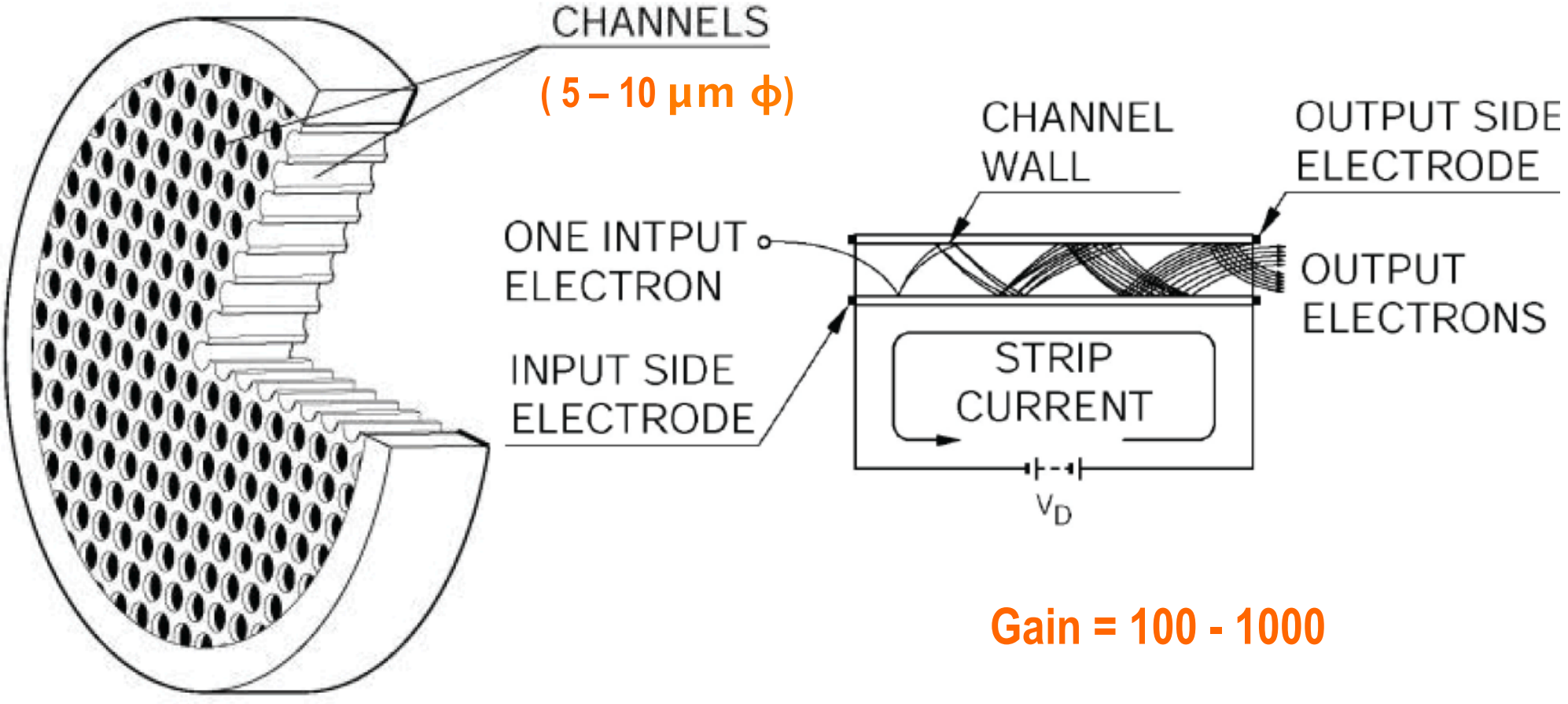
5k – 500k fps

CMOS Camera
Photron SA-1

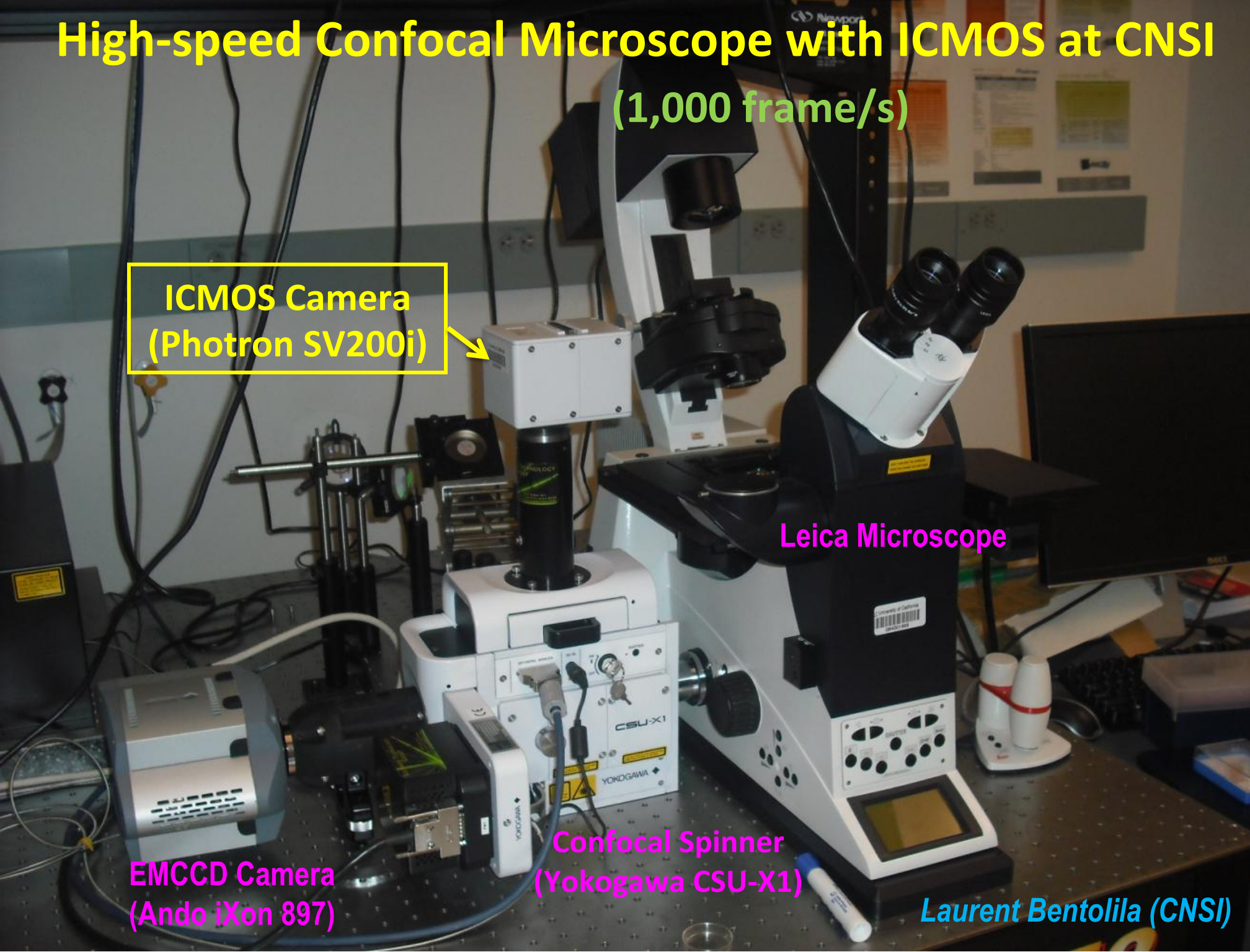
Principle of ICMOS



MCP (Micro Channel Plate)

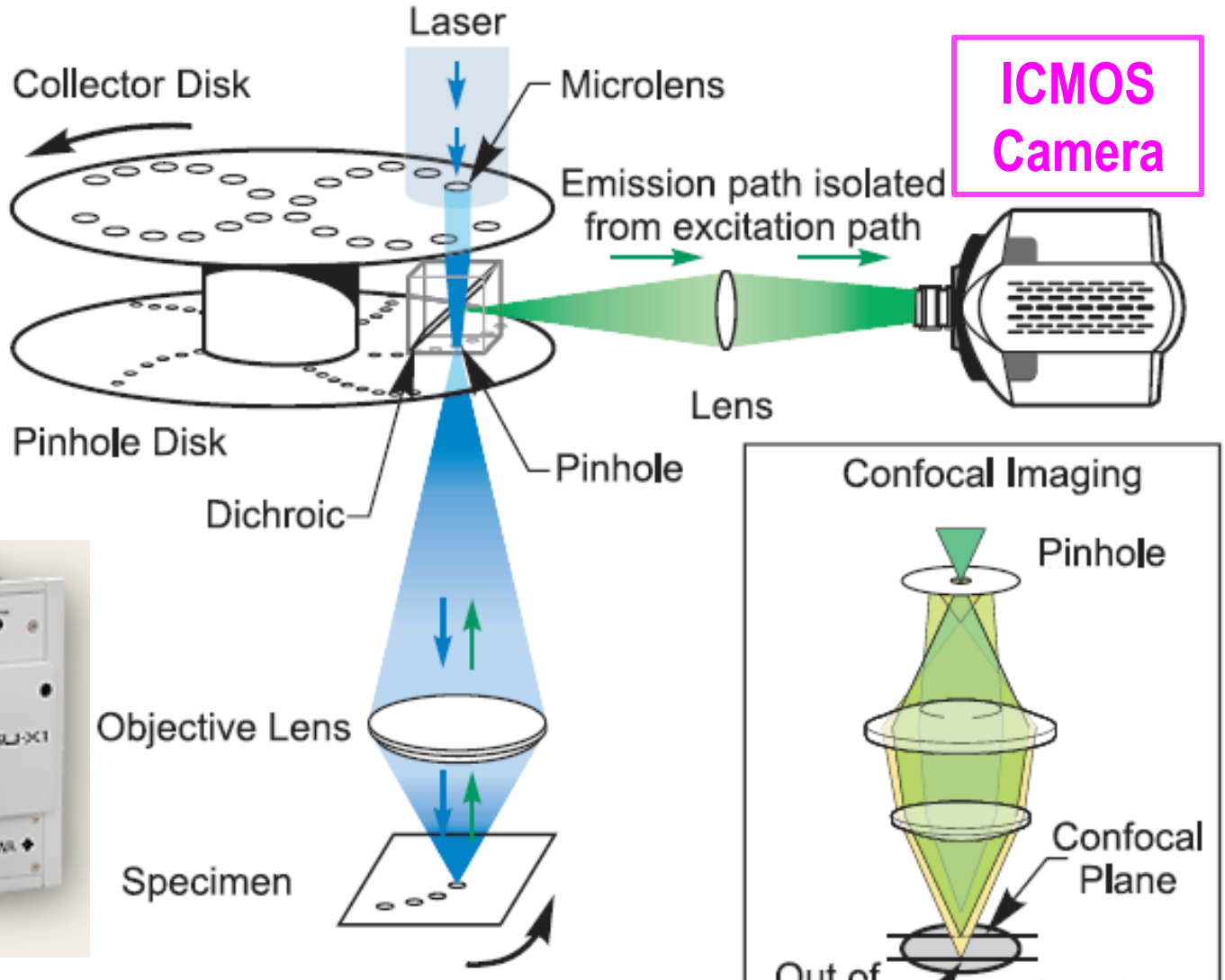


Gain = 100 - 1000


High-speed Confocal Microscope with ICMOS at CNSI
(1,000 frame/s)
ICMOS Camera
(Photron SV200i)
Leica Microscope
EMCCD Camera
(Ando iXon 897)
Confocal Spinner
(Yokogawa CSU-X1)
Laurent Bentolila (CNSI)

Yokogawa CSU-X1

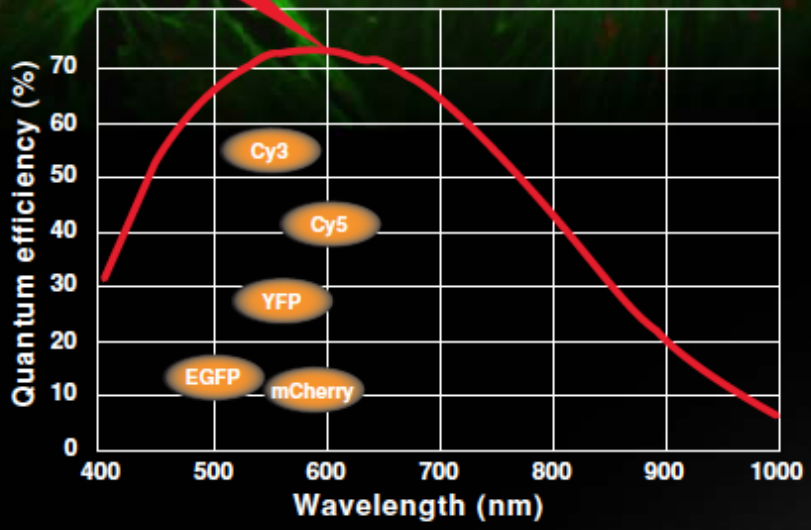
2,000 fps



Confocal Dual Spinning Disk

Exceptional sensitivity

Over 70 % at 600 nm



DIGITAL CAMERA

ORCA®-Flash4.0

Low noise

1.3 electrons

at 100 frames/s

High-speed readout

100 frames/s

at full resolution

High resolution

4.0 megapixels

at 6.5 µm × 6.5 µm pixels

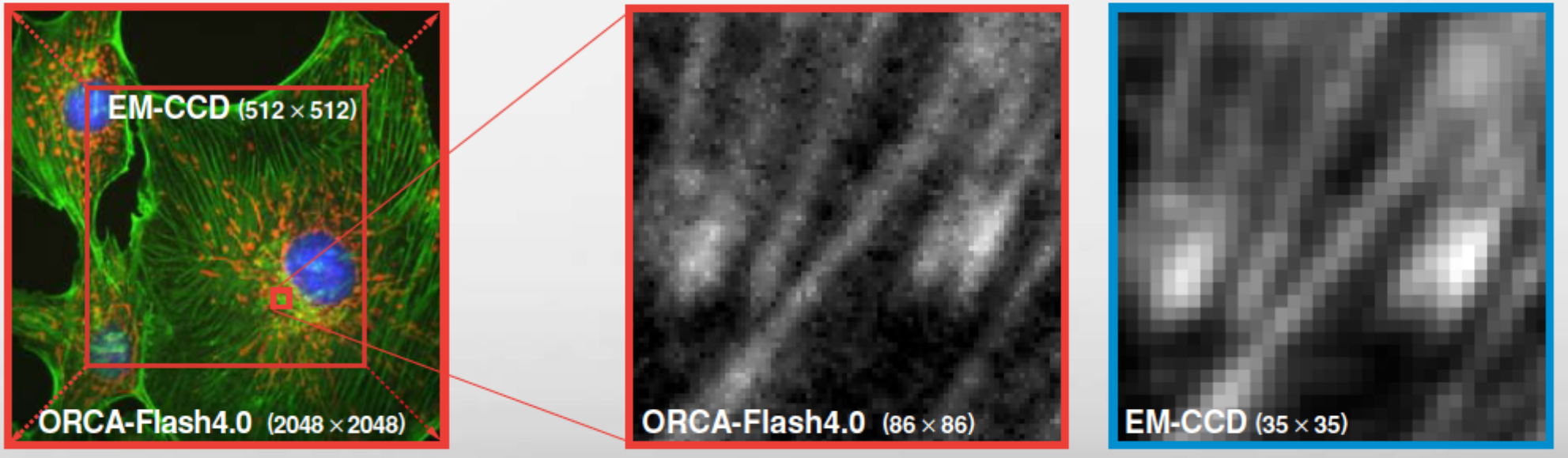
HAMAMATSU

■ Comparison of field of view

Field of view is 2.5× larger than that of a standard EM-CCD camera.

■ Comparison of resolution

The 6.5 μm × 6.5 μm pixels of the ORCA-Flash4.0 enable much finer detail to be resolved when compared to the 16 μm × 16 μm pixels of an EM-CCD camera.

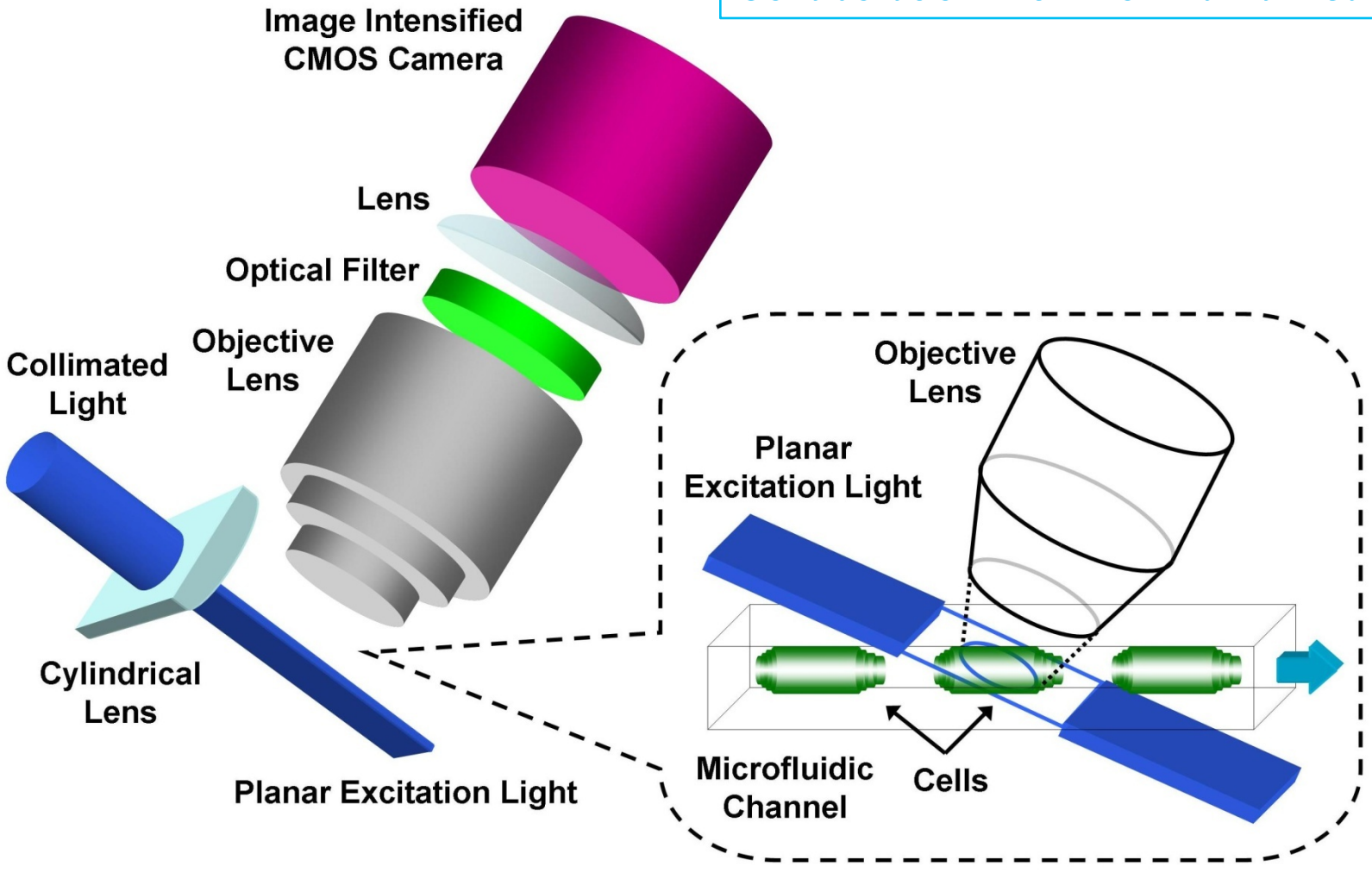


▲ Sample: FluoCells Prepared Slide #1, Object lens: S Plan Fluor 100×

Readout Method	Number of Pixels	Readout Speed at center position (frames/s)
Full Resolution	2048 x 2048	100
Sub-array readout (Typical examples)	2048 x 1024	200
	2048 x 512	400
	2048 x 256	800
	2048 x 64	3200
	2048 x 8	25,600

Imaging Flow Cytometerby Planar Illumination

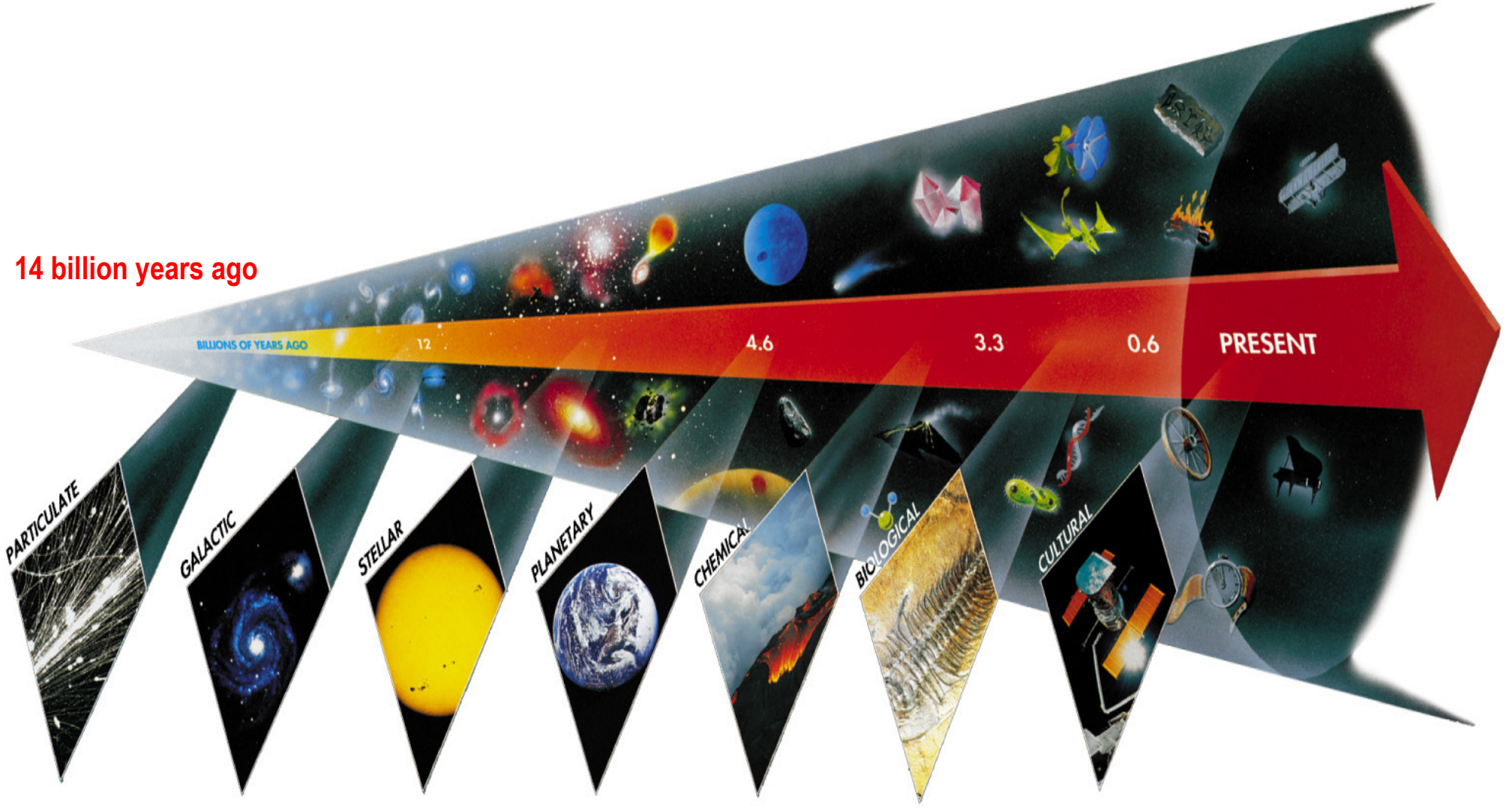
Collaboration with Prof. Bahram Jalali (EE)



Speeding up evolution of life by accelerating mutations.

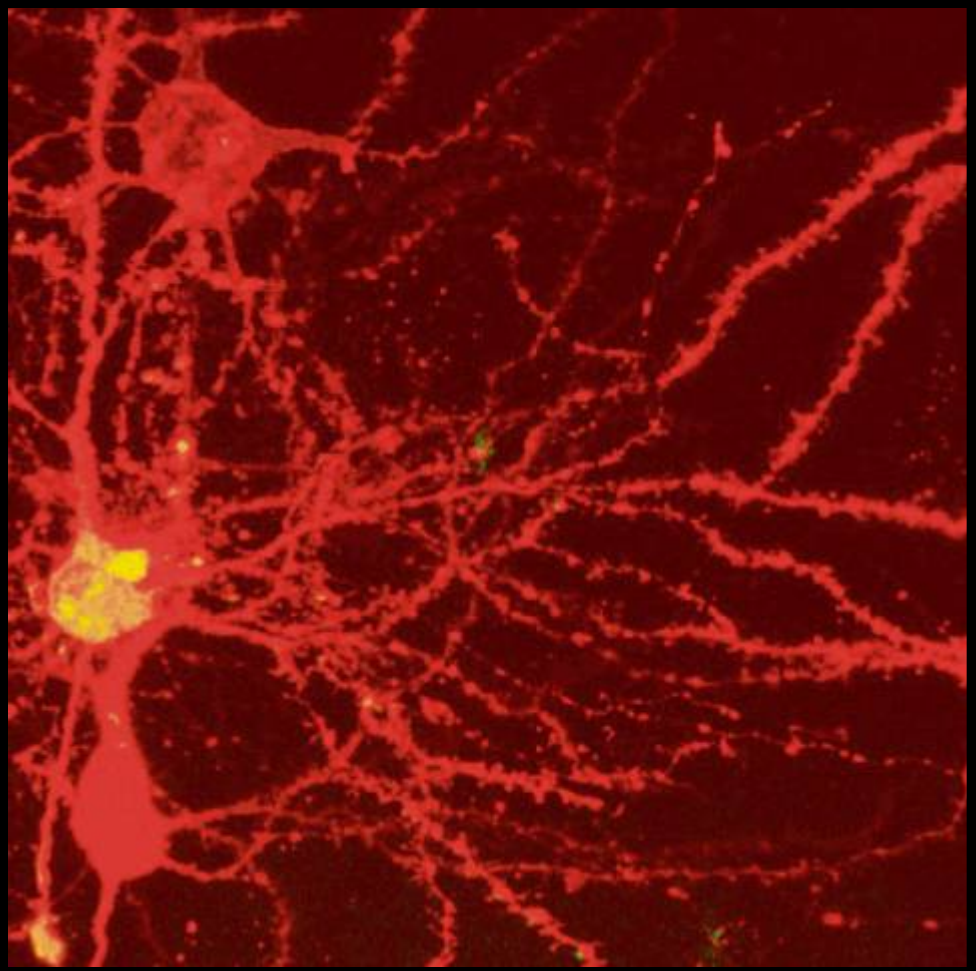
Origin of Consciousness

Seven Phases of Cosmic Evolution



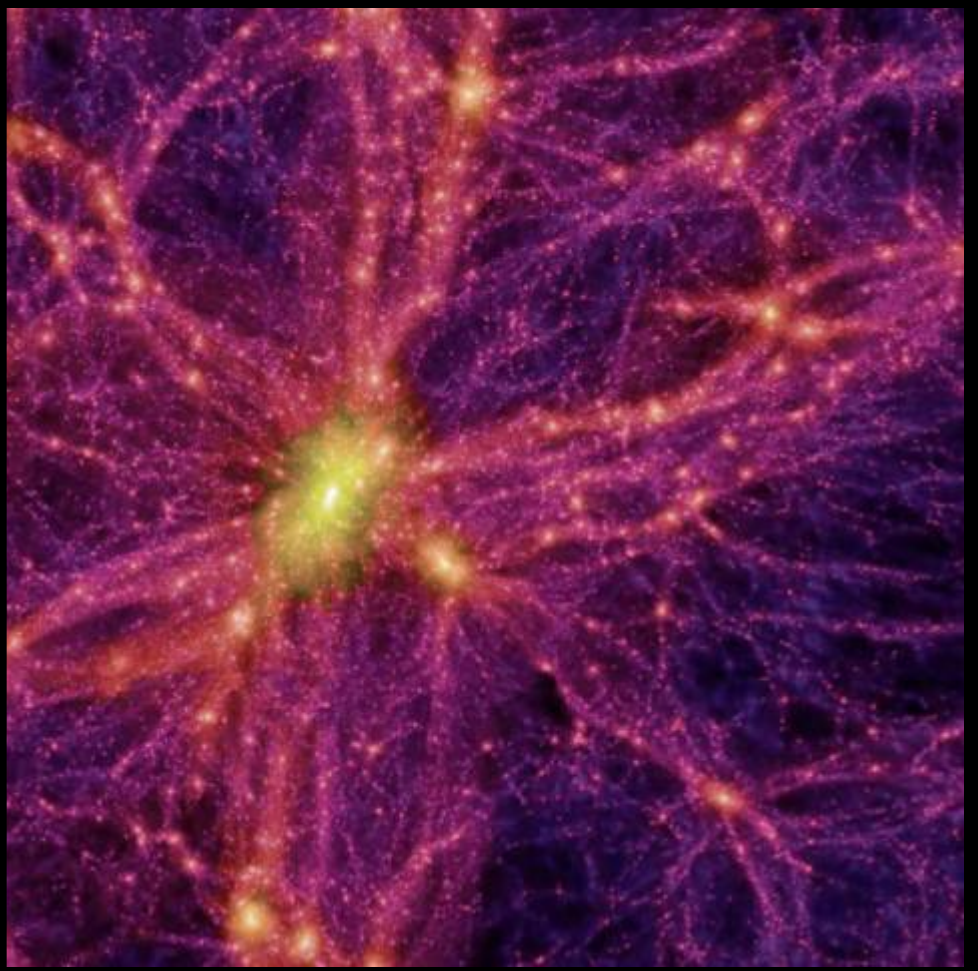
Origin of Consciousness

Brain



100 Billions Neurons

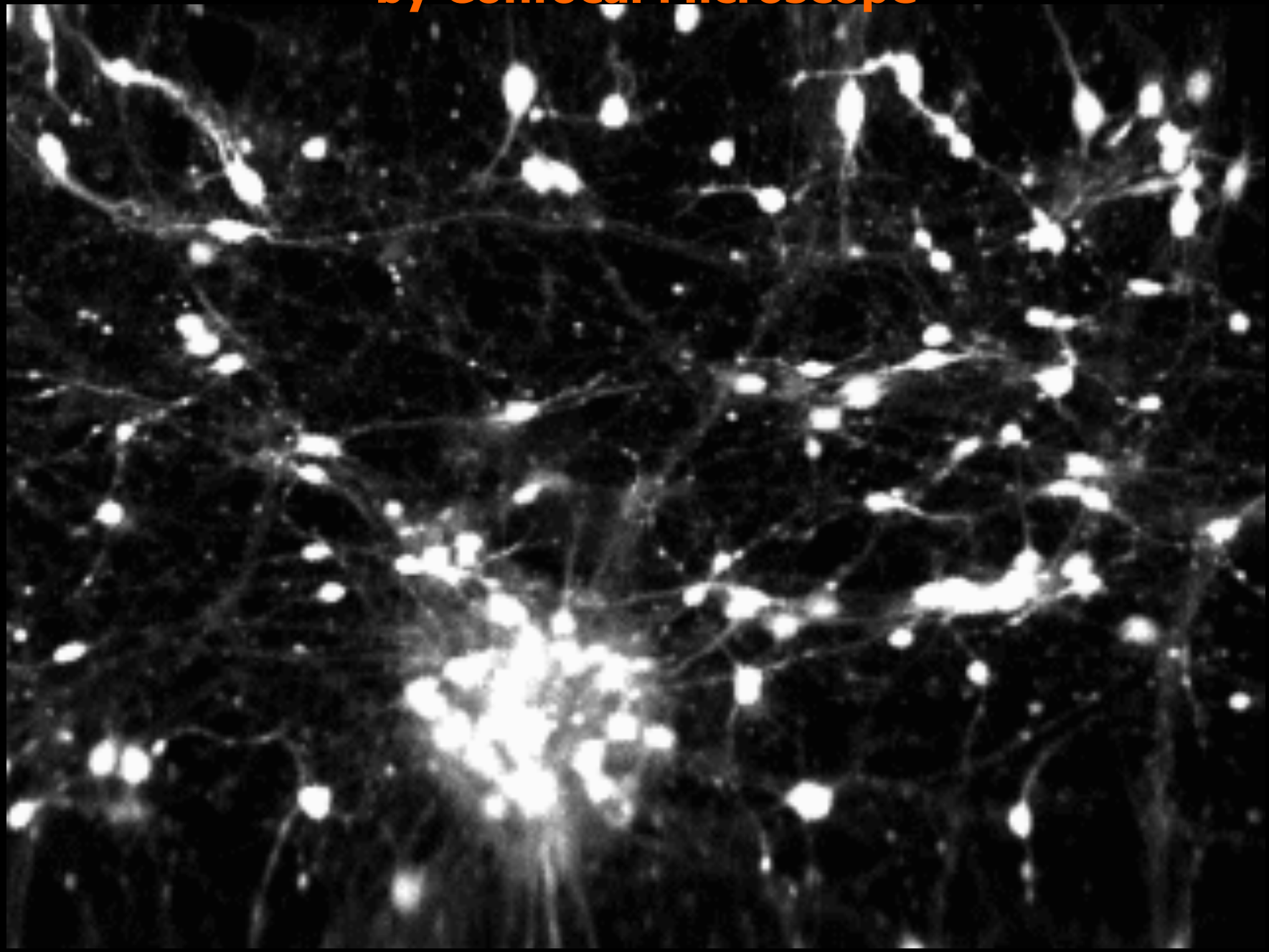
Universe



100 Billions Galaxies

New York Times 8/21/2006

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

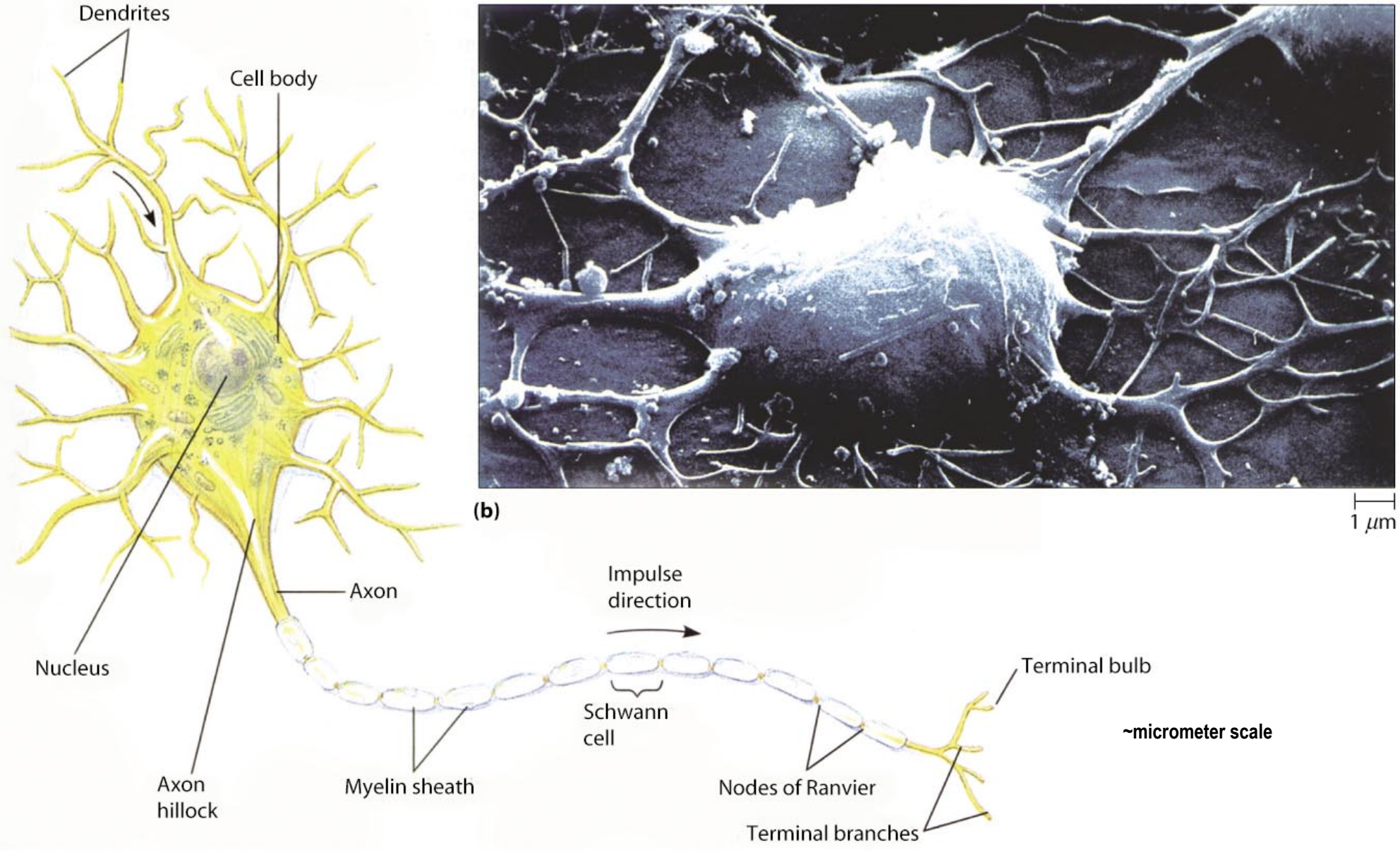


Andrew Charles (Neurobiology)

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.

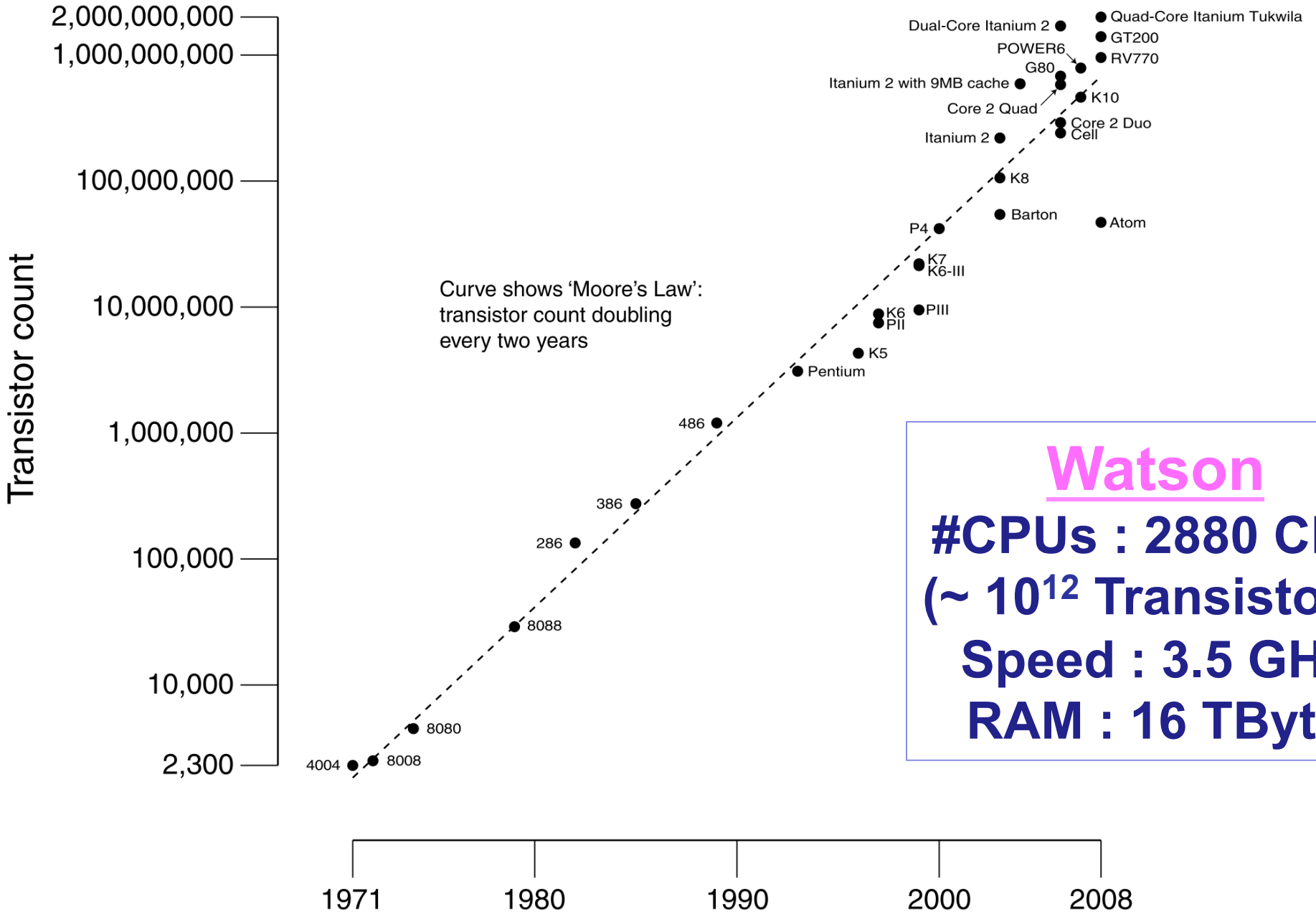
Jennings holds the record for number of consecutive Jeopardy matches won, with 74. Rutter has won more money than anyone else on Jeopardy.

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

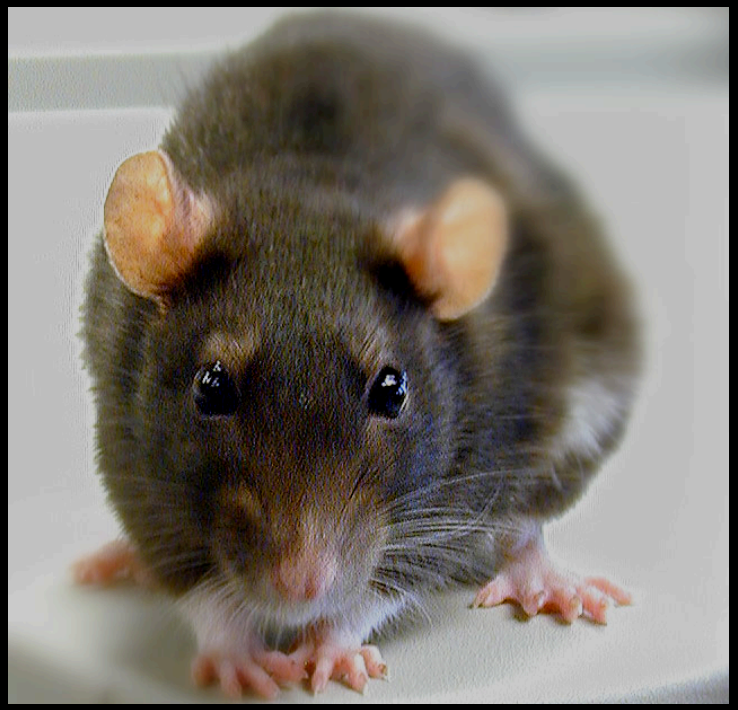
From No Brain to Big Brain

Paramecium (Single Cell)

Lymnaea (~1,000 neurons)

Zebrafish (~10,000 neurons)

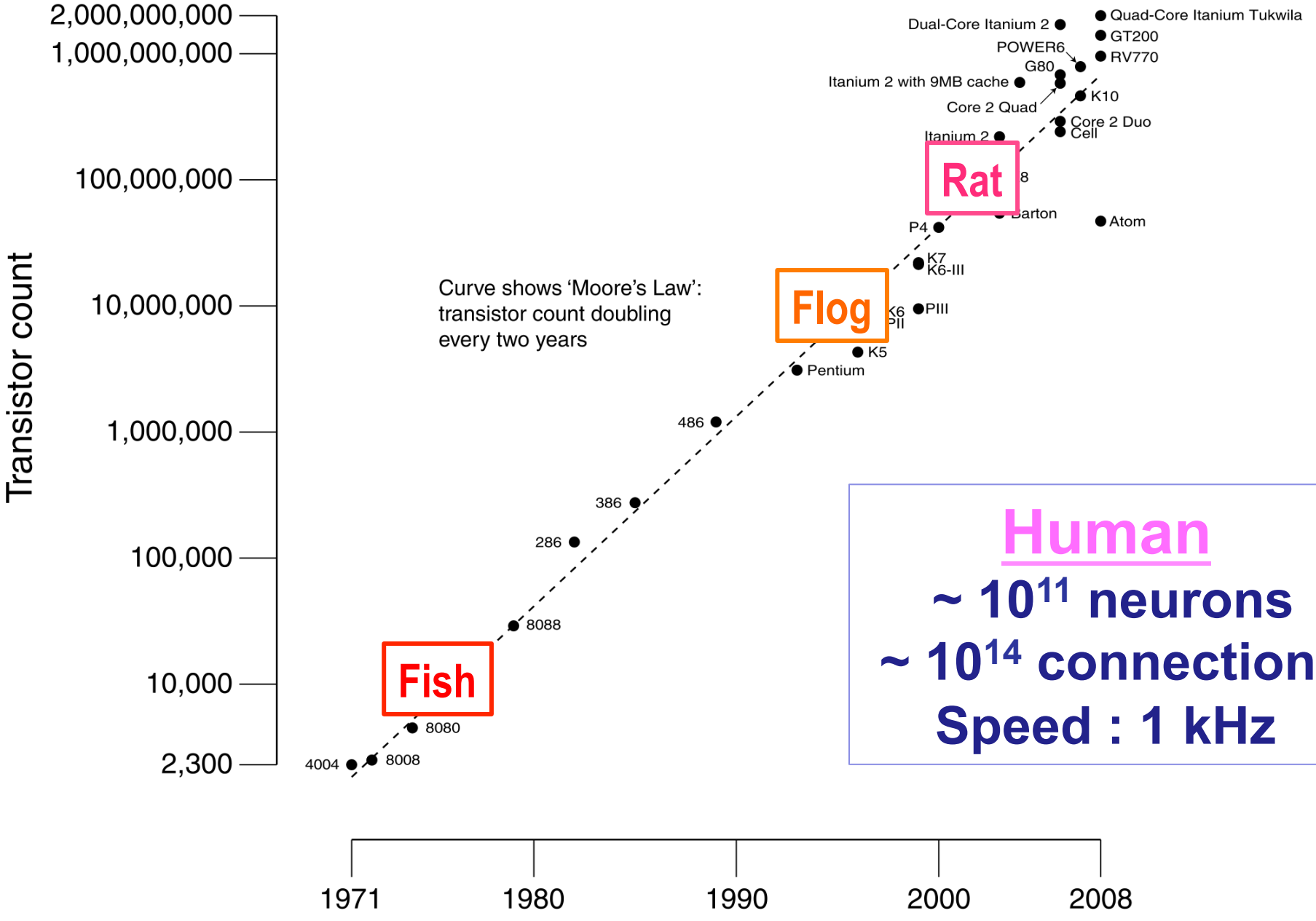
Bullfrog (~10^7 neurons)



Rat (~10^8 neurons)

Neurons in Brain

Human



Human

~ 10^{11} neurons

~ 10^{14} connections

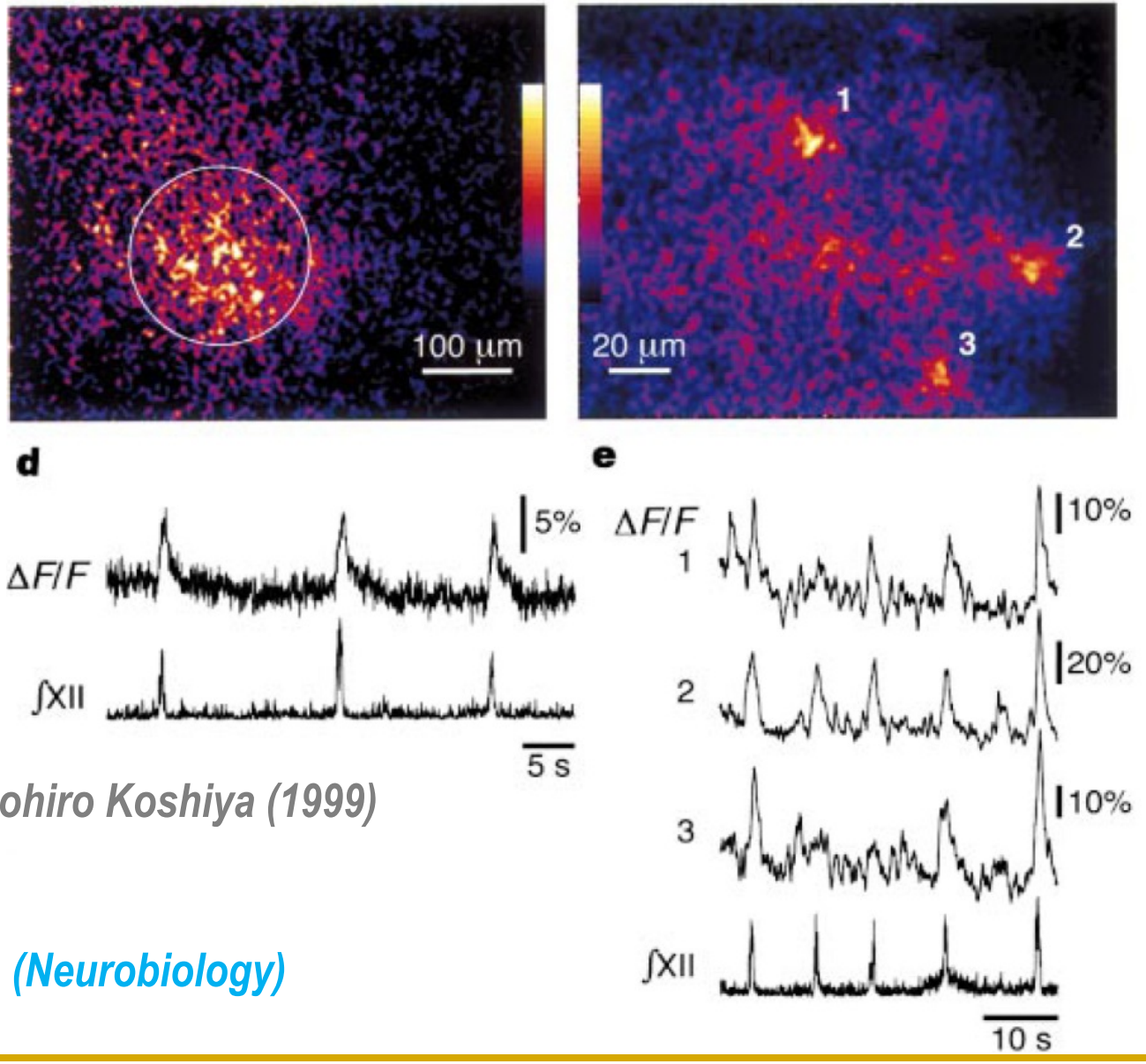
Speed : 1 kHz

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

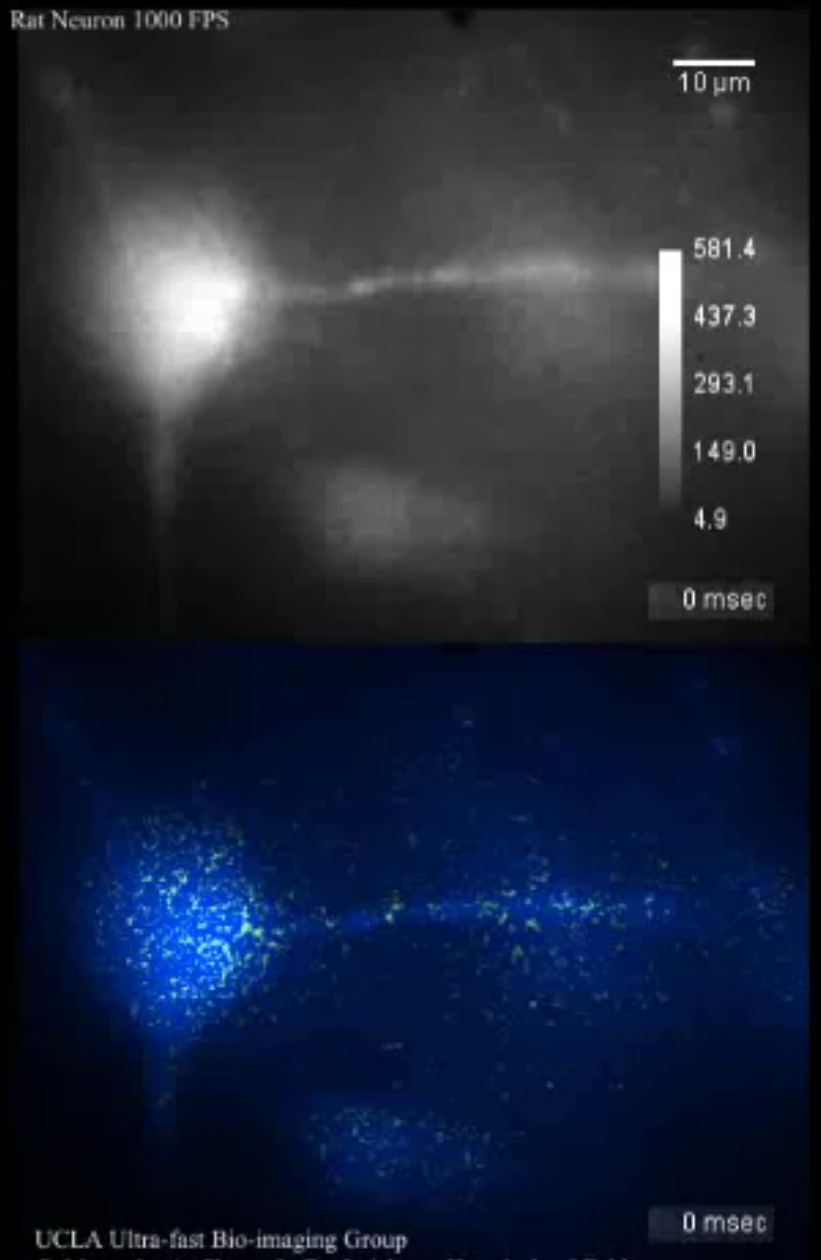


Nature by Naohiro Koshiya (1999)

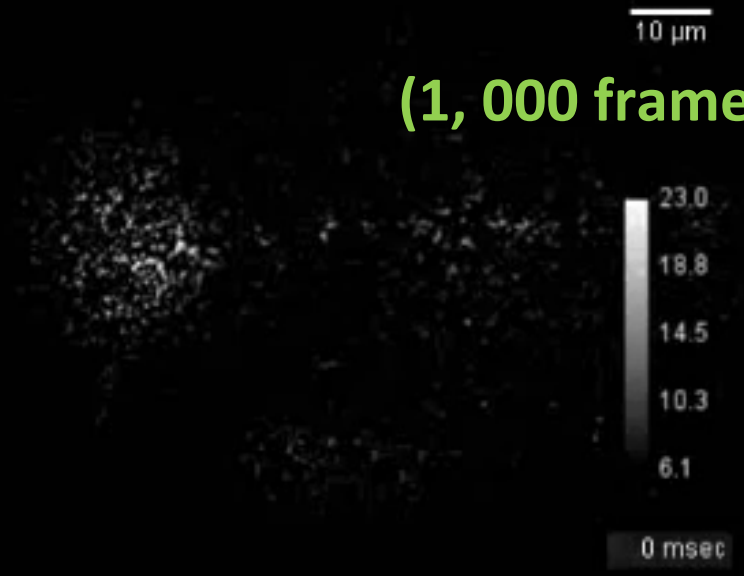
Jack Feldman (Neurobiology)

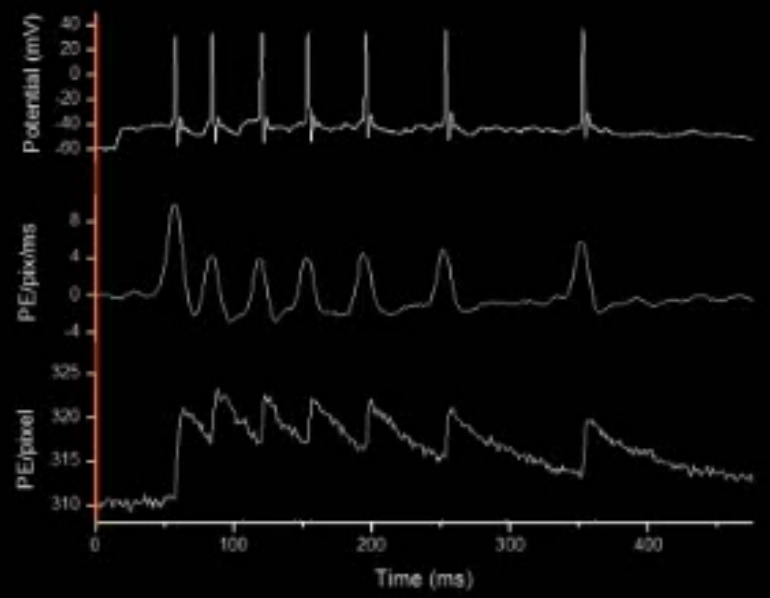
High-speed Ca^{2+} Imaging of pre-Botzinger Cells of Rats

Prof. Jack Feldman (Neurobiology)

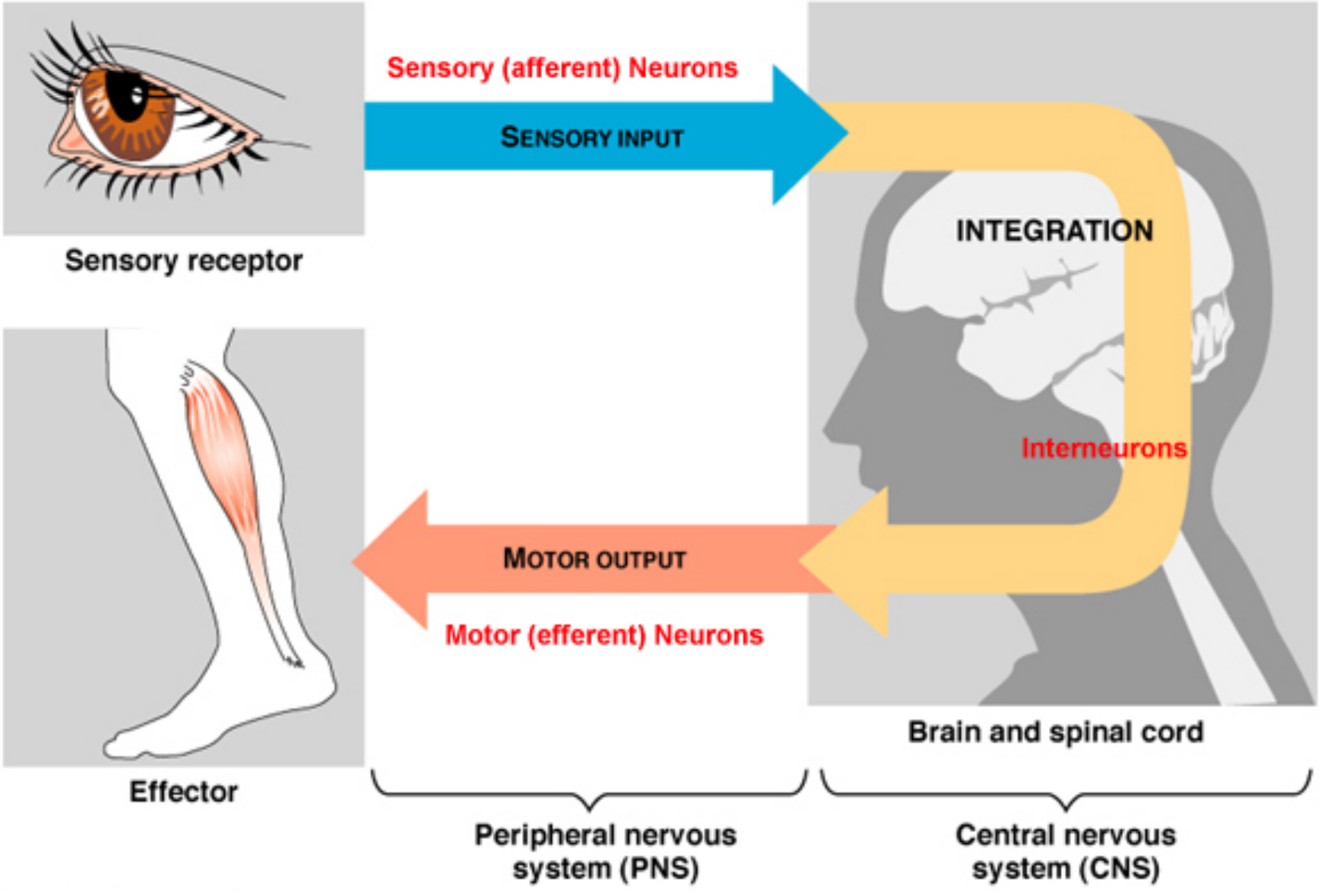


(1, 000 frame/sec)



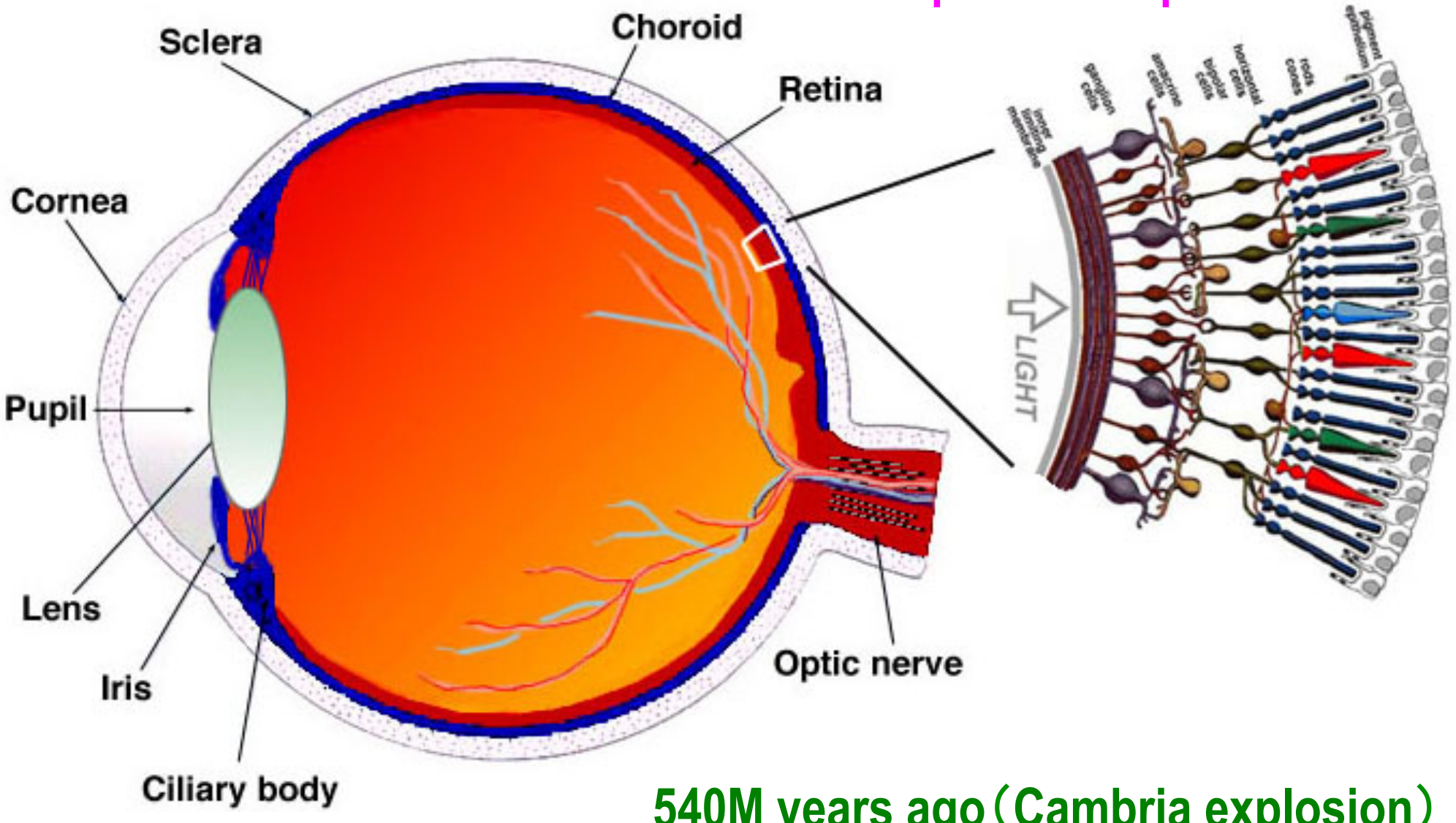


Sensory Input and Decision Making in Brain



Human Eyes

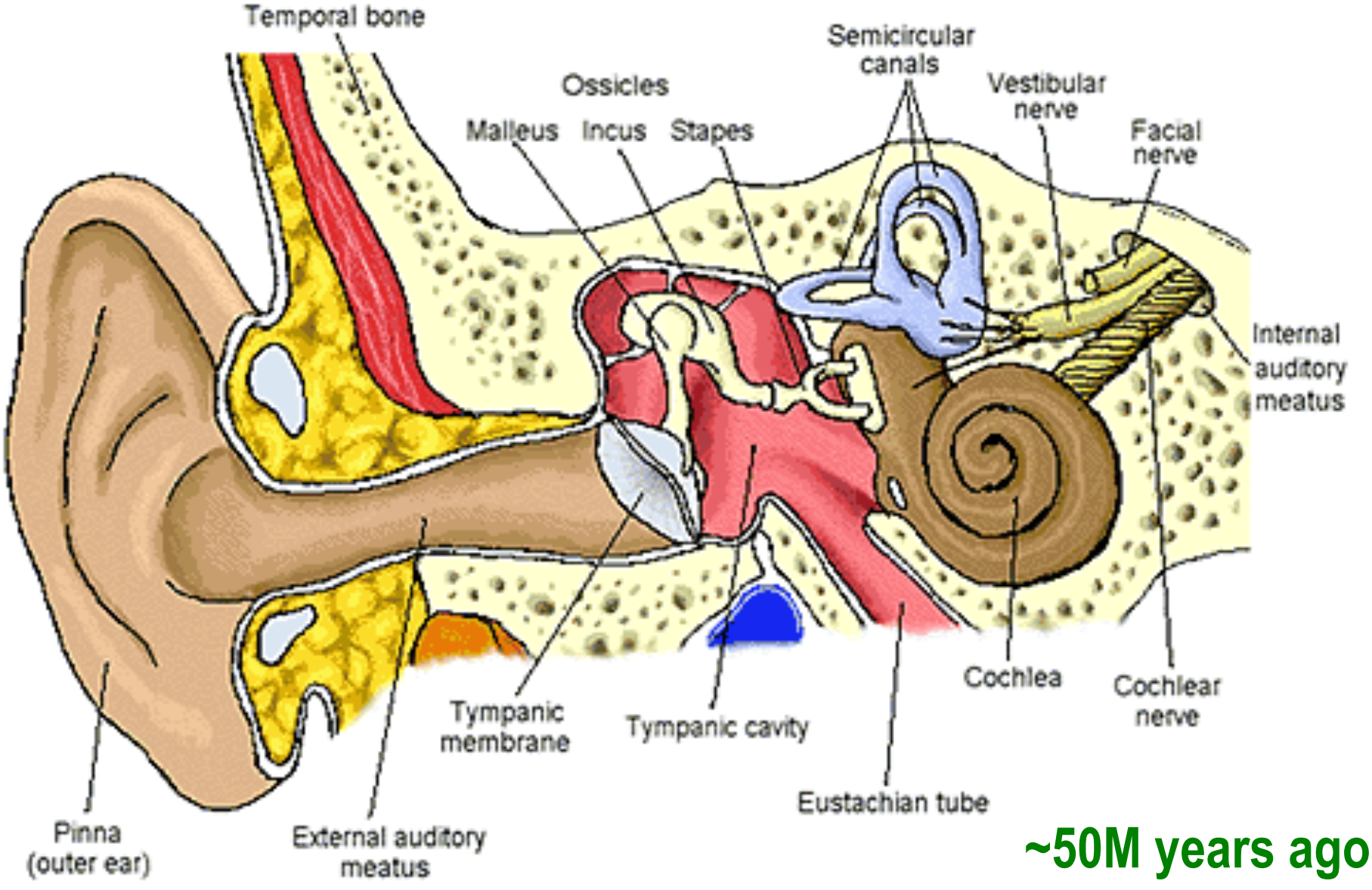
~100M photo receptors



540M years ago（Cambria explosion）

Human Ears

~10,000 Hair Cells

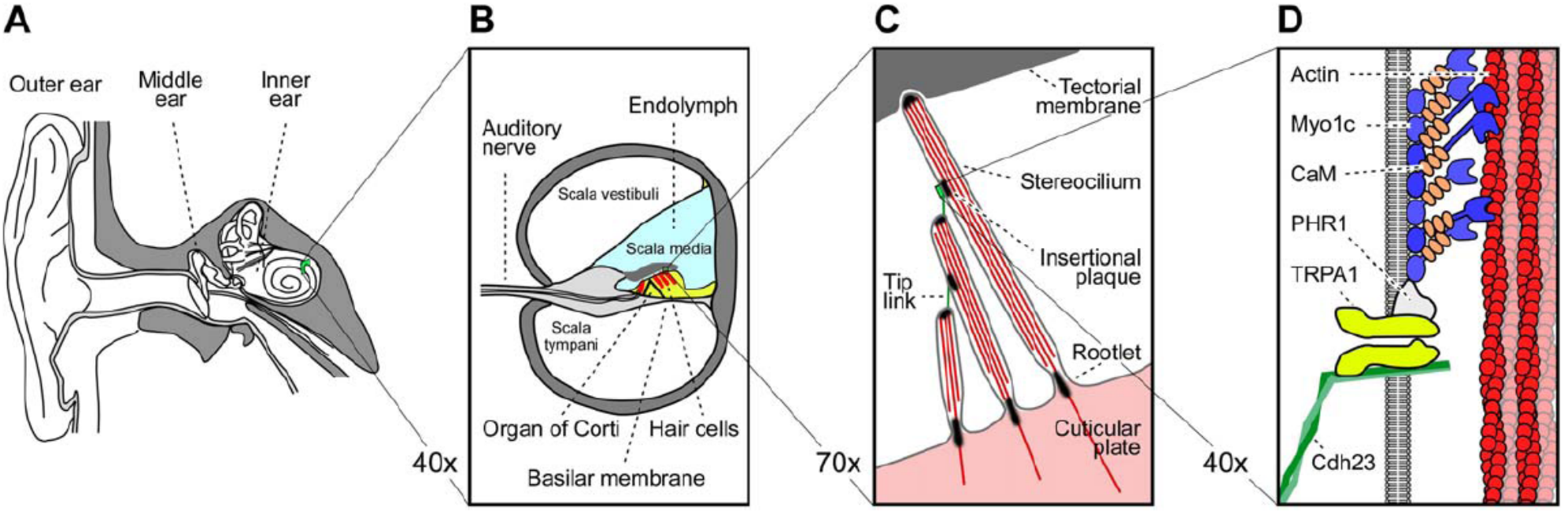


~50M years ago

Anatomy of Inner Ear

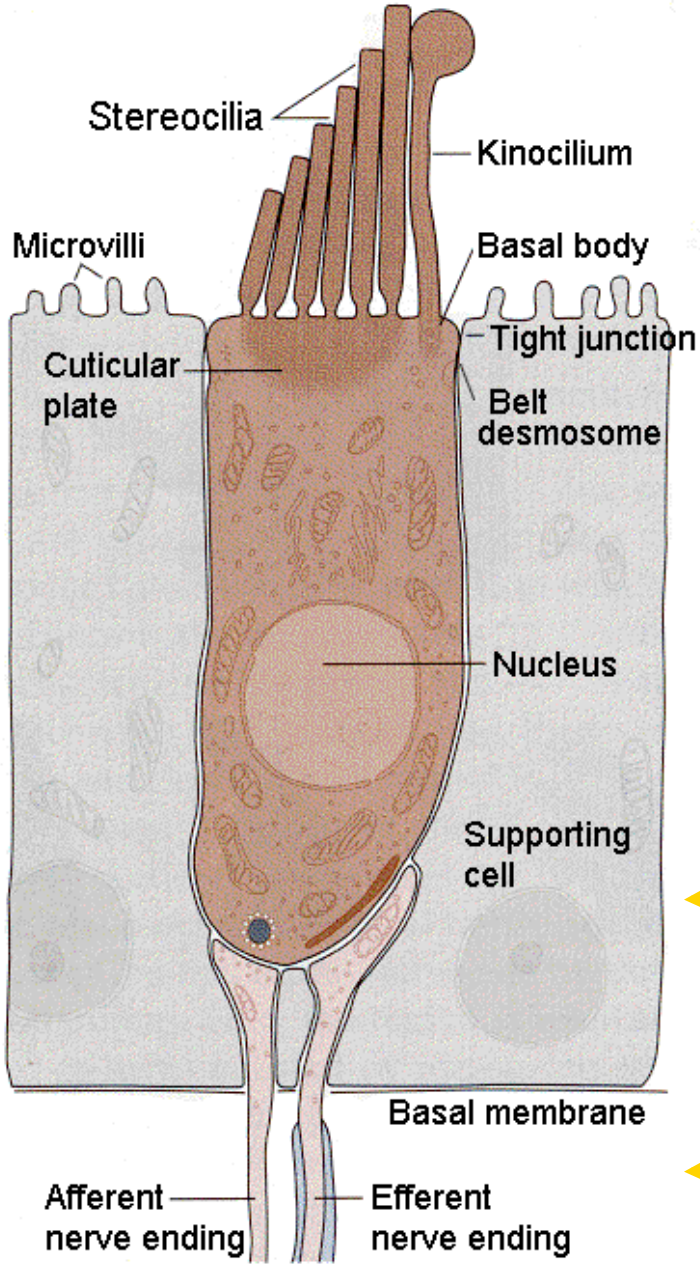
Dolores Bozovic (Physics)

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



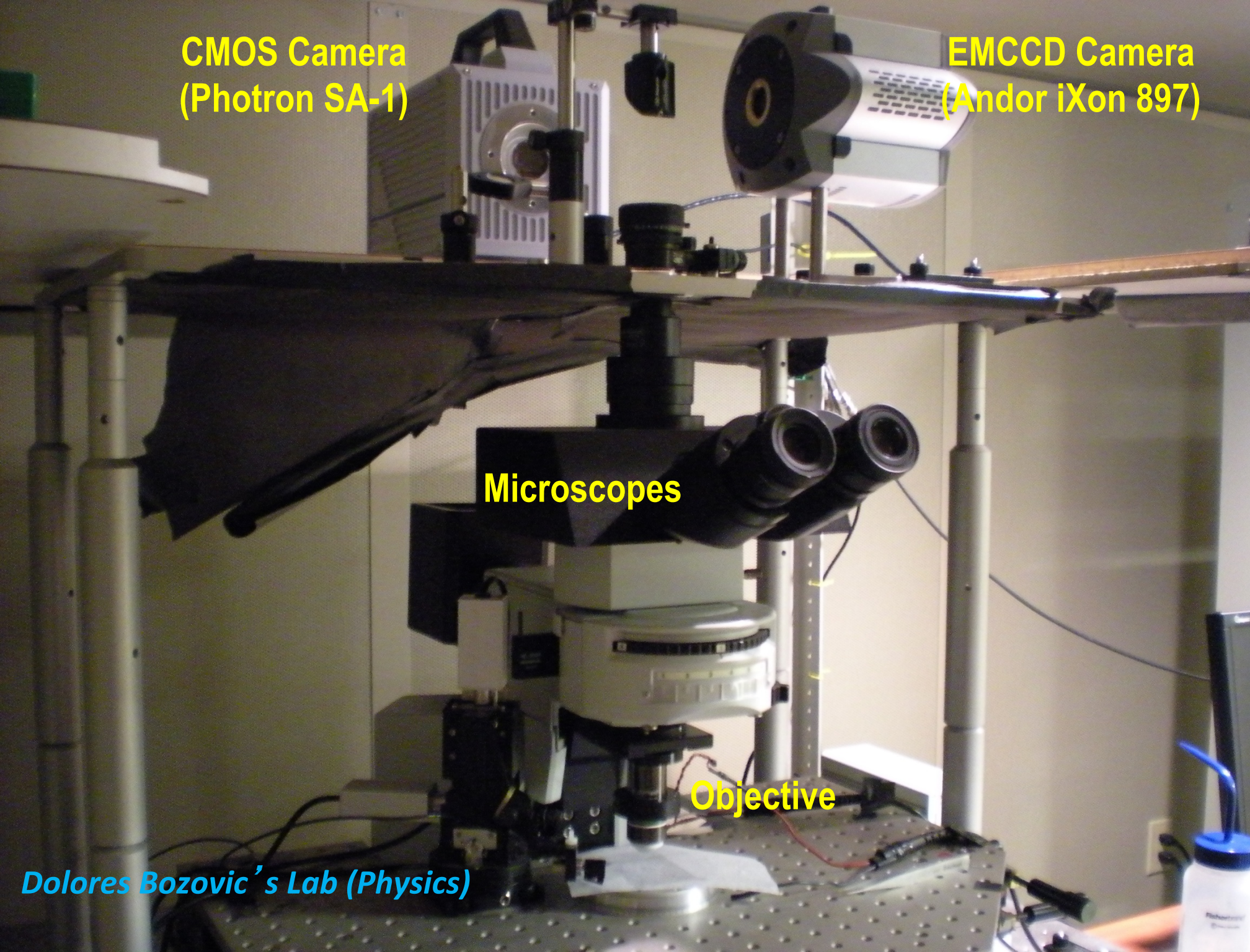
Mechanical Motion

Ca^{2+} Intake

Action Potential Propagation in Hair Cell

Receptor in Synapse

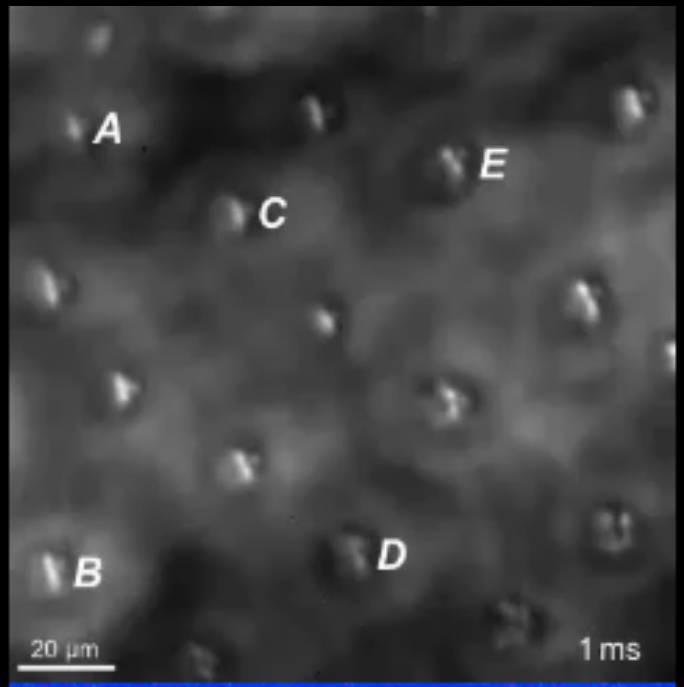
Action Potential Propagation Into Dendrite

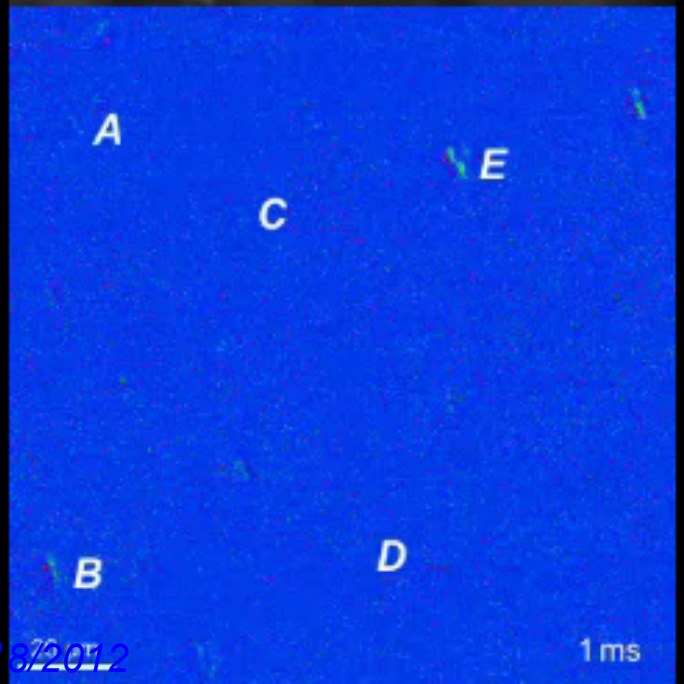

CMOS Camera
(Photron SA-1)
EMCCD Camera
(Andor iXon 897)
Microscopes
Objective
Dolores Bozovic's Lab (Physics)

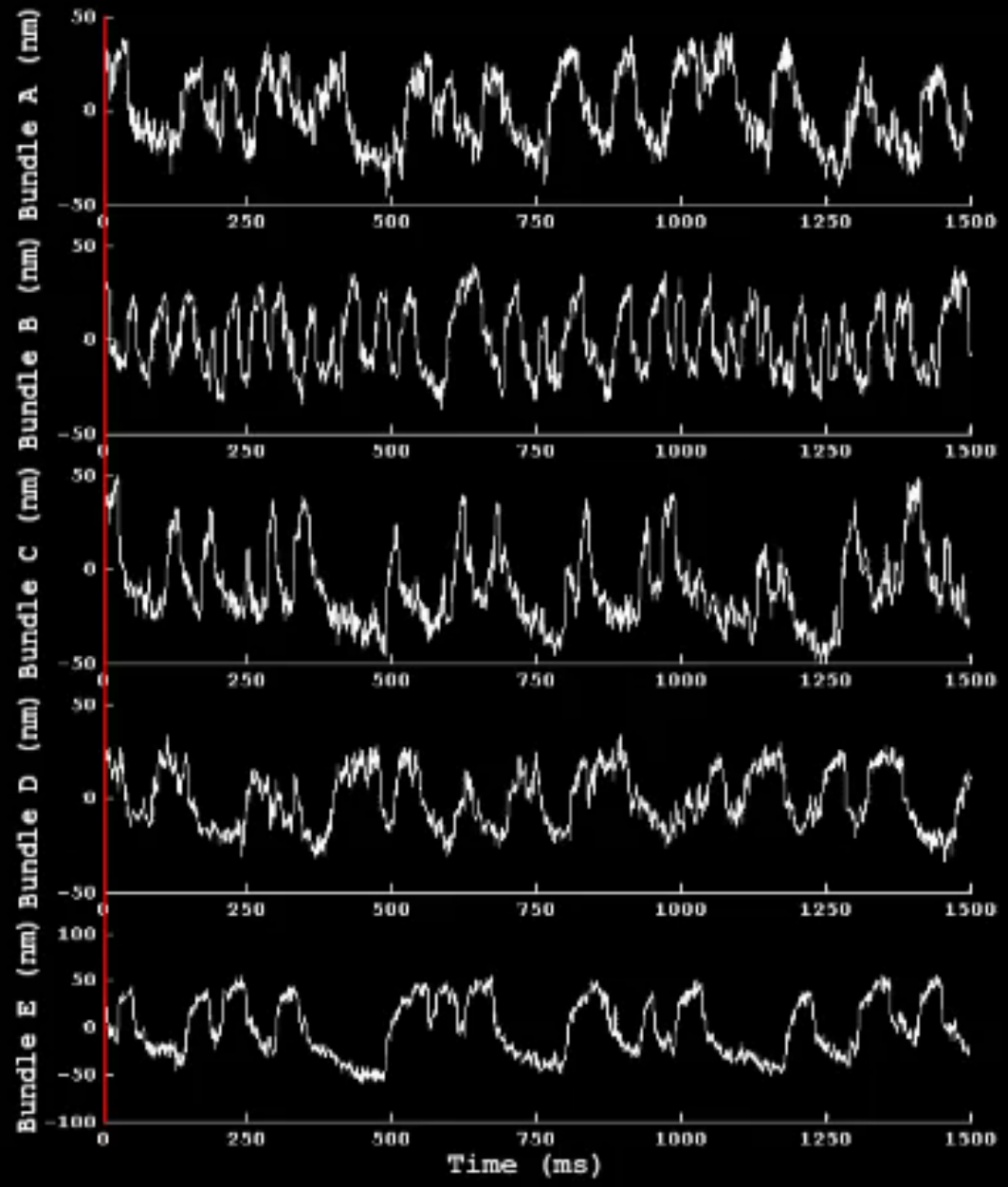
Mechanical Motion of Hair Cells in Inner Ear

Prof. Dolores Bozovic (Physics)

(1, 000 frame/sec)







UCLA Fast Bio-Imaging Group

L. Fredrickson, A. Cheng, K. Jewhurst, C. E. Strimbu, D. Bozovic, K. Arisaka

Mystery of Hearing

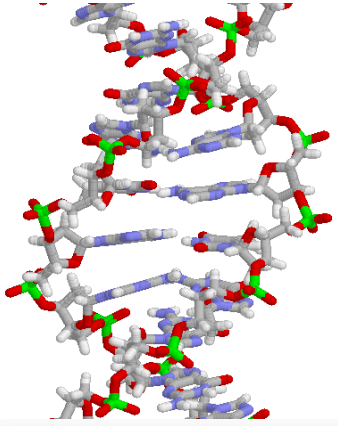
- **Extremely wide dynamic range in amplitude.**
  - 10^6 compressed to 100
  - Smallest amplitude is 0.3 nm
- **Extremely wide frequency range.**
  - 20 Hz – 20 kHz
    - Dynamic range of 1000
    - Corresponding to 10^6 in k
  - Selectivity of 0.2%
    - up to 5 kHz
  - How can the brain handle up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

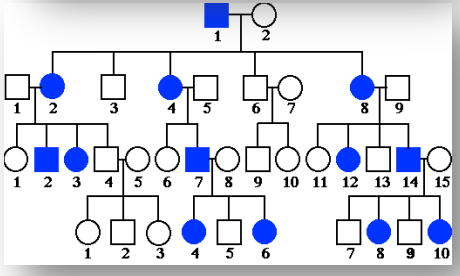
$$\omega = \sqrt{\frac{k}{m}}$$

How can I recognize a woman so far away?

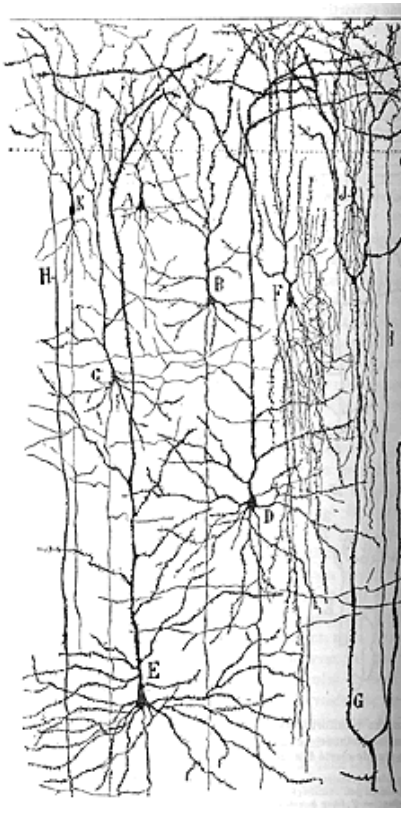
- Genetically encoded?
- Learning and memory?

Nature vs. Nurture

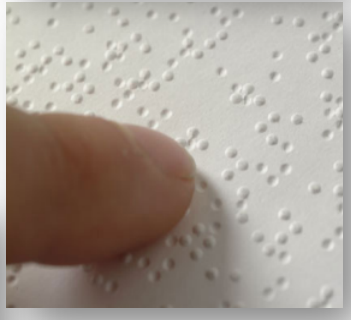


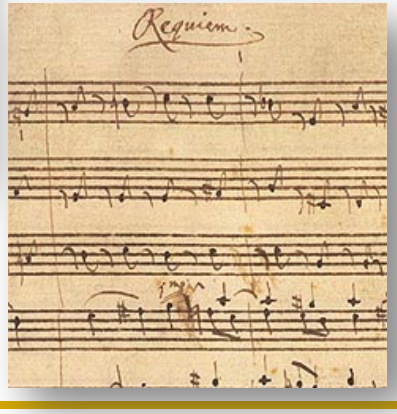


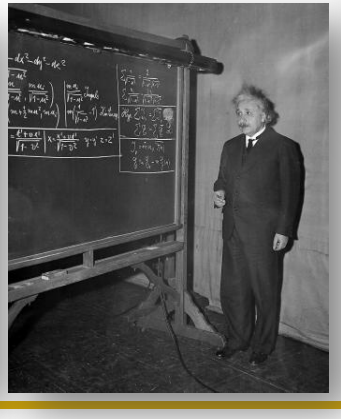
Nature



Nurture

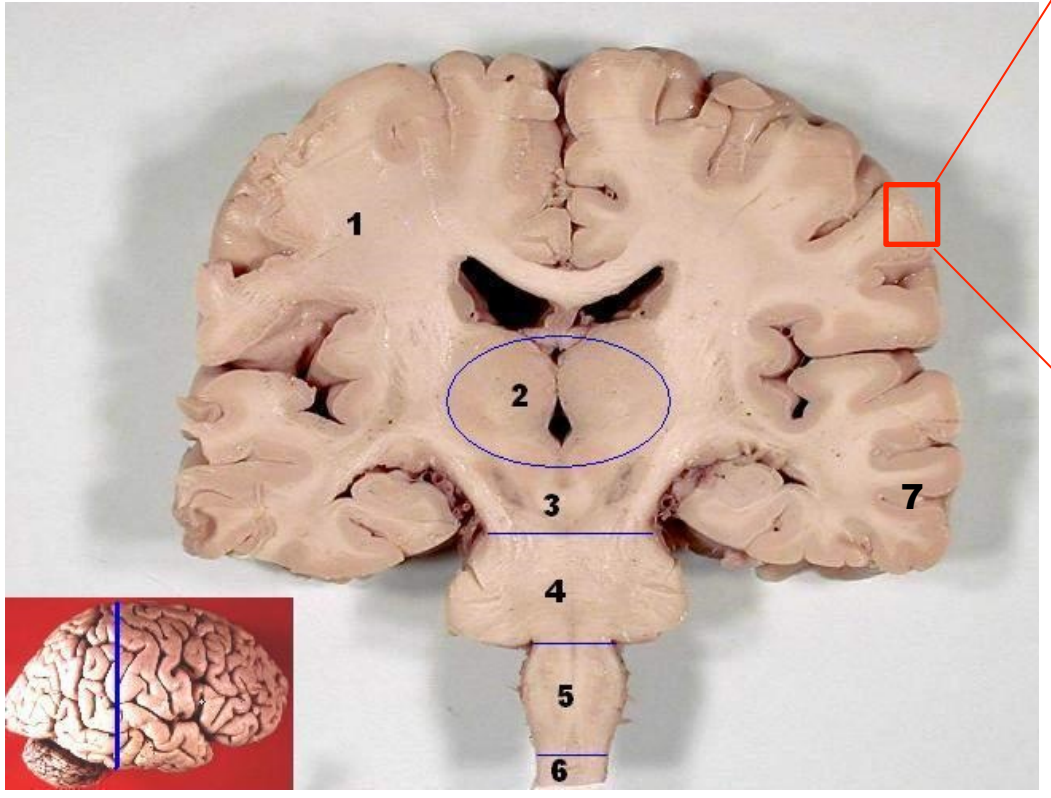




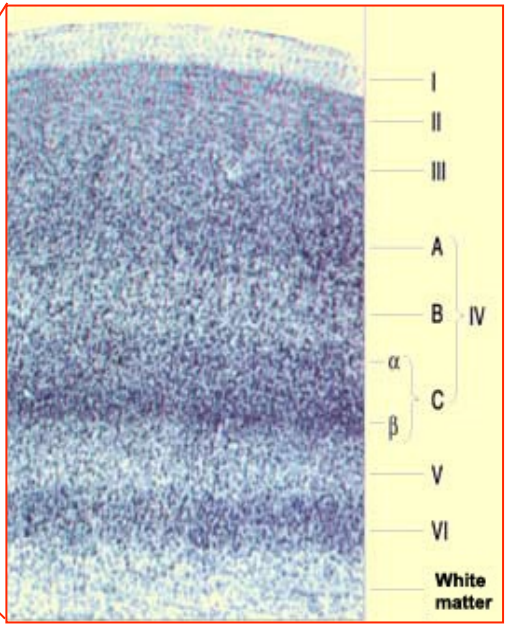


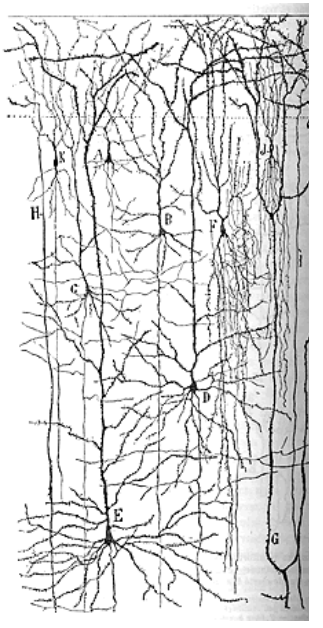
The Cerebral Cortex

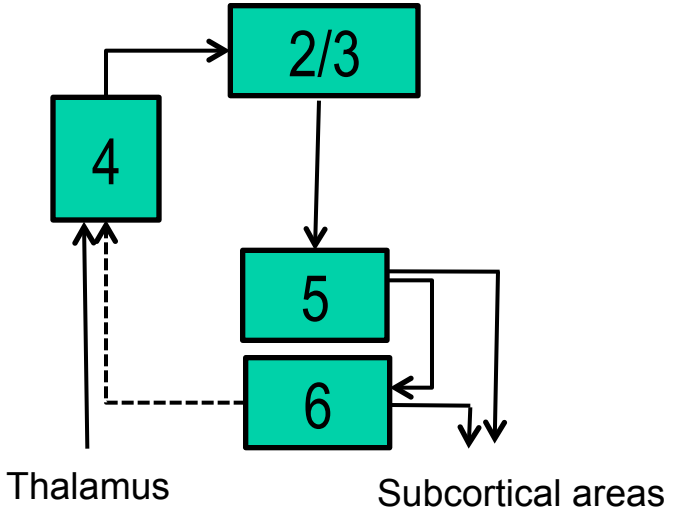
Conscious



Unconscious

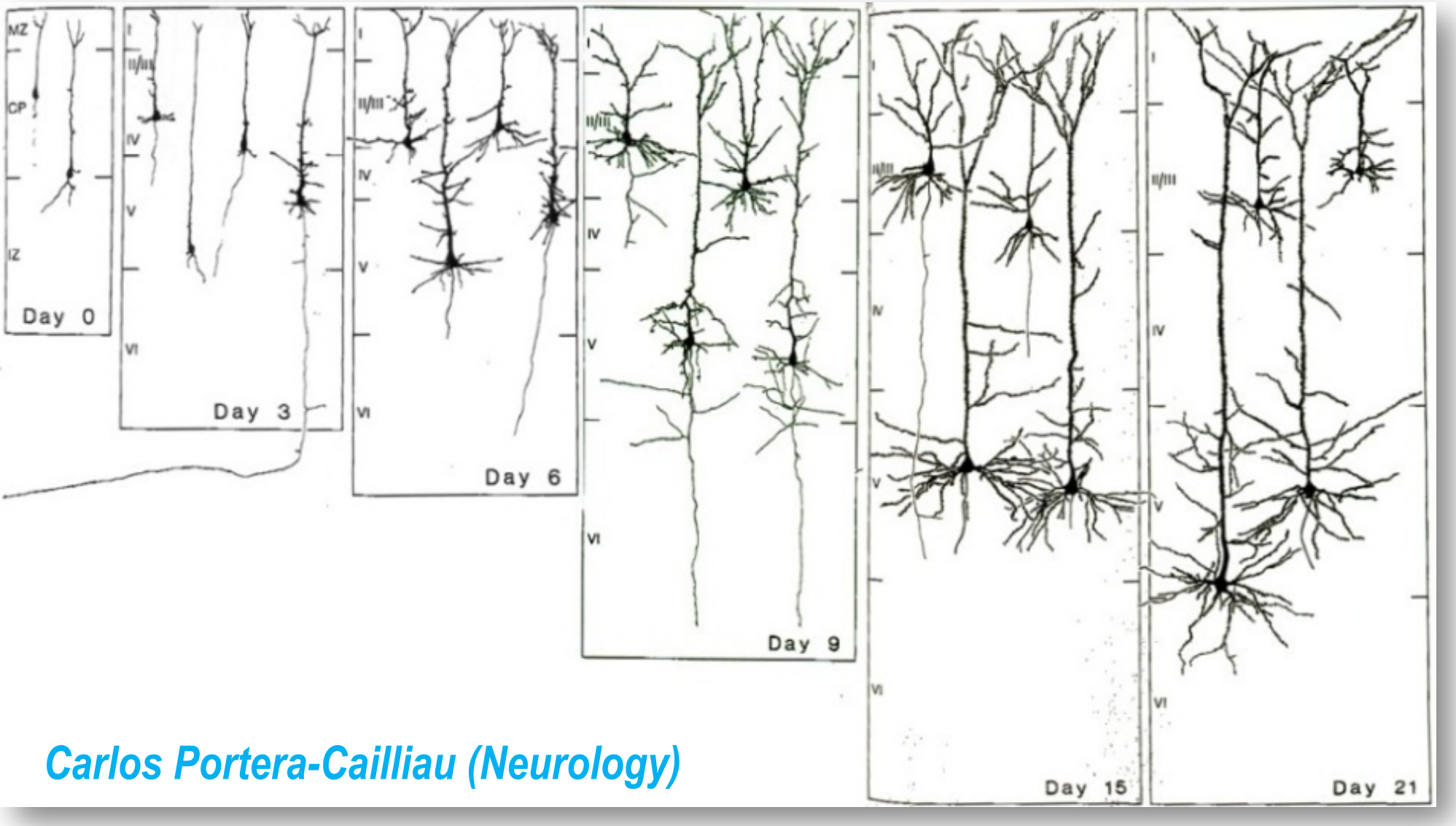






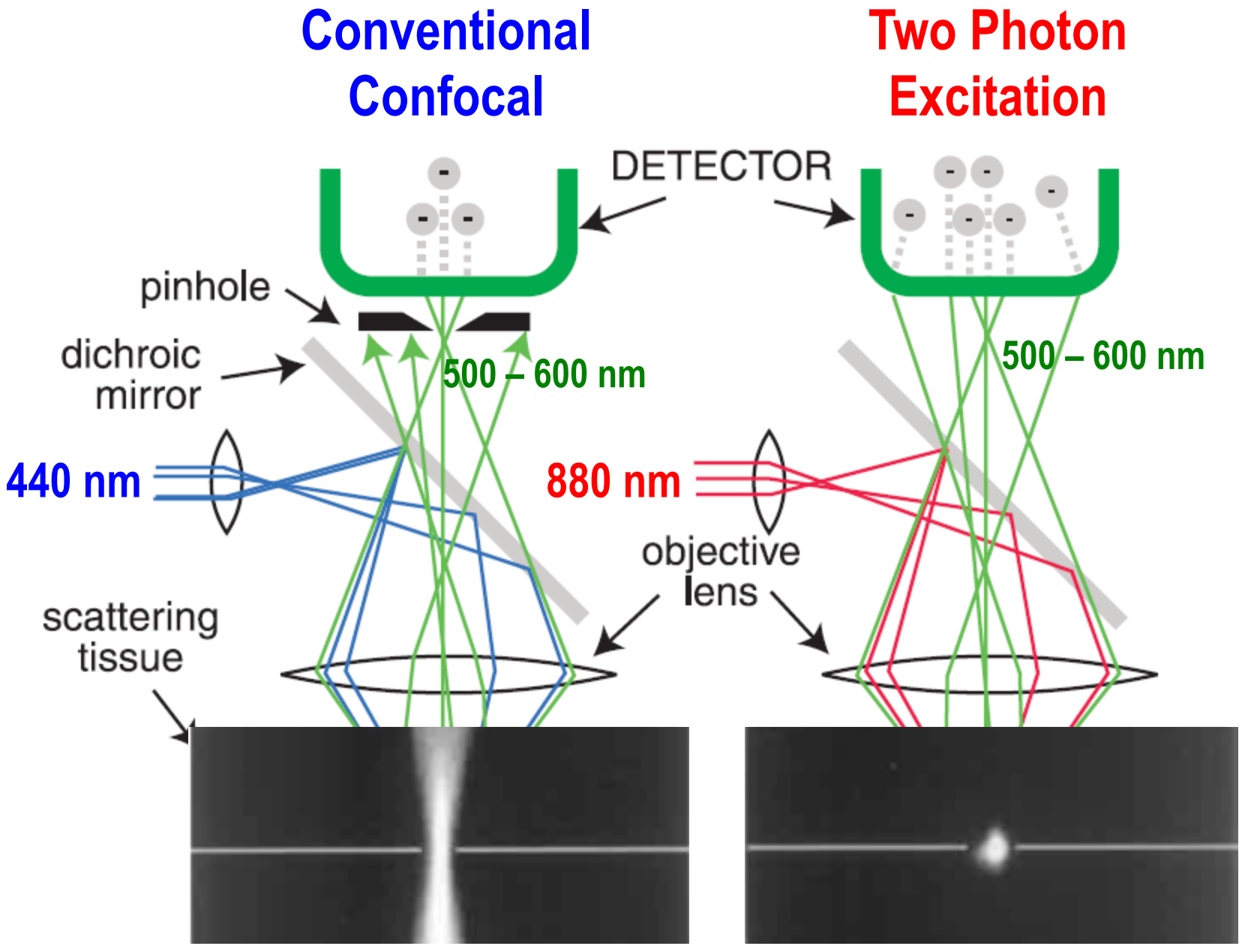
Assembly of rat's cortical circuits during development

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



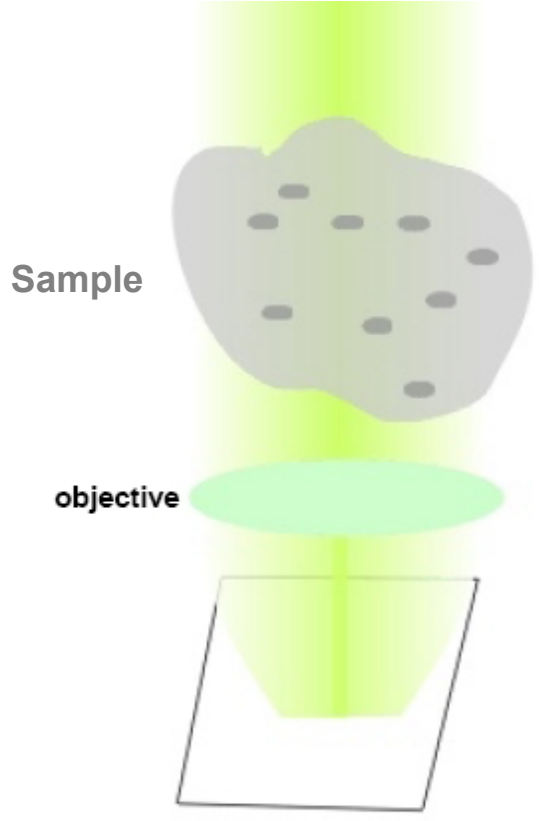
Carlos Portera-Cailliau (Neurology)

Mutiphoton Microscope



Principle of High-speed Bio Imaging

Wide Field

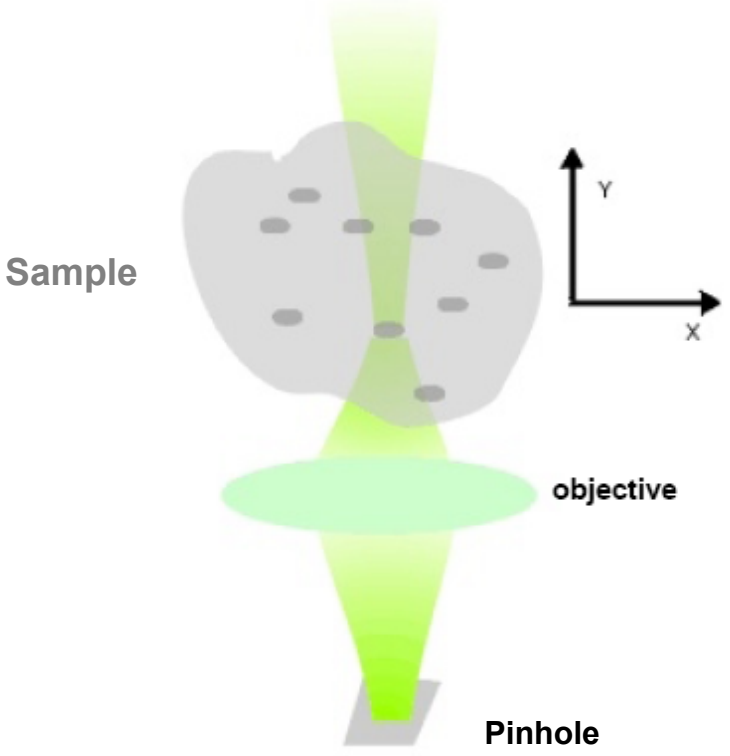


CCD + FADC (10 – 50 MHz)

⇩

CMOS [FADC (50 MHz) * 100]

Confocal

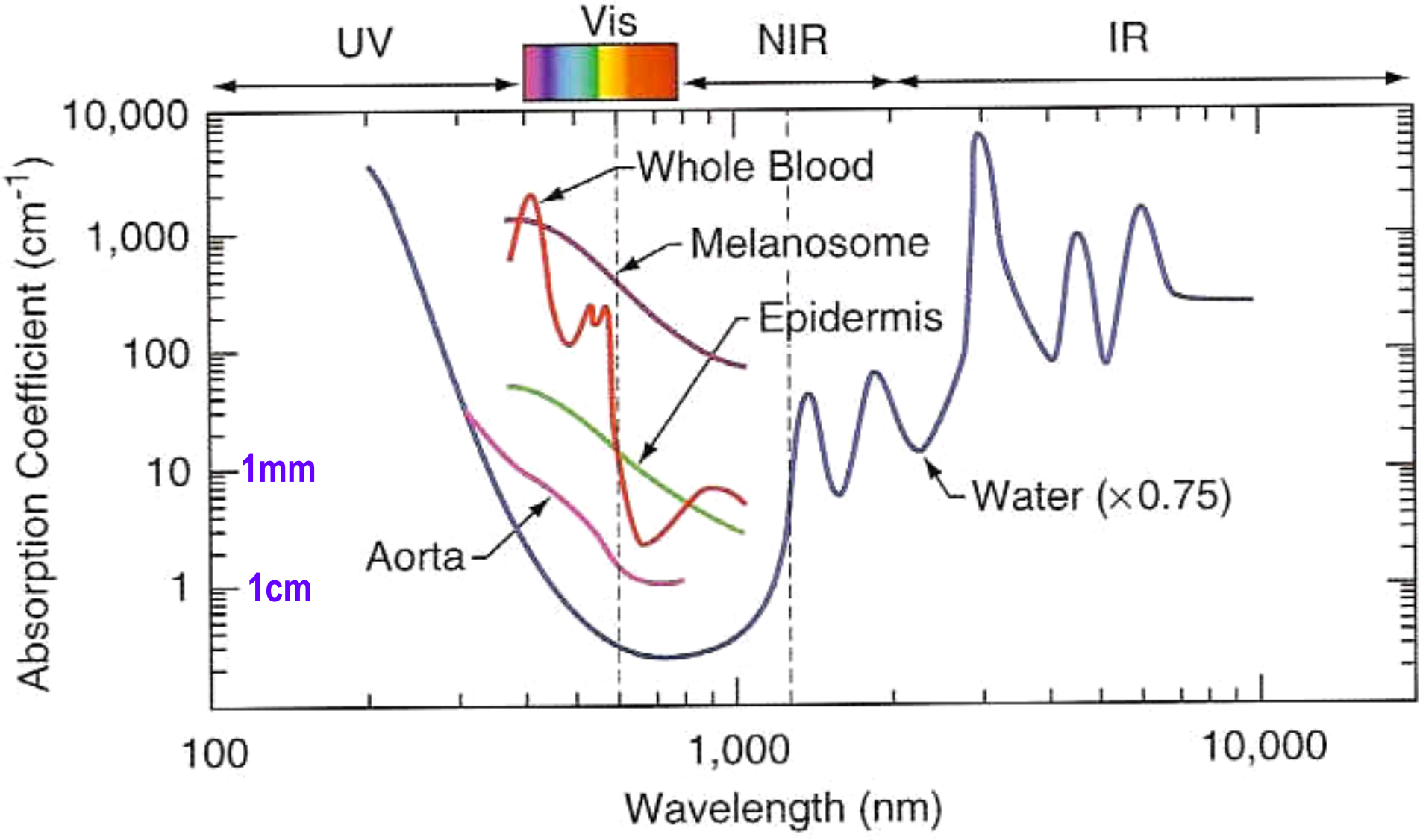


PMT + FADC (10 – 50 MHz)

⇩

[HAPD + FADC (1 GHz)] * 64

Absorption of light



TECHNICAL INFORMATION

OCT. 2008

HIGH SPEED COMPACT HPD (Hybrid Photo-Detector) R10467U SERIES

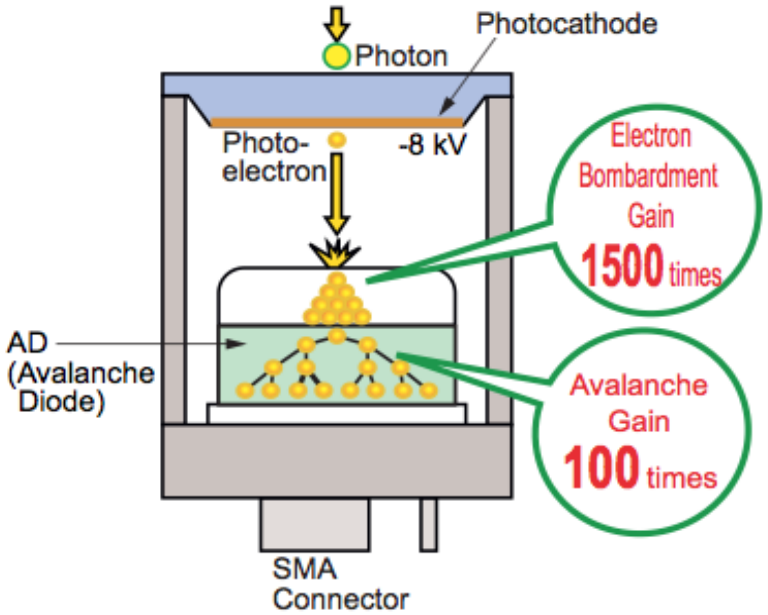
FEATURES

- Fast Time Response
- Excellent Timing Resolution
- Capable of Photon Counting

APPLICATIONS

- Laser Scanning Microscope
- FCS (Fluorescence Correlation Spectroscopy)
- LIDAR (Light Detection and Ranging)
- TCSPC
  (Time-Correlated Single Photon Counting)

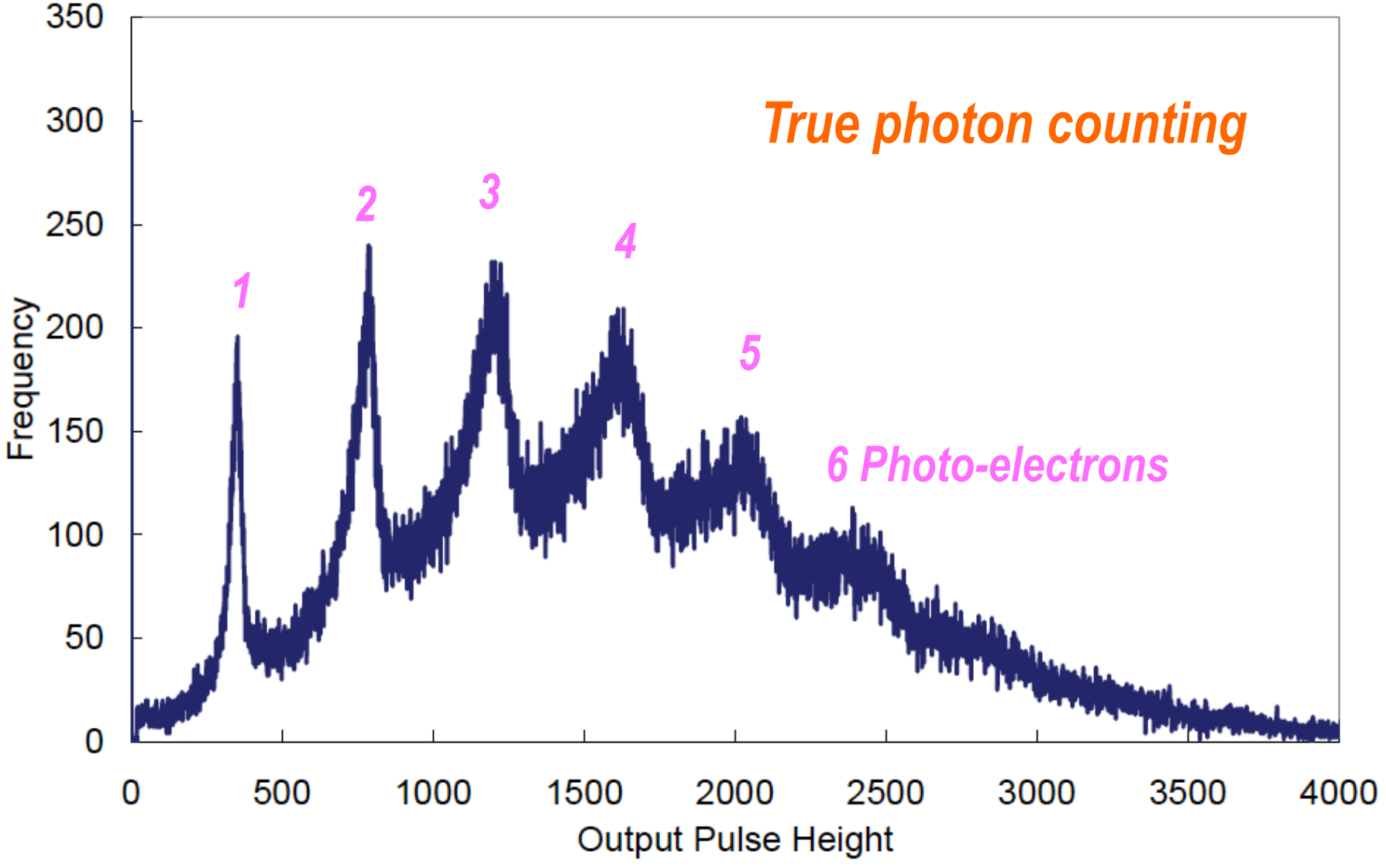
■ Principle



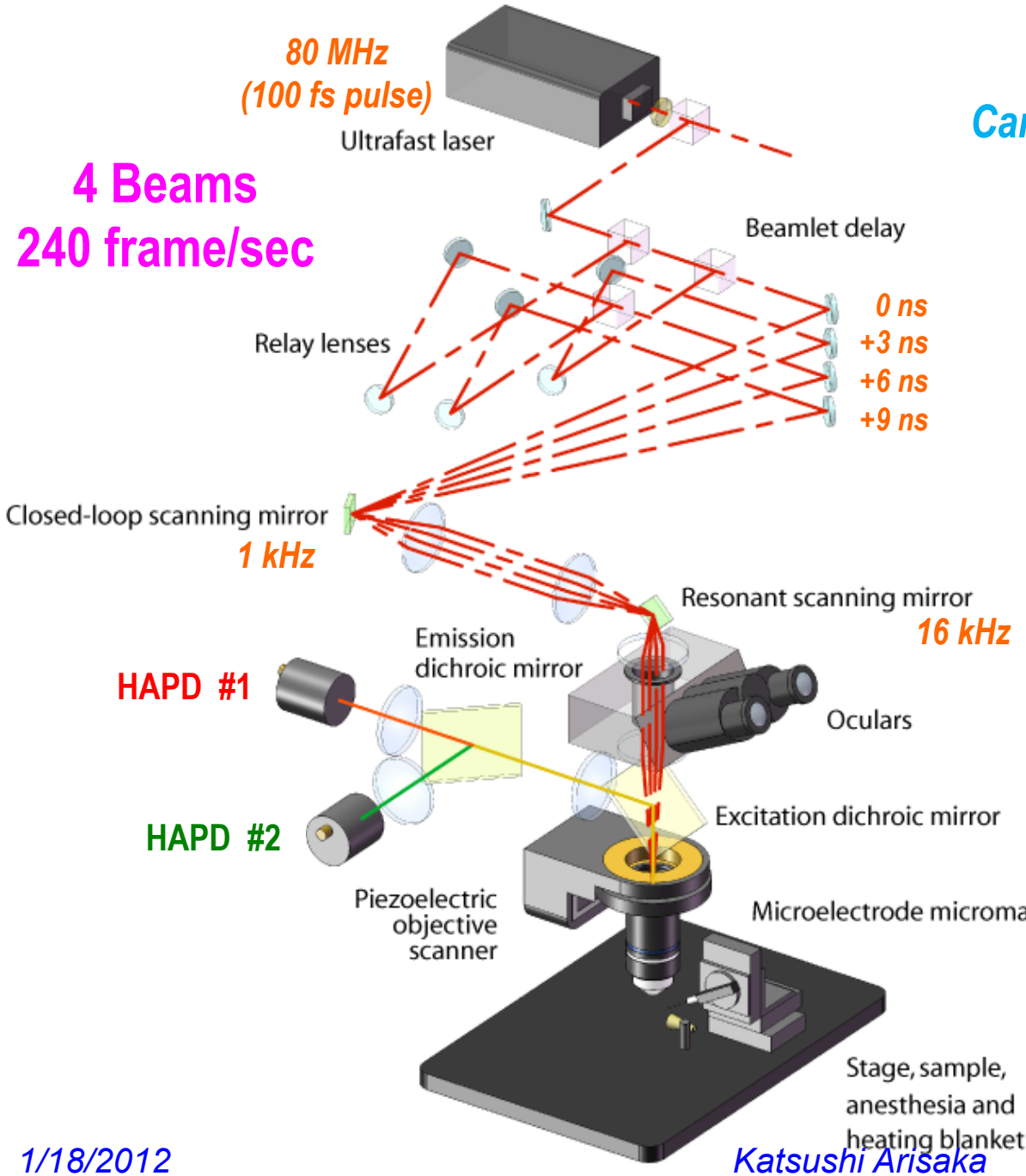
GENERAL

Parameter		R10467U-06	R10467U-40	Unit
Spectral Response		220 to 650	300 to 720	nm
Photocathode	Material	Bialkali	GaAsP	—
	Effective Area	φ6	φ3	mm
Window Material		Synthetic Silica	Borosilicate Glass	—
Window Type		Plano-concave	Flat	—
Operating Ambient Temperature		+15 to +35		℃

1, 2, 3 … Photo-electron Distribution

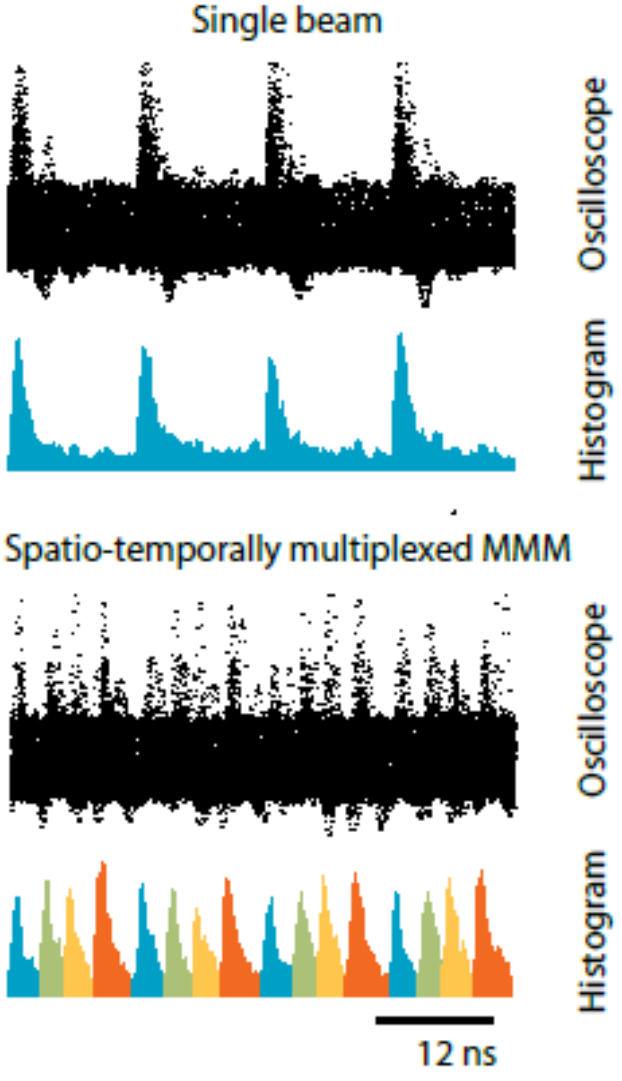


Spatio-Temporal Excitation-Emission Multiplexing (STEM) Microscope

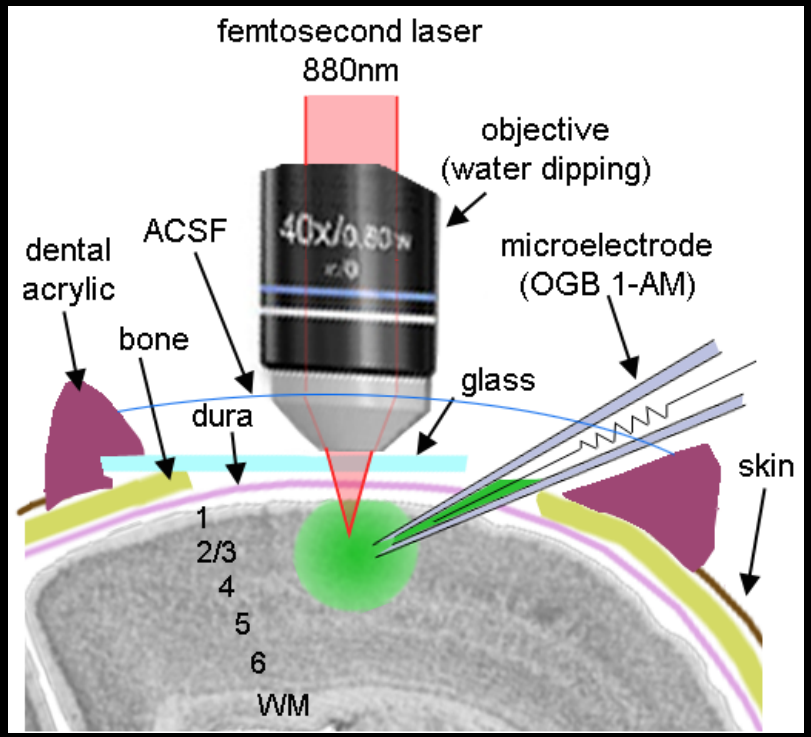


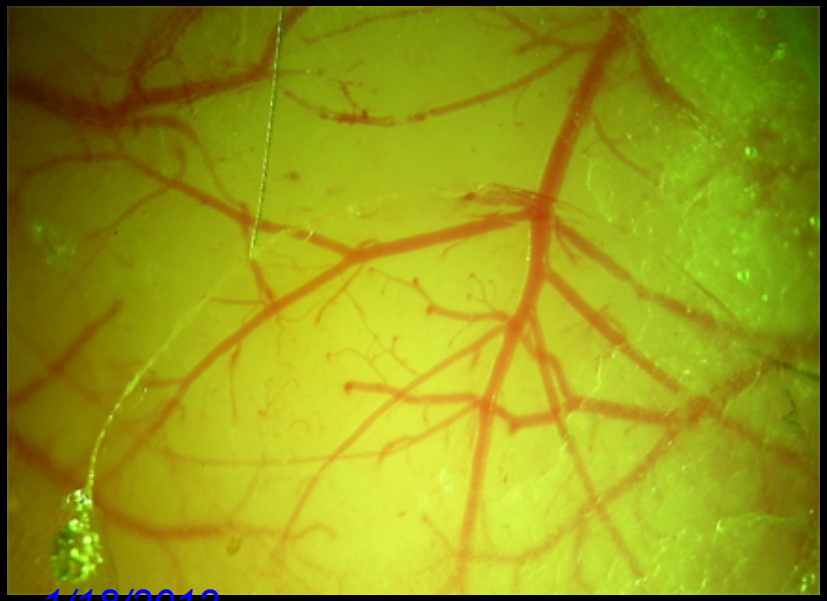
Adrian Cheng (Physics)

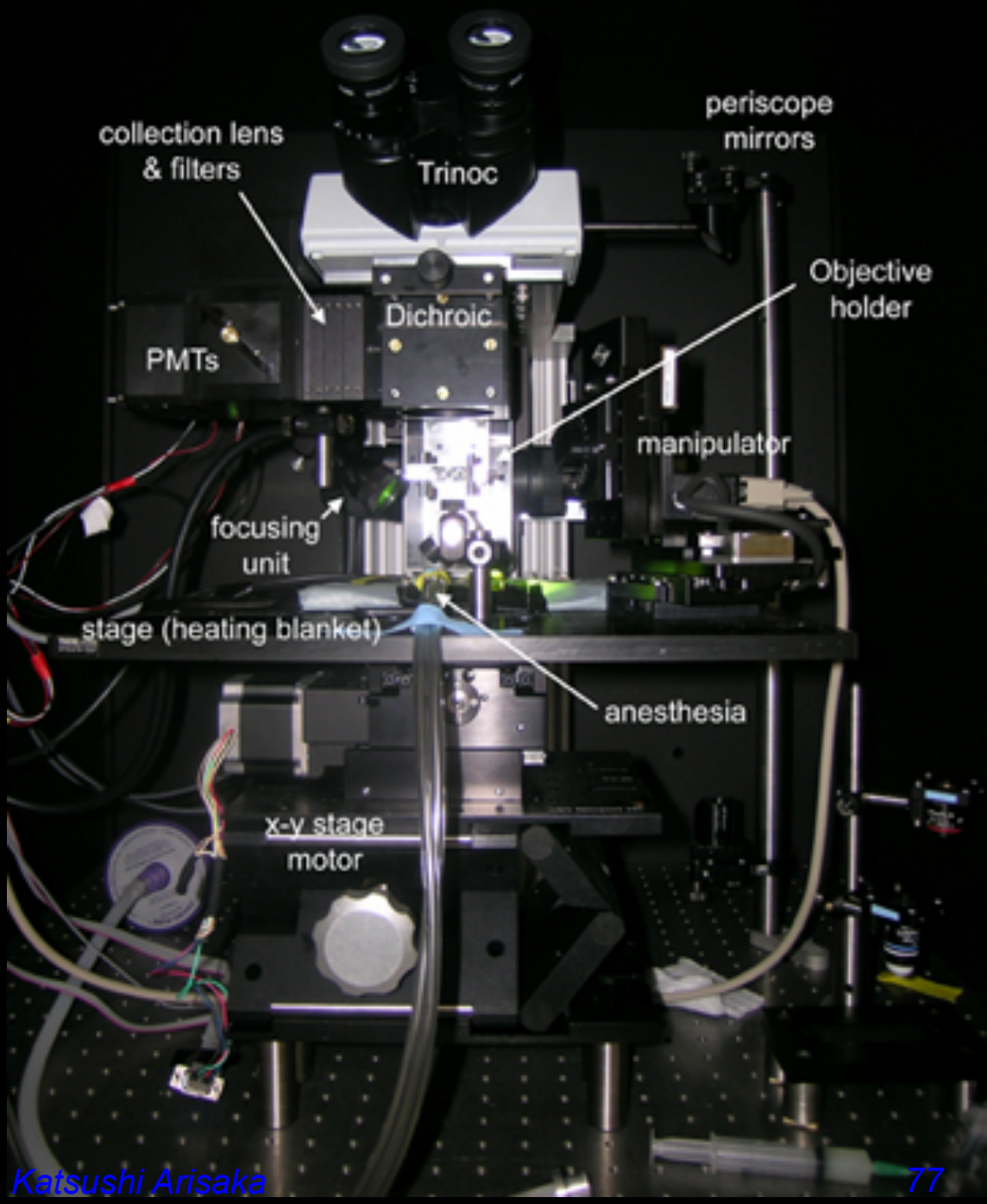
Carlos Portera-Cailliau (Neurology)

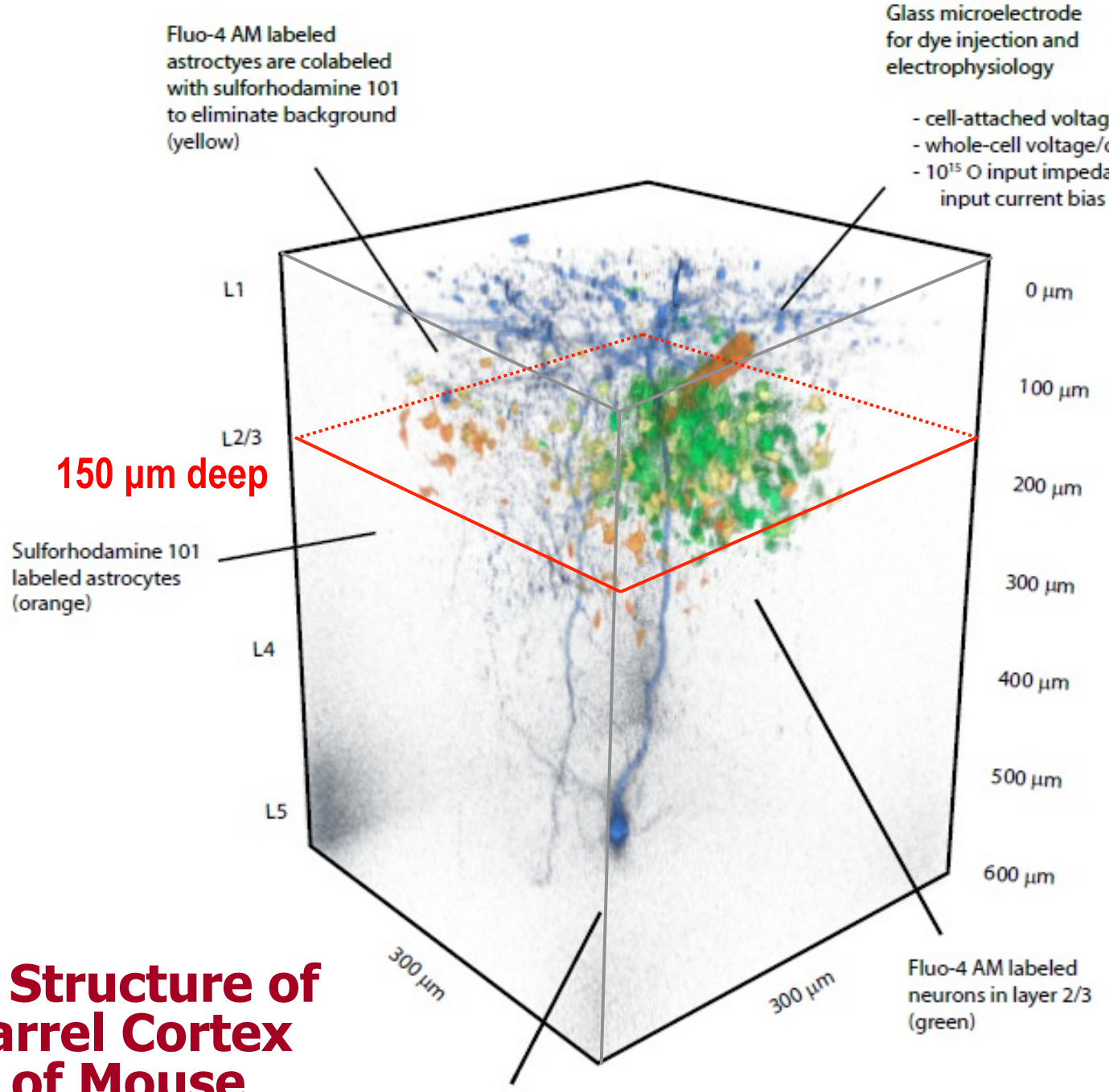


In vivo calcium imaging of neuronal activity









3D Structure of Barrel Cortex of Mouse

Adrian Cheng (Physics)

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

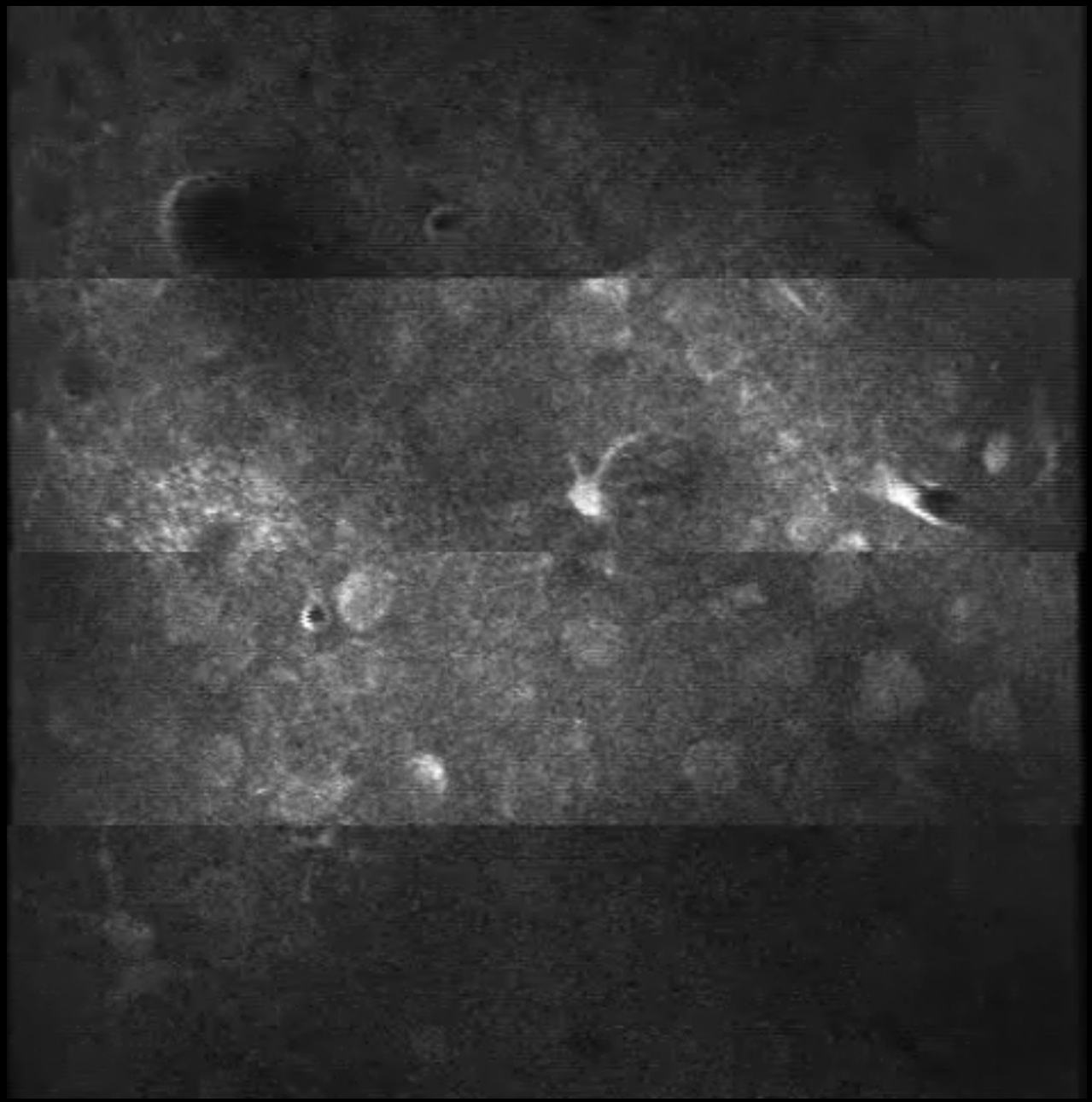
In vivo calcium imaging of Barrel Cortex of Mouse

Barrel Cortex
Layer 2/3

150 μm deep

240 fps
Raw Data

(x3 faster
than real)



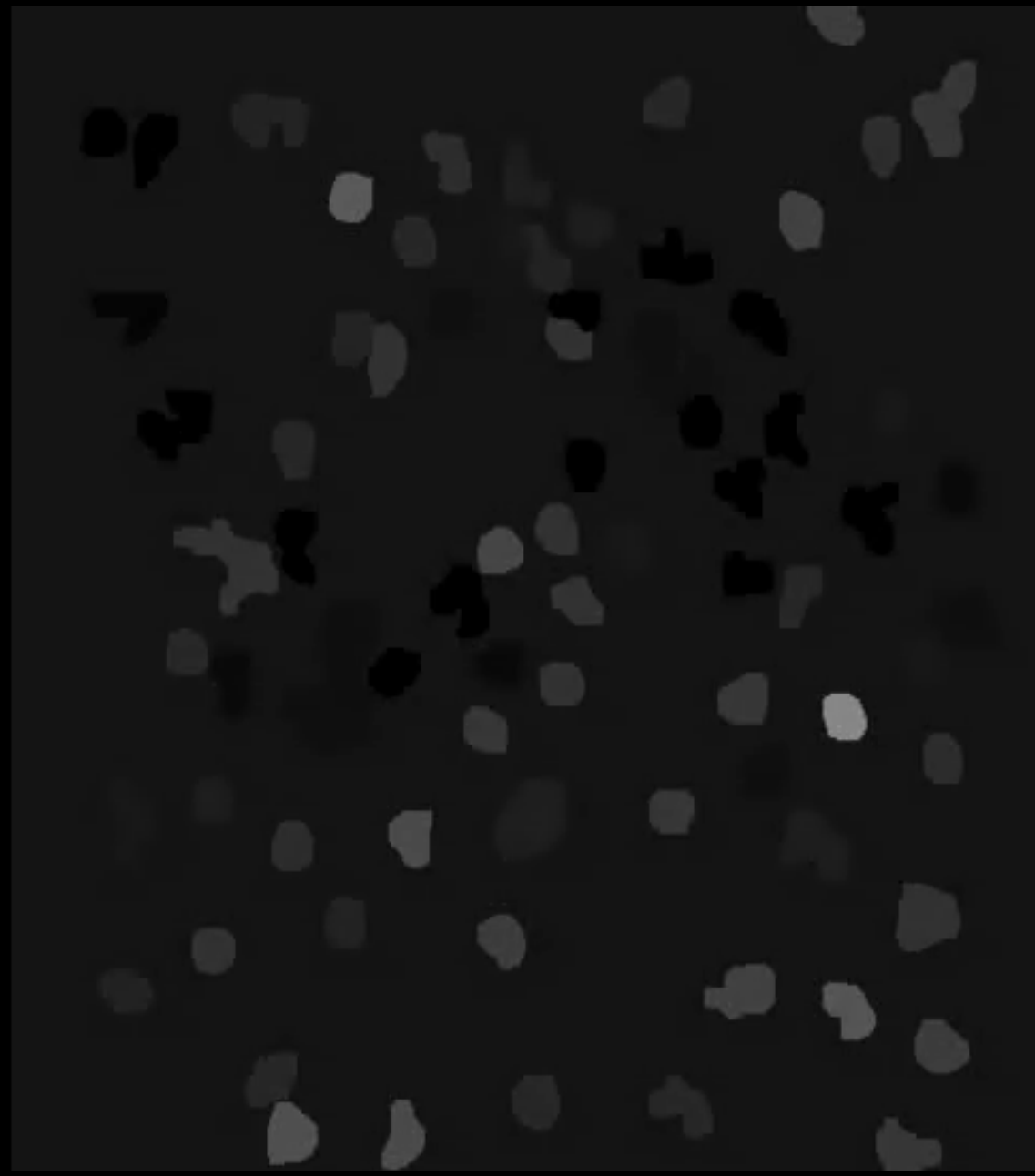
In vivo calcium imaging of Barrel Cortex of Mouse

Barrel Cortex Layer 2/3

150 μm deep

After averaging

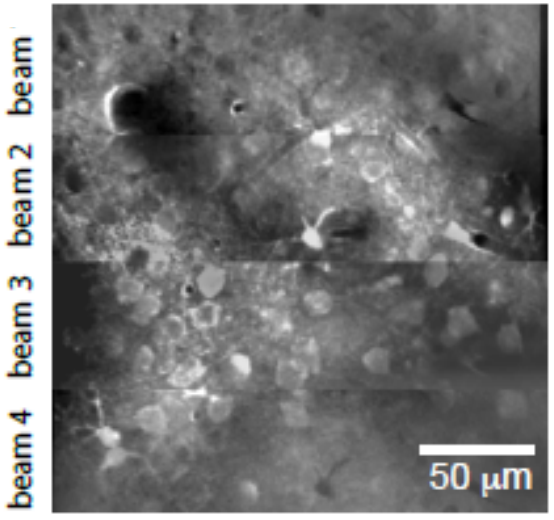
(x3 faster than real)

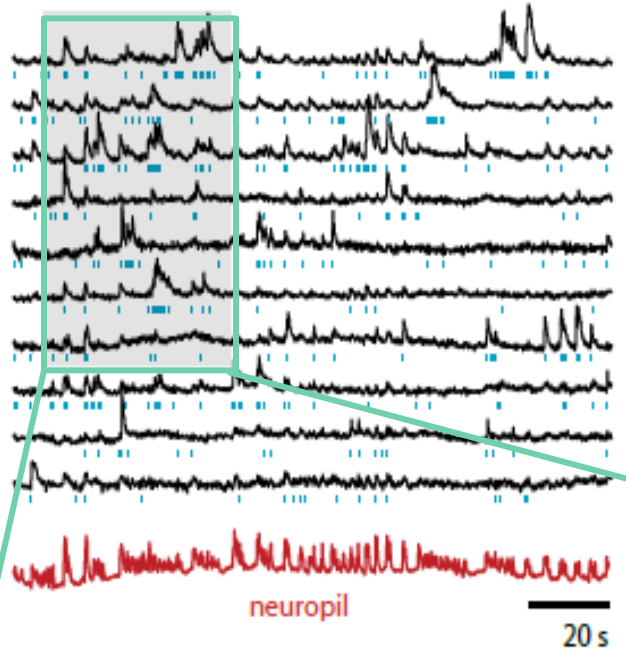


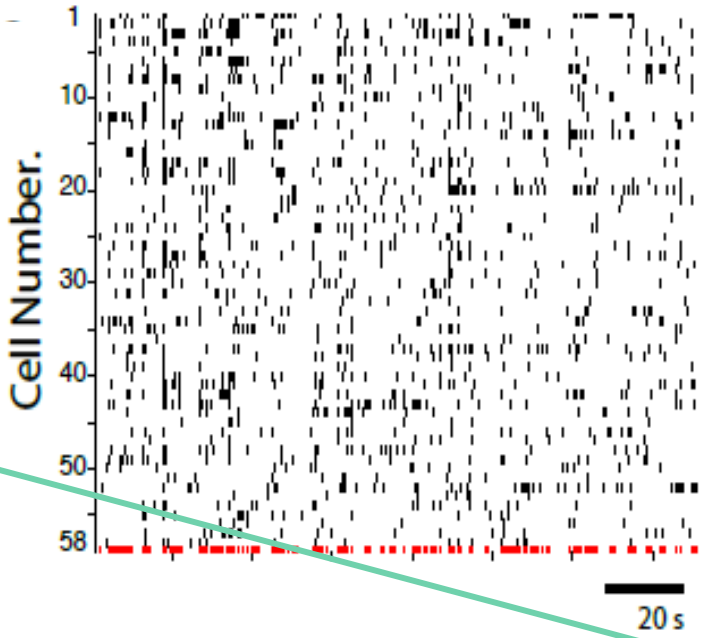
58 neurons

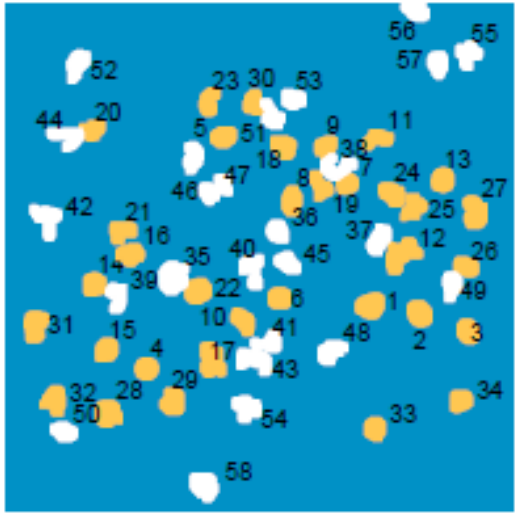
(~100 billons neurons in our brain)

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

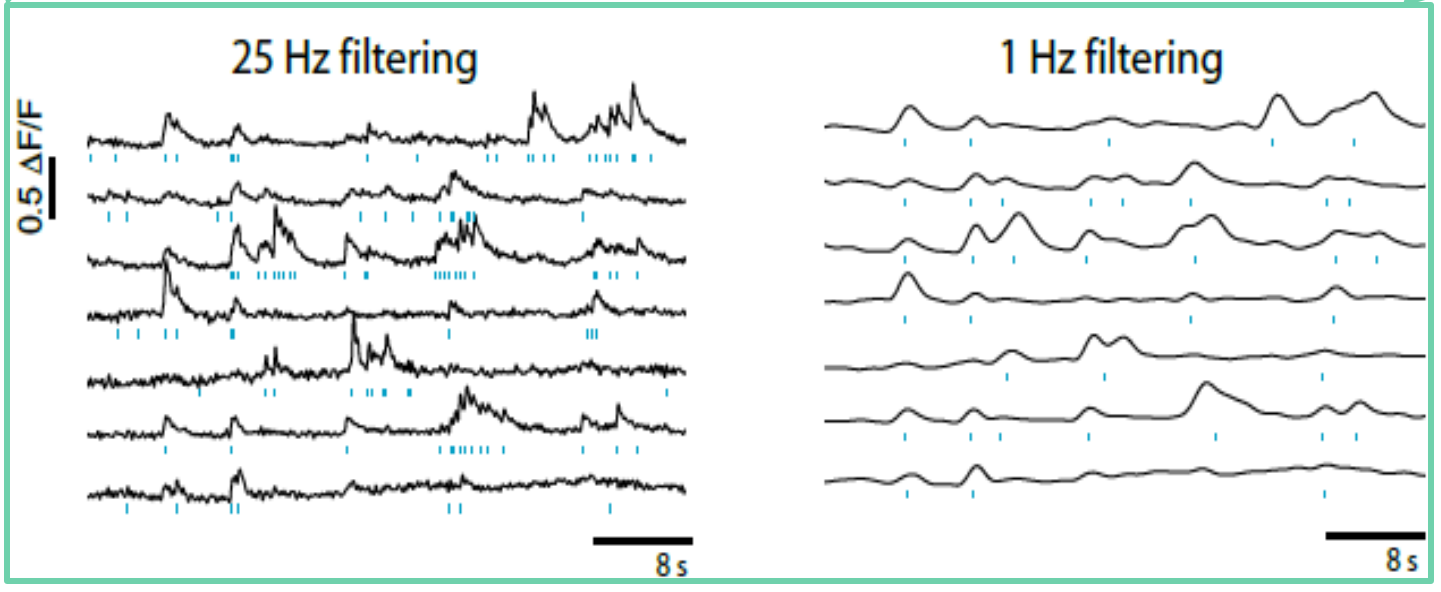


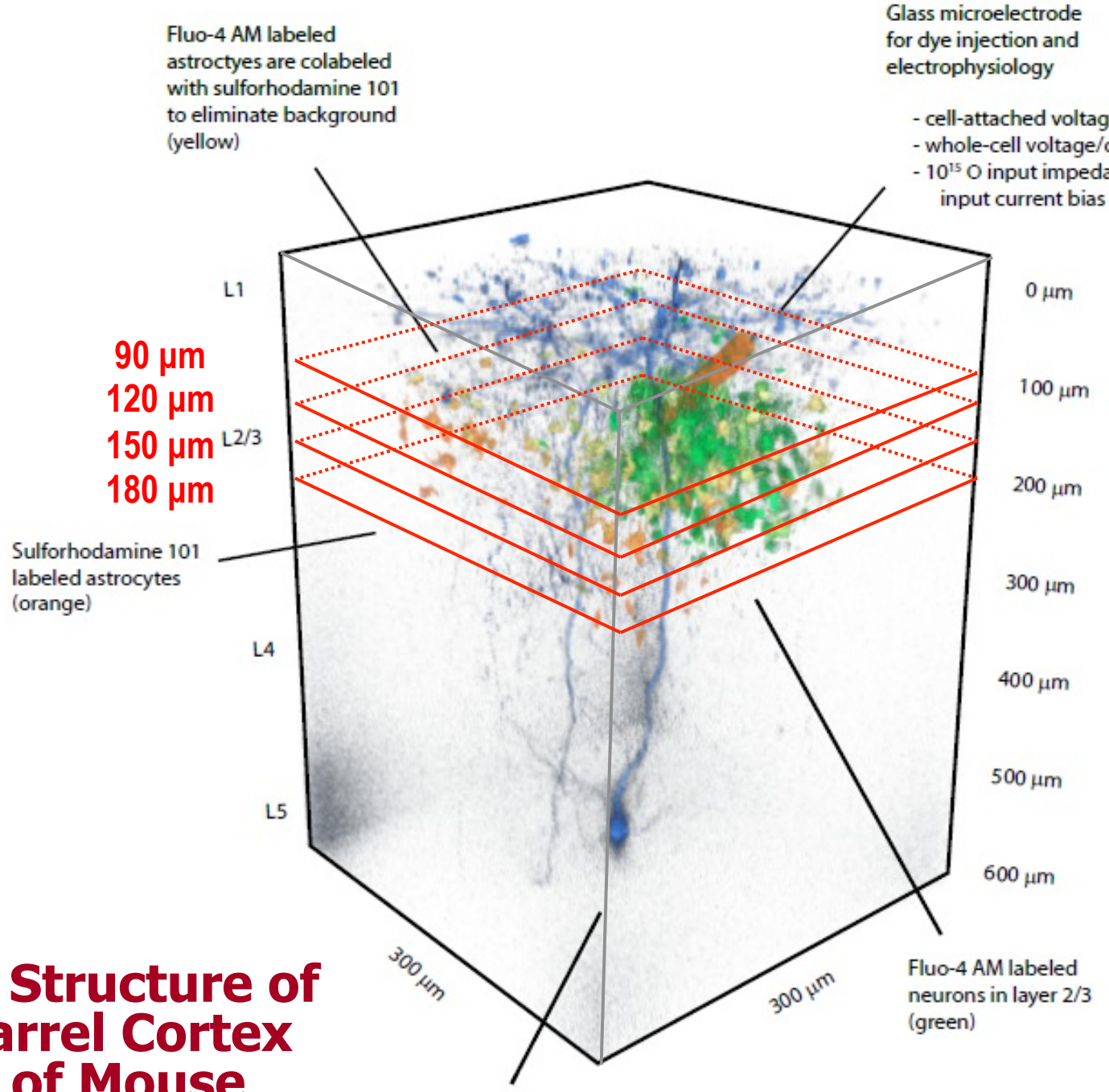






Adrian Cheng (Physics)





3D Structure of Barrel Cortex of Mouse

Adrian Cheng (Physics)

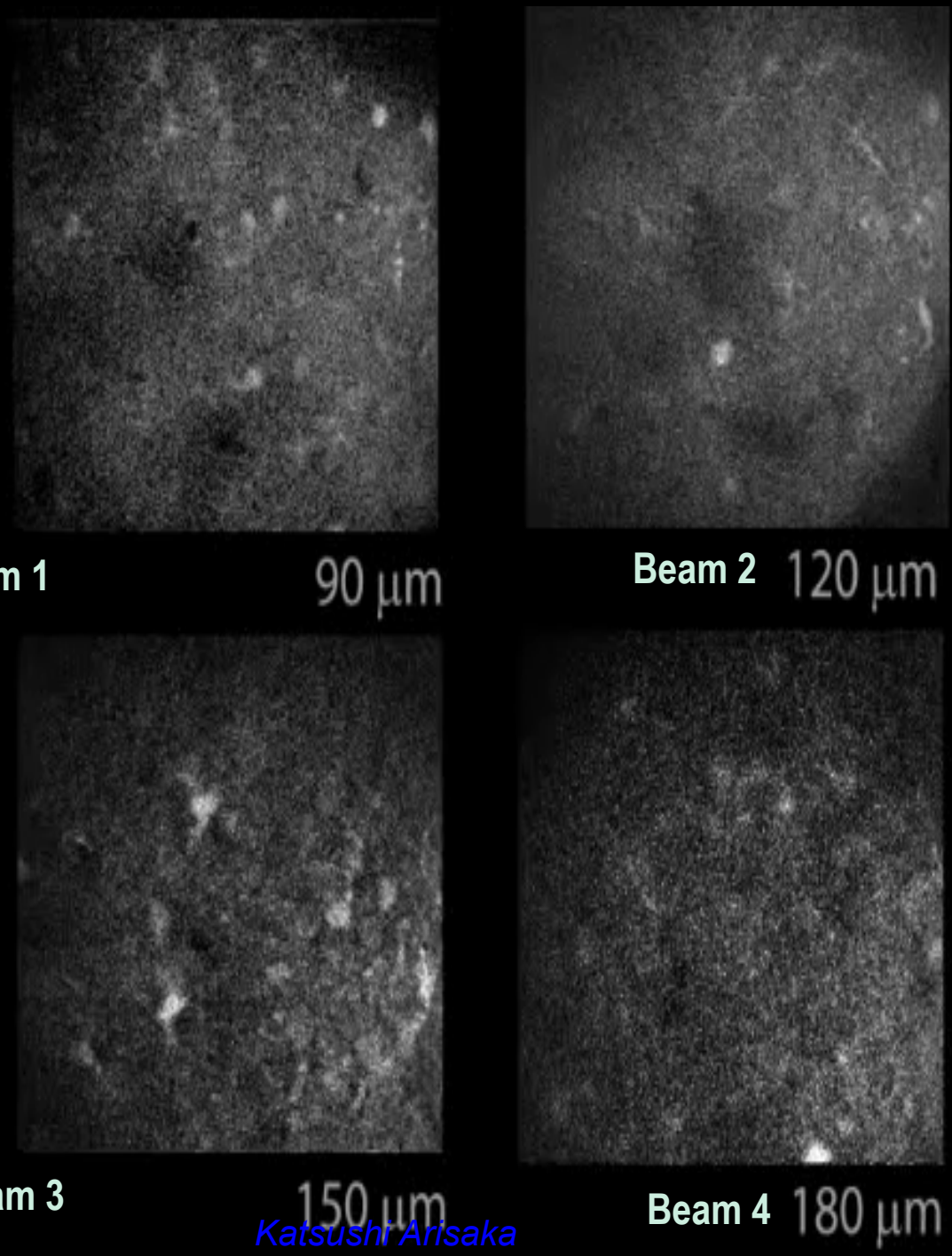
Tiago Goncalves, Peyman Golshani, Carlos Portera-Cailliau (Neurology)

Simultaneous in vivo calcium imaging in 4 axial planes

Barrel Cortex Layer 2/3

60 fps

(x3 faster than real)



UCLA Newsroom on January 11, 2011

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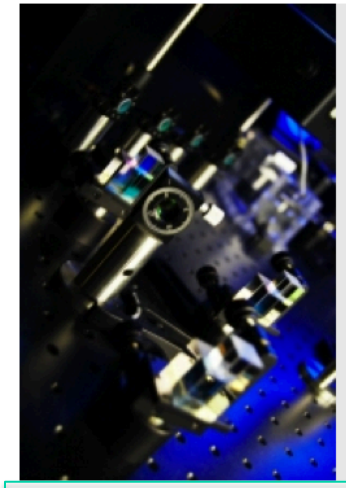
New UCLA-designed microscope records firing of thousands of individual neurons in 3-D

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 the brain can use.

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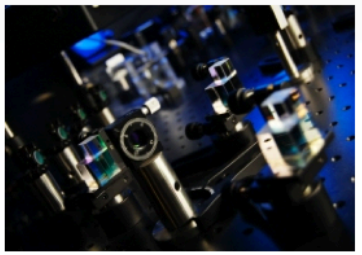
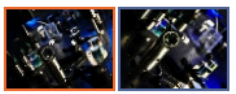


STEM microscope designed at UCLA



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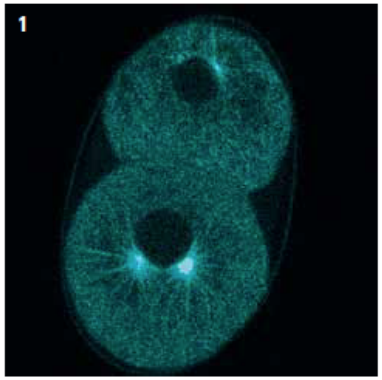
Leica

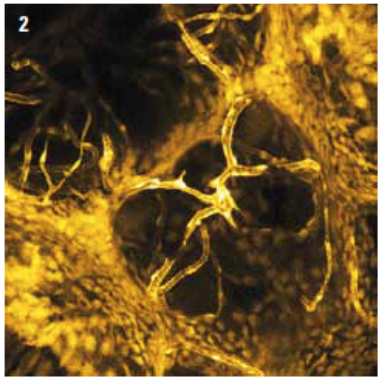
MICROSYSTEMS

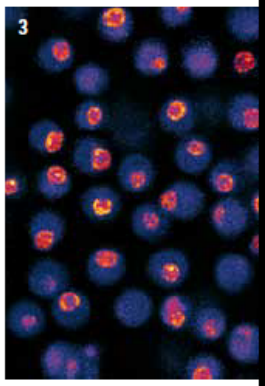
Leica HyD for Confocal Imaging

Hybrid detection technology for high fidelity

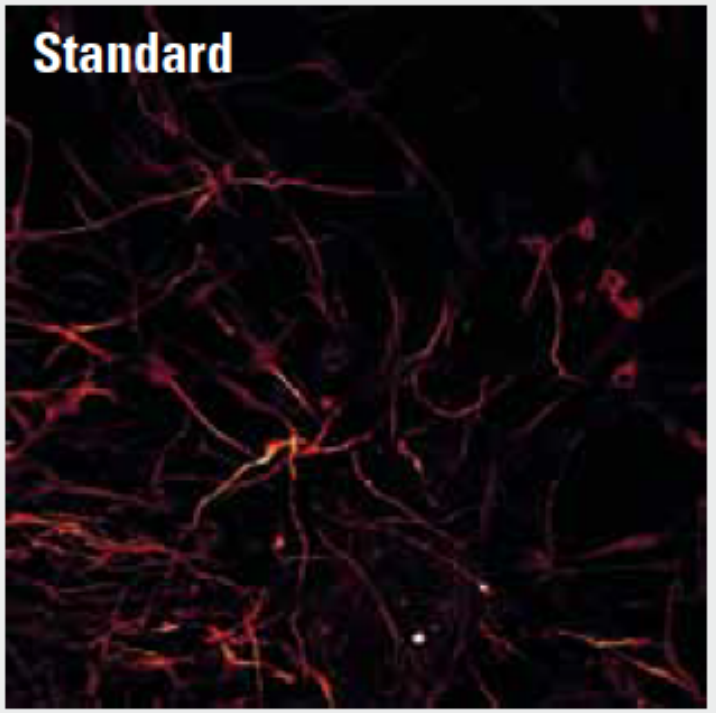
Living up to Life

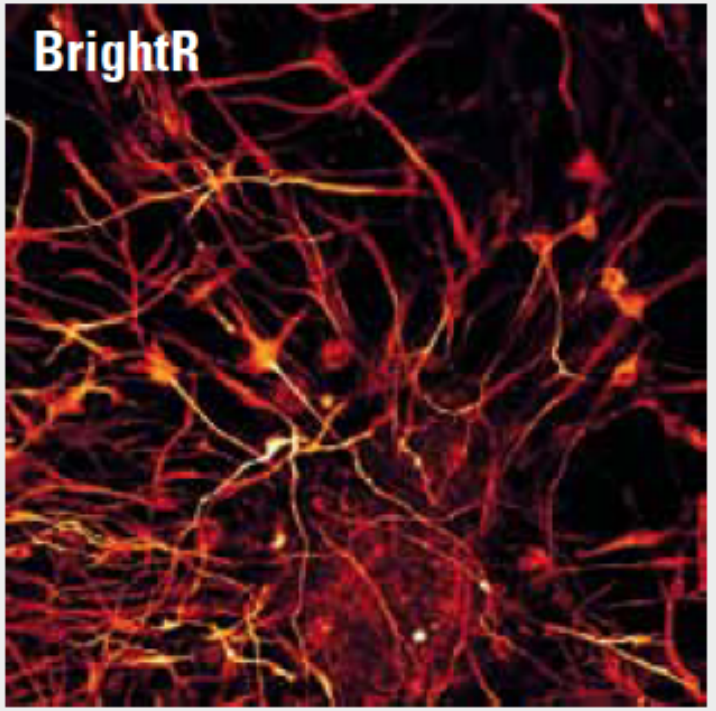


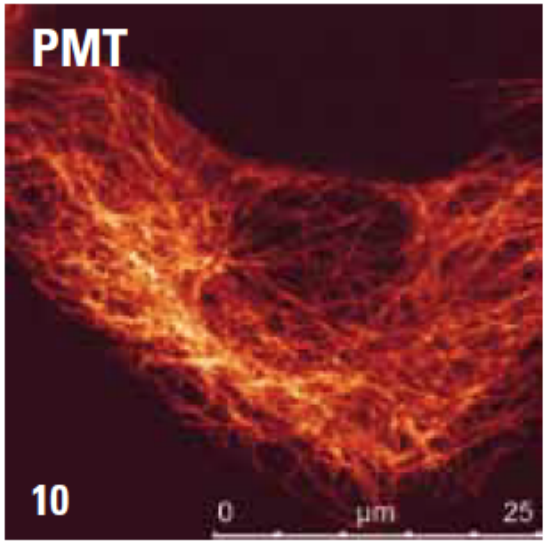


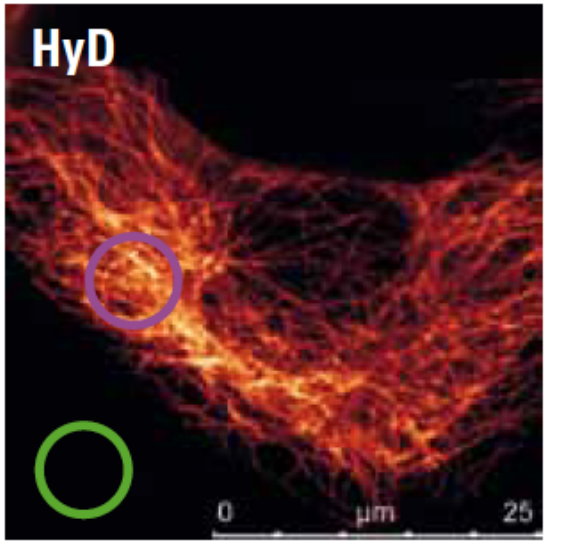


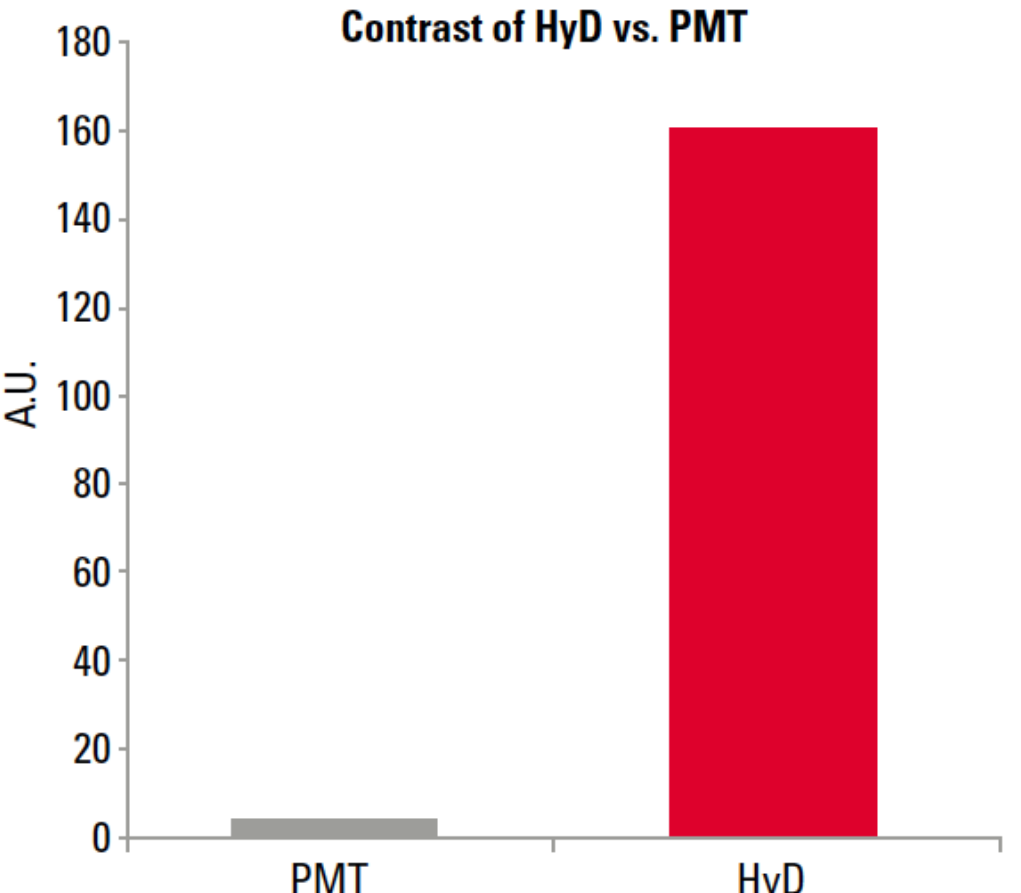
- Large dynamic range
- Improved cell viability
- High-speed imaging
- Single photon counting
- Open upgrade path


Standard


BrightR


PMT
10
0
µm
25


HyD
0
µm
25


Contrast of HyD vs. PMT
A.U.
180
160
140
120
100
80
60
40
20
0
PMT
HyD

Compactification of Extra Dimensions

- **In generally, each photon carries 6 dimensional information.**
  - ***Position :*** ***x, y, z (nm)***
  - ***Time :*** ***T (μs)***
  - ***Decay Time :*** ***τ (ns)***
  - ***Wavelength :*** ***λ (nm)***

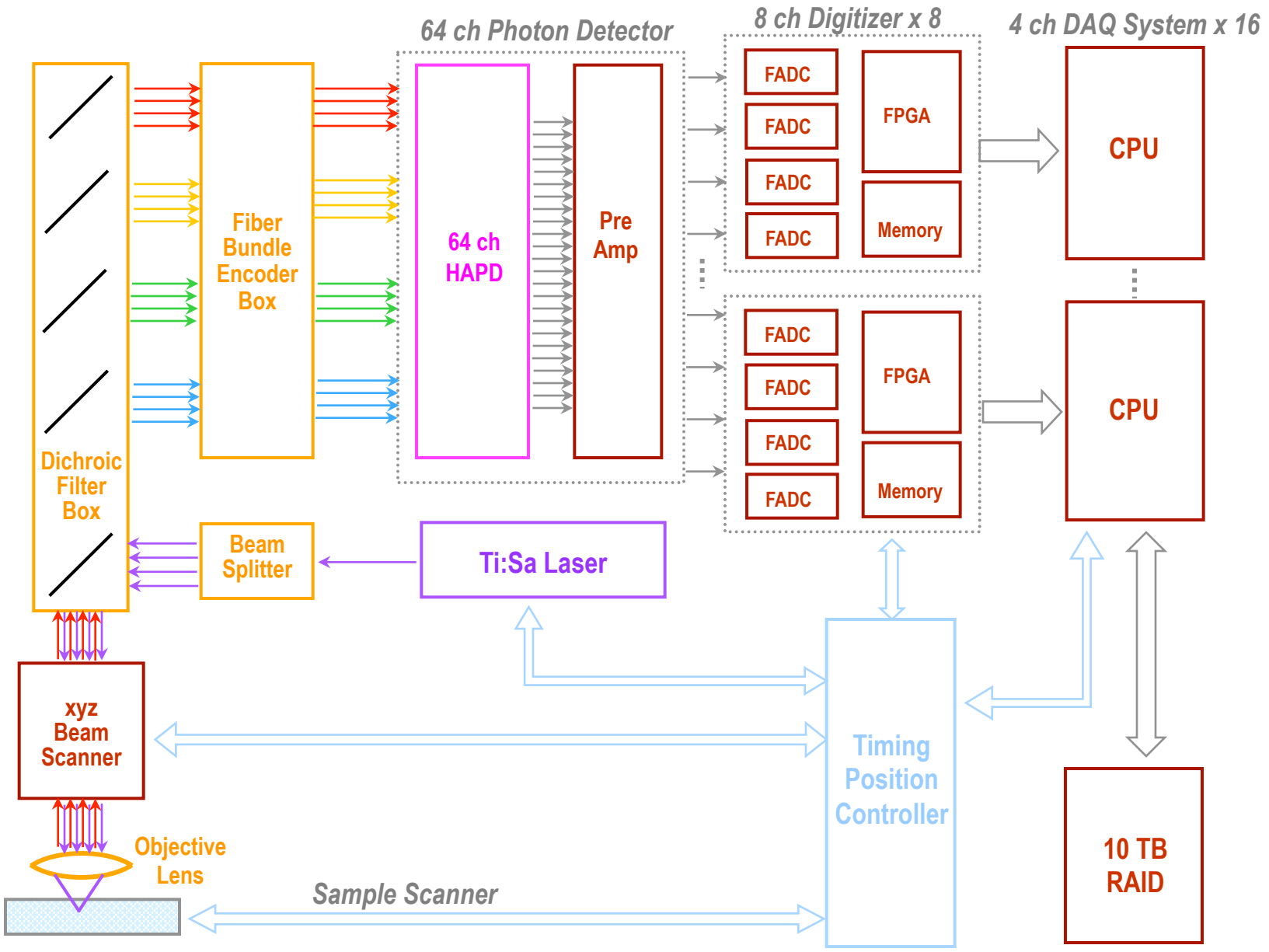
  } ***6D Nano Technology***

- **Digitized signals must be one dimension.**
  - **or at most two, in case of parallel processing.**

⇩

- **Compactification of extra dimensions is required.**

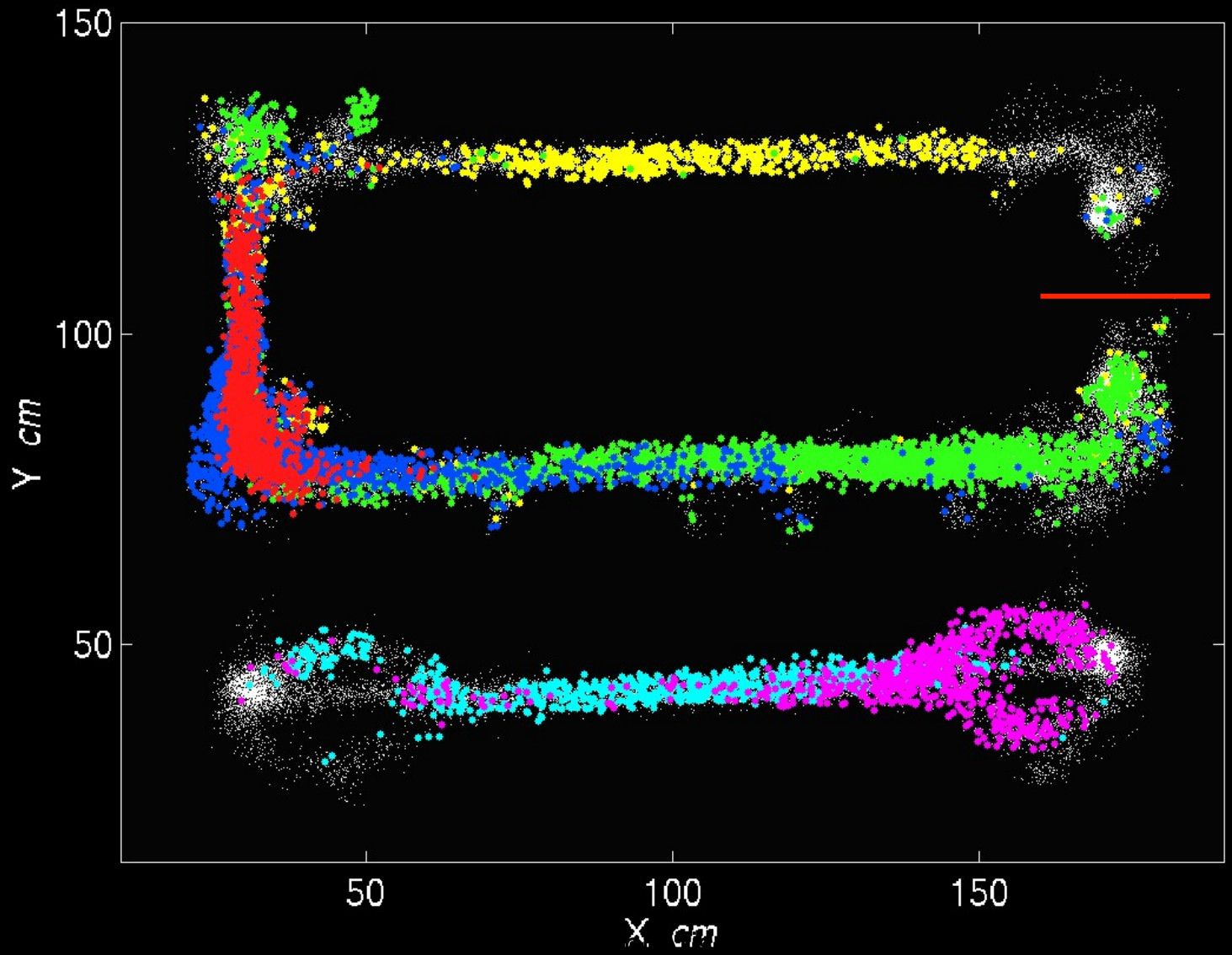
Block Diagram of Multi-beam Confocal Microscope



Future Directions
- Virtual Reality -

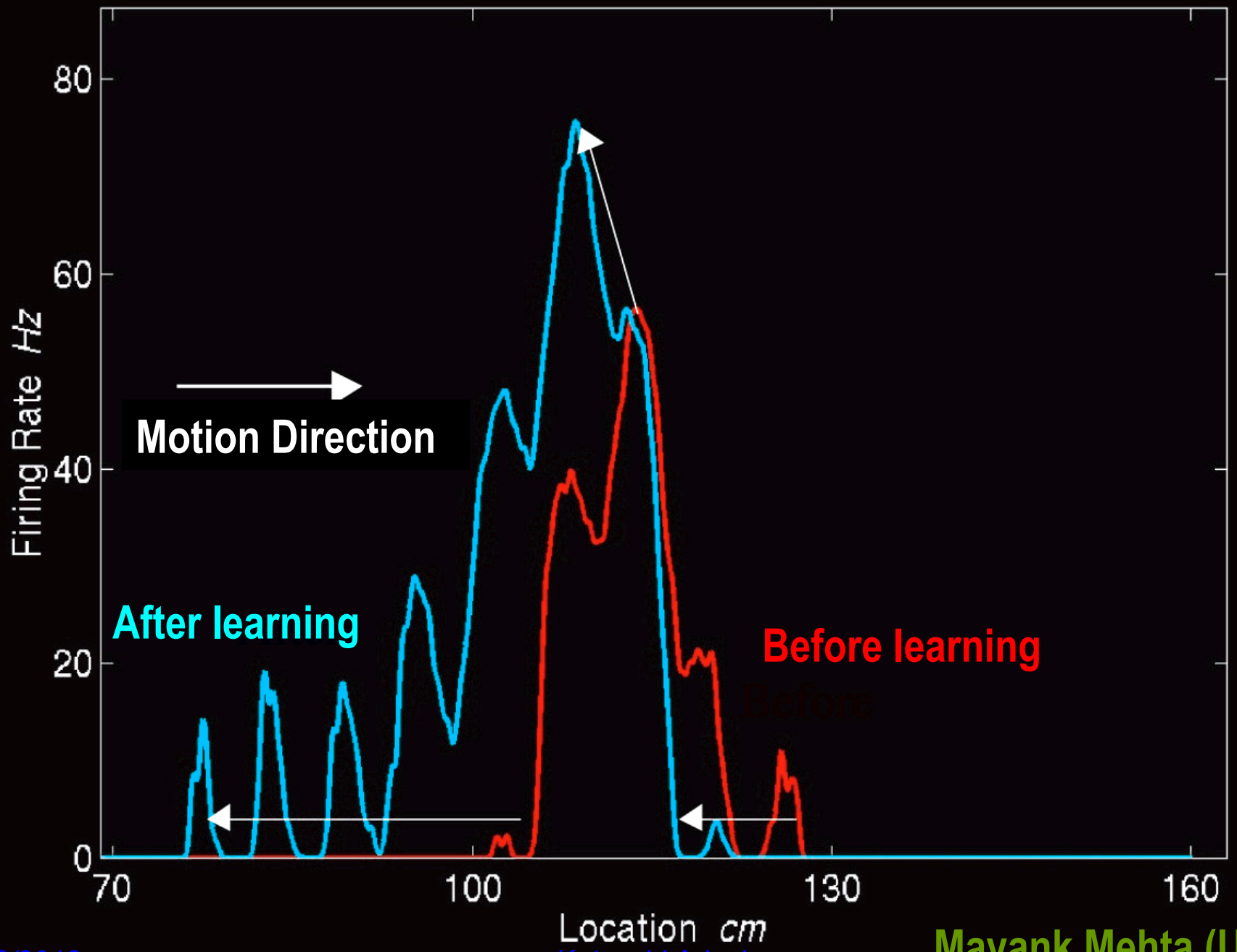
Activity of (excitatory) pyramidal neurons in CA depends on rat's position: place cells

Mayank Mehta (Physics, Neurology)



Hippocampus has a cognitive map of space

Learning and Memory by Hippocampus

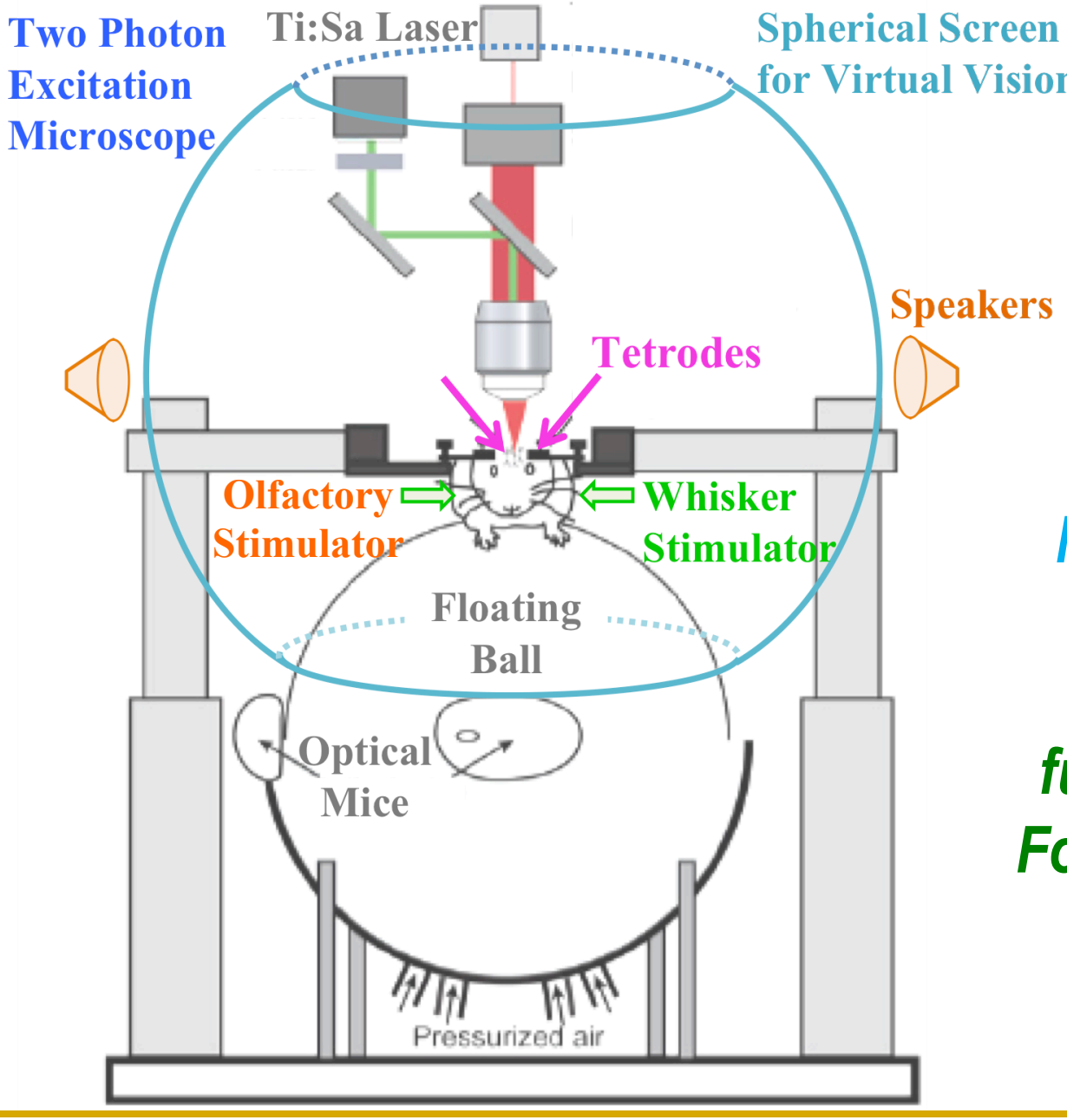


Mayank Mehta (UCLA)

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.

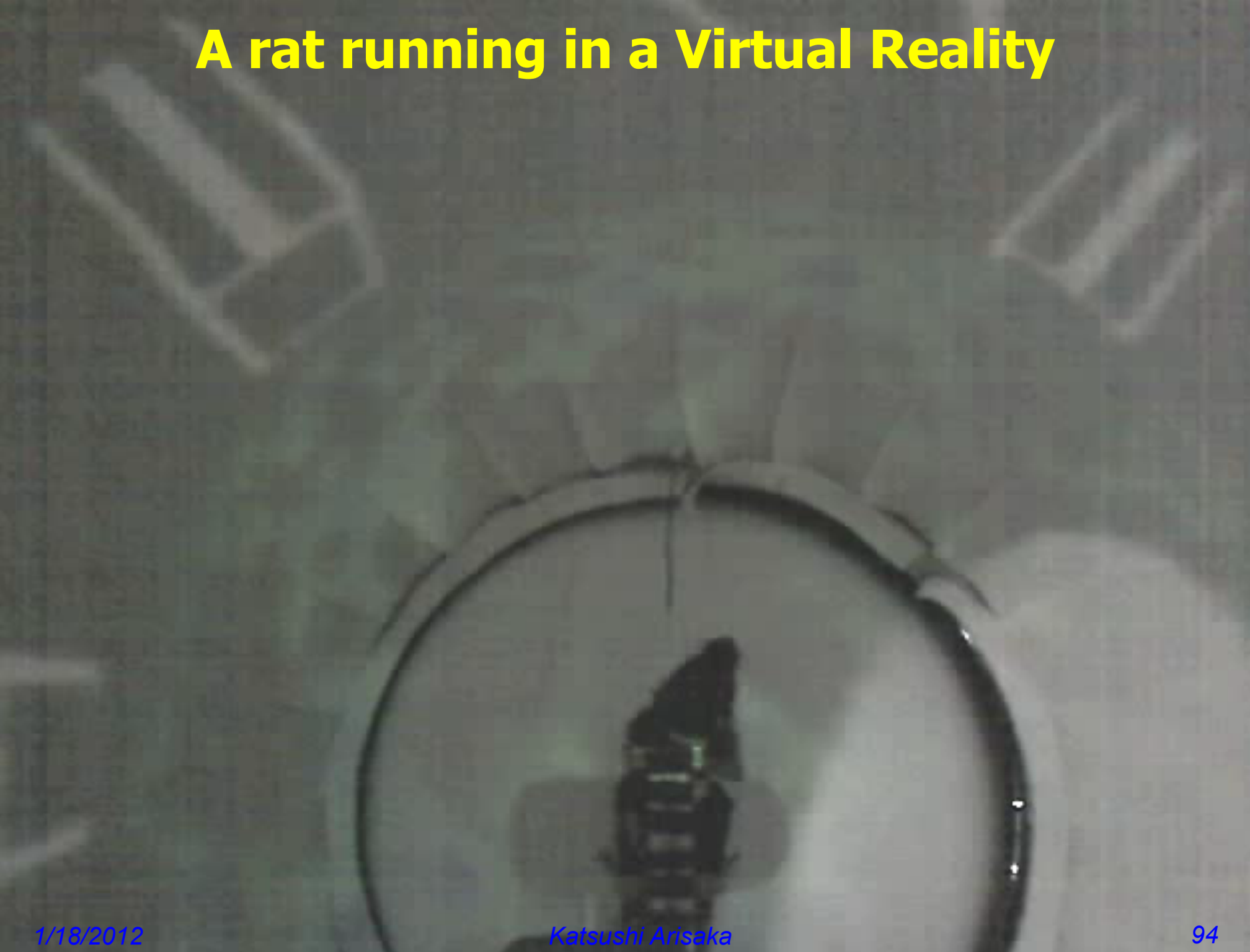
Virtual Reality Experiment on Awake Rats



Mayank Mehta (Physics)

funded by Keck Foundation ($1M)

A rat running in a Virtual Reality

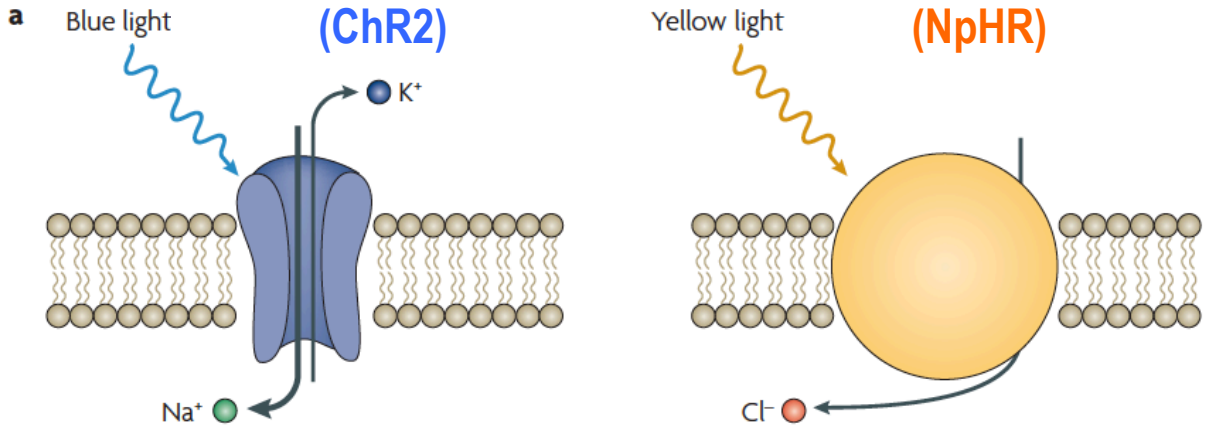


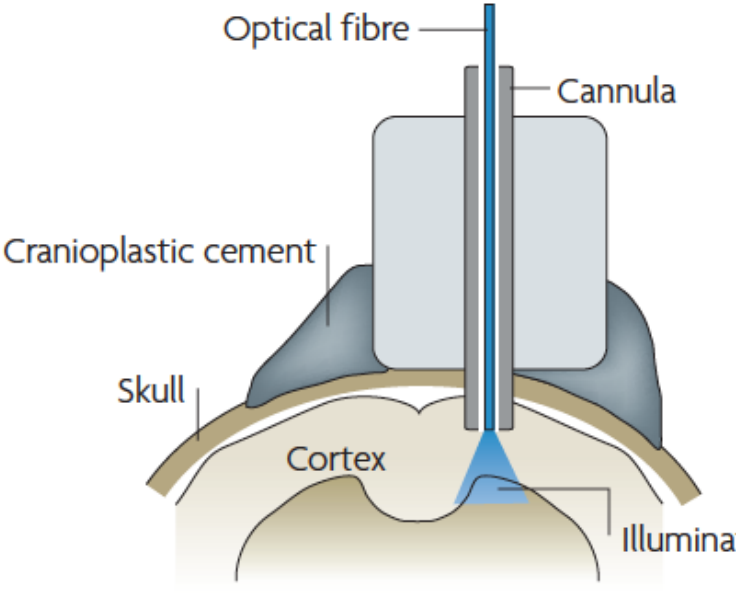
Optogenetic Excitation of Neurons

Karl Deisseroth (Stanford)

Excitation by Channelrhodopsin-2 (ChR2)

Inhabitation by Halorhodopsin (NpHR)

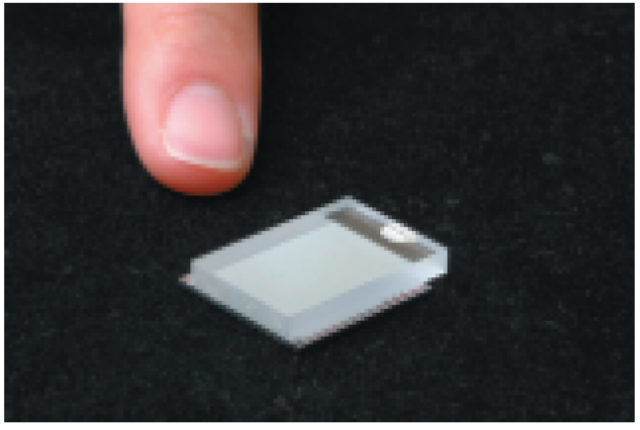




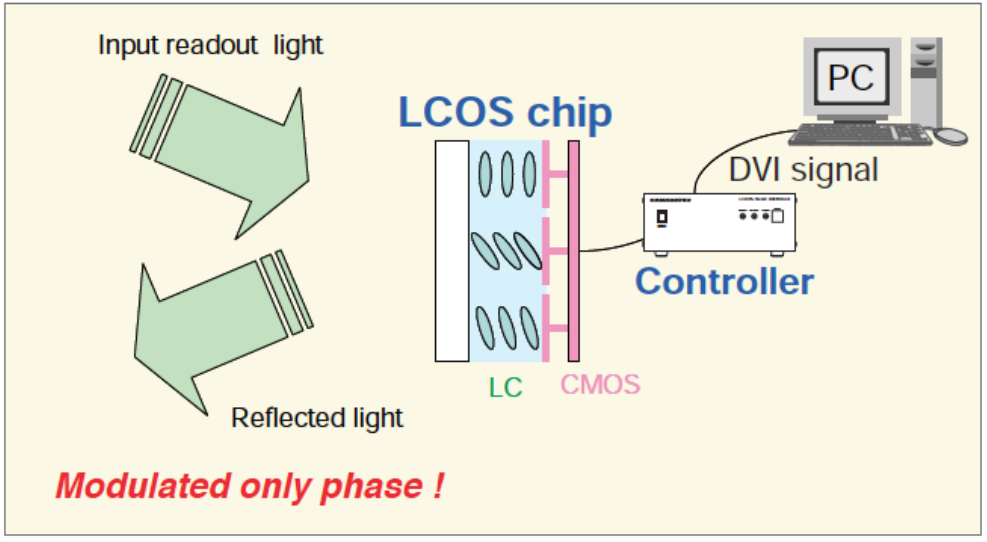
LCOS (Liquid Crystal on Silicon) for SLM (Spatial Light Modulator)

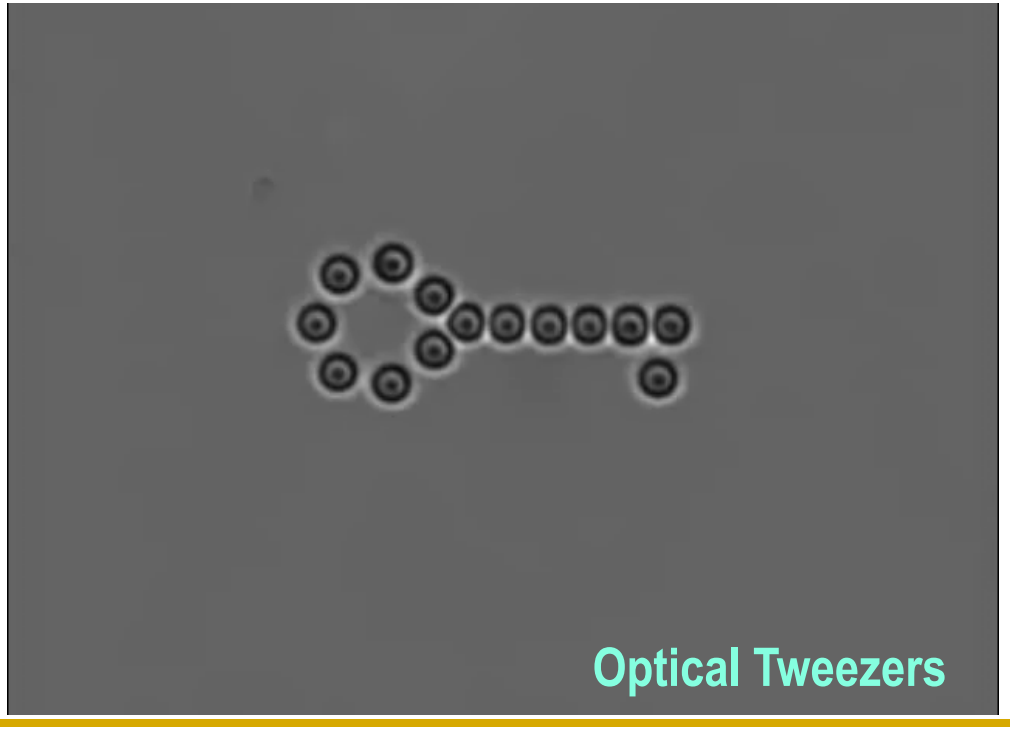
Hamamatsu

X10468 Head and Controller

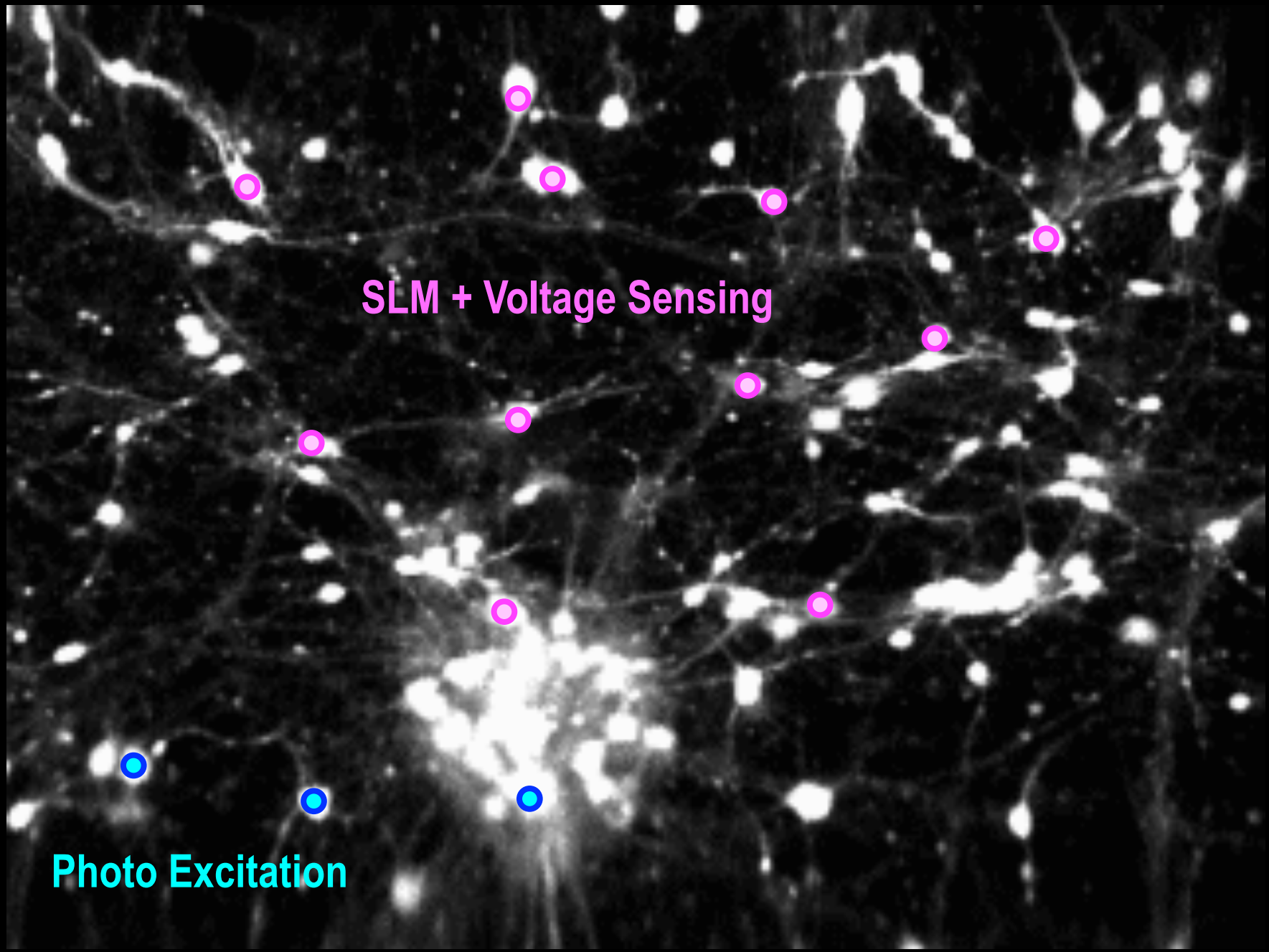


LCOS chip inside the Head





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



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

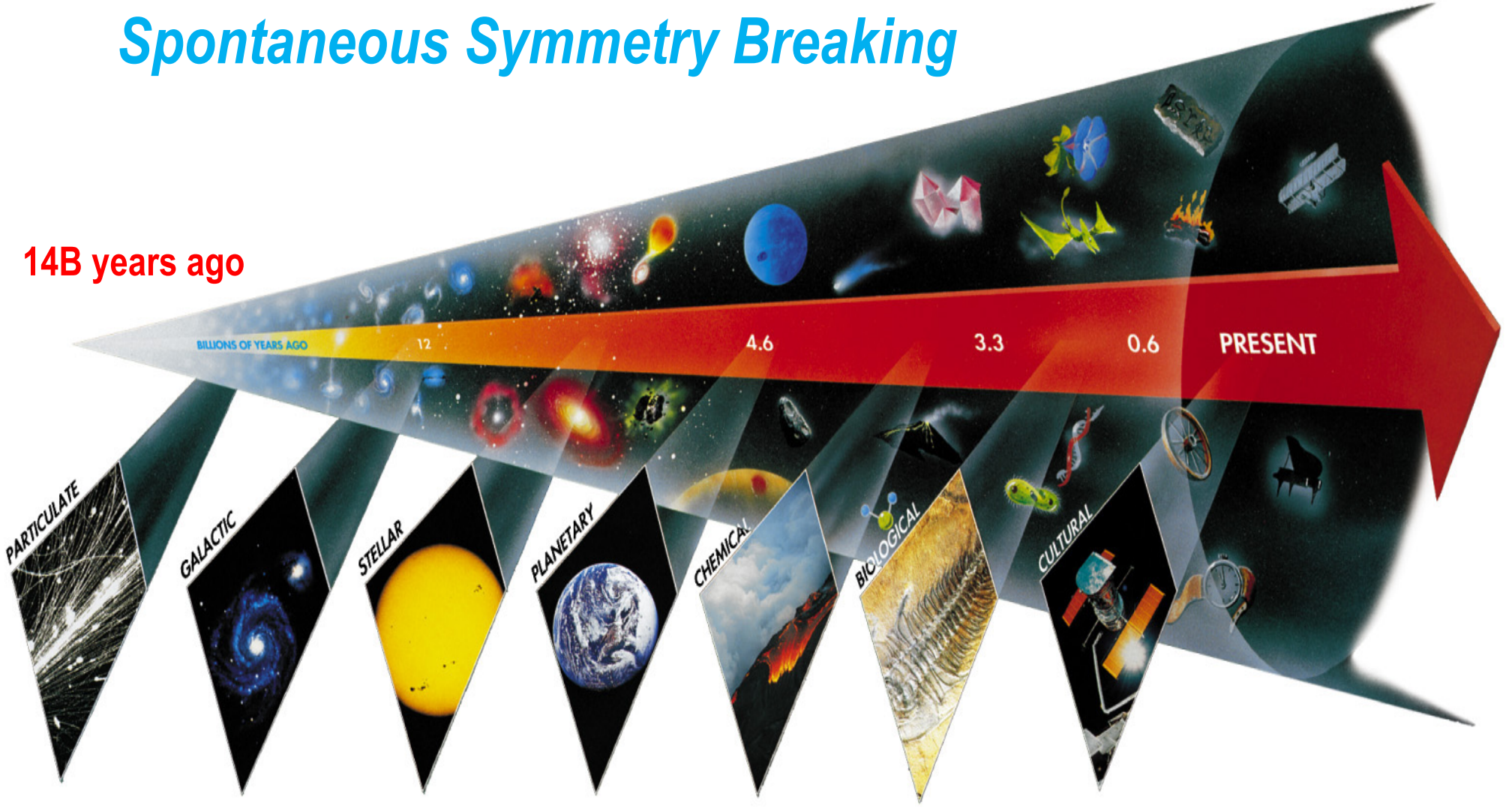
The Origin of Consciousness

- 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

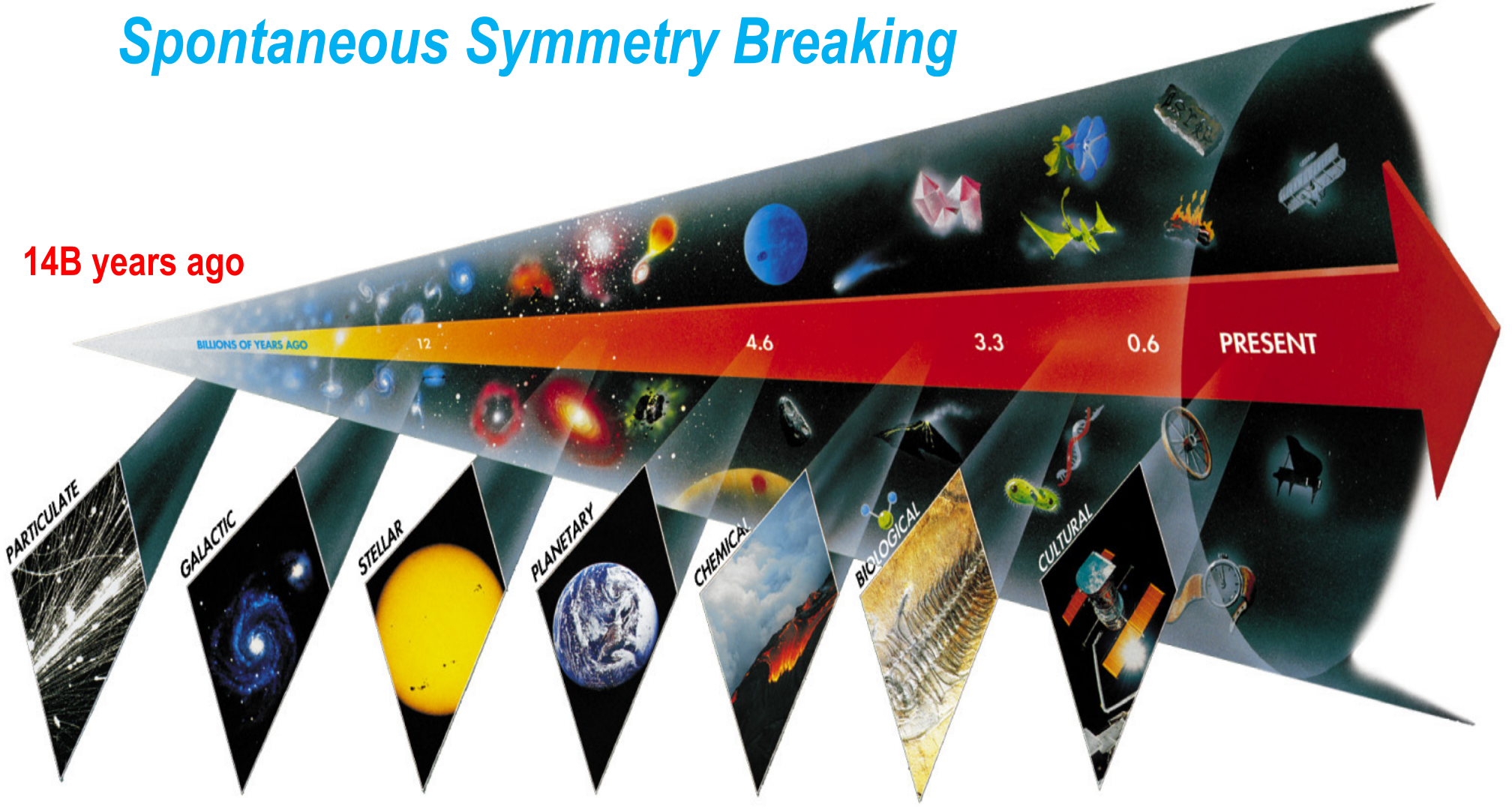
Spontaneous Symmetry Breaking



Simple ⟹ **Coherent Complex System**

Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking



Origin of Particles

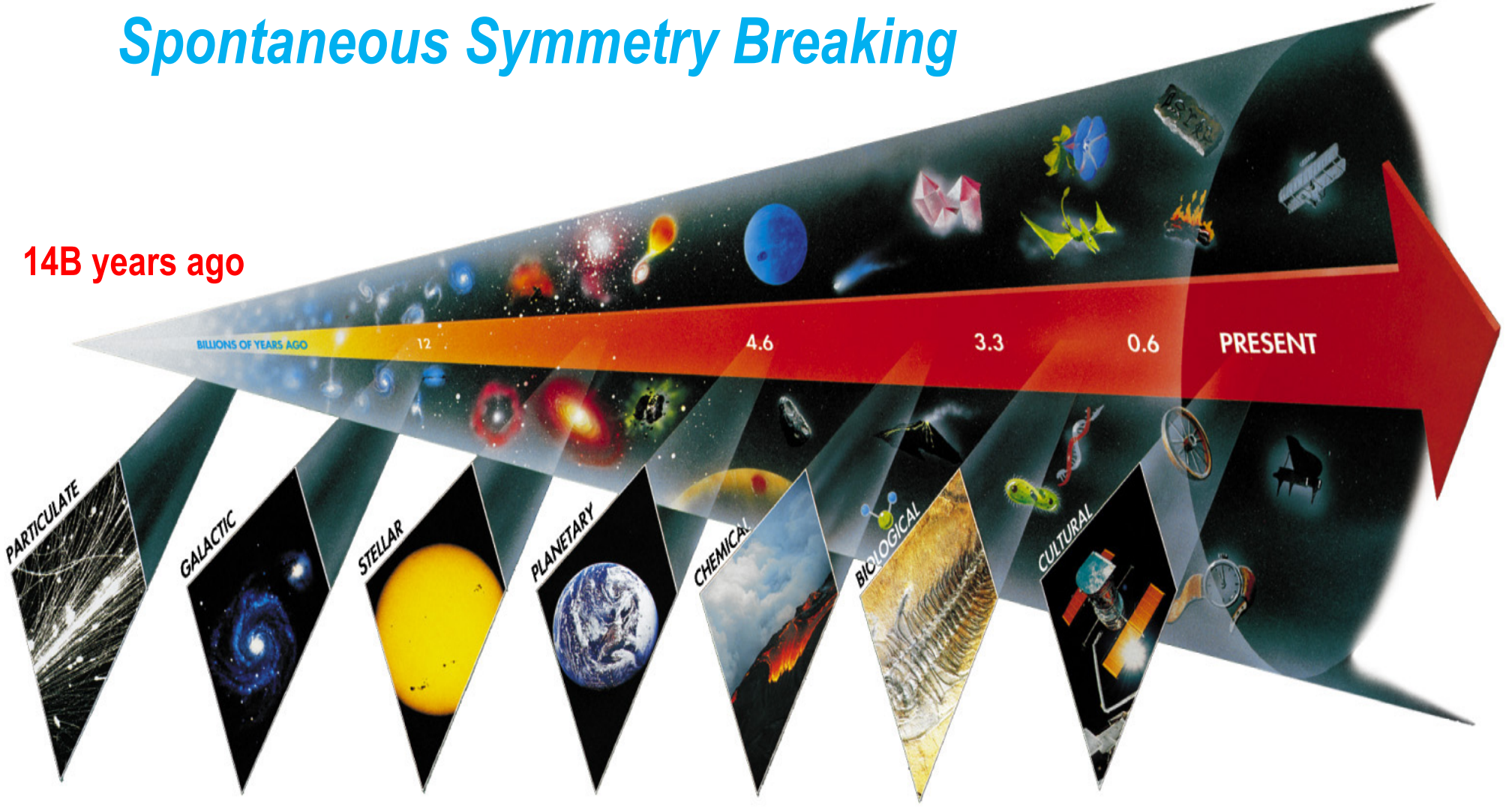
Origin of Structure

Origin of Life

Origin of Consciousness

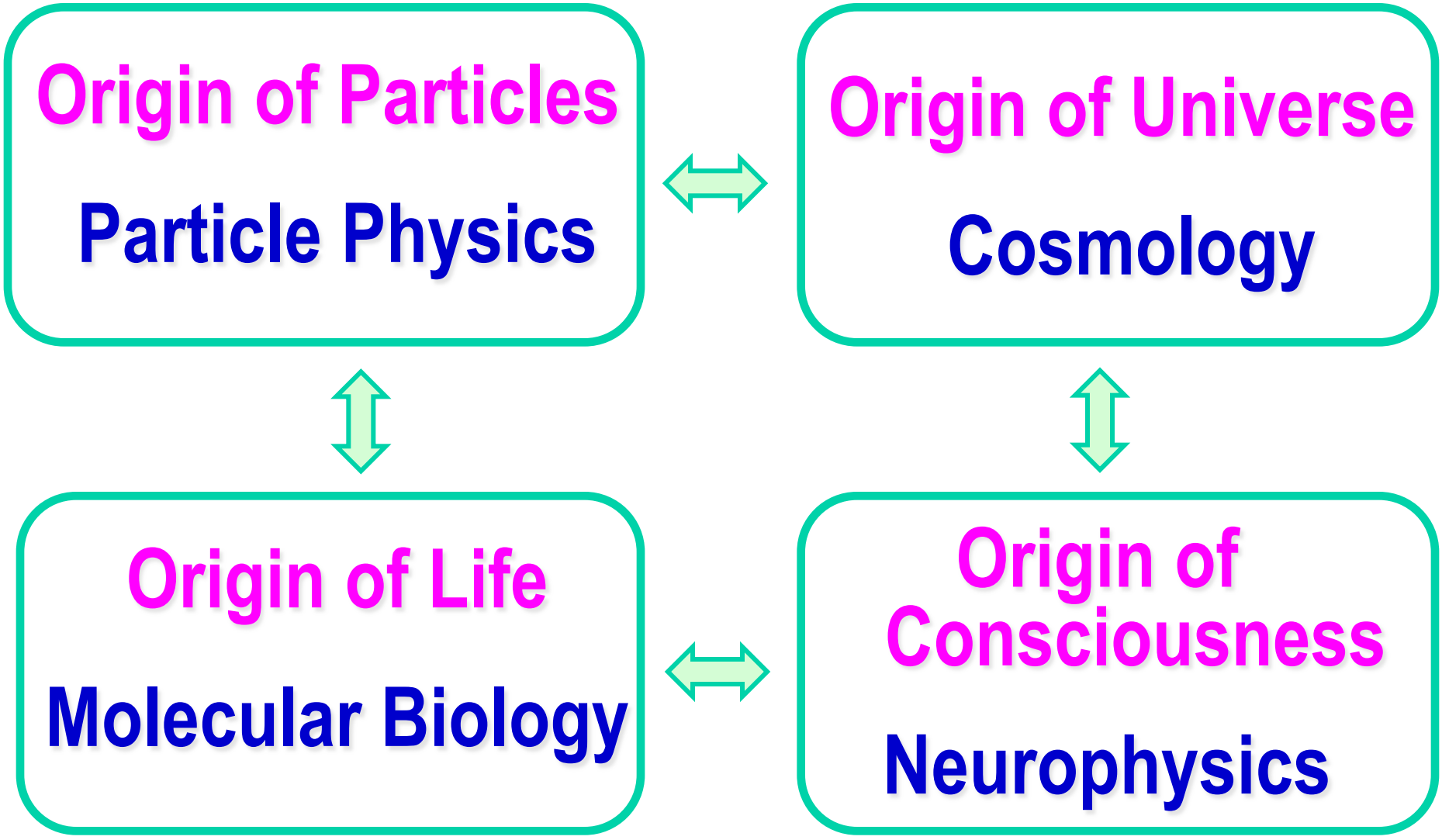
Seven steps of cosmic evolution

Spontaneous Symmetry Breaking



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

Four Major Science



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.

Thanks to all the Collaborators!

Scientific Objectives	Department	Prime PI	Other Senior Person	Grad Students	Sample	High-speed Microscopes	Funding	Activities
Neurophysics (Virtual Reality)	Physics & Astronomy, Neurology	Mayank Mehta		Daniel Aharoni, Bernard Willers	Rat	2PE, Tetrode	Keck Foundation	2009 - Now
Hair cell motion	Physics & Astronomy	Dolores Bozovic		Lea Fredrickson	Frog	CMOS	NSF MRI	2007 - Now
Neutral Networks	Physics & Astronomy	Katsushi Arisaka	Luis Beltran-Parrazal	Adrian Cheng	Zebrafish	2PE, Conforcal	NSF MRI	2008 - 2009
Single Molecule	Chemistry	Shimon Weiss	Xavier Michalet, Adrian Cheng	Daniel Aharoni	Cells	64ch FCS, ALEX	NIH R01	2006 - Now
TfR tracking on Cancer cells	Oncology, Physics & Astronomy	Manuel Penichet, John Miao	Gustavo Helguera, Jose Rodriguez		Cells	CMOS, ICMOS	(NSF MRI shared)	2007 - 2008
Neural networks for breathing	Neurobiology	Jack Feldman	Consuelo Morgado	Adrian Cheng	Rat	ICMOS, Confocal	(NSF MRI shared)	2007 - 2008
Neural networks (Voltage sensing dyes)	Neurobiology	Tom Otis		Bernard Willers	Sliced Brain	ICMOS, 2PE	NIH Rec. Act	2009 - Now
Development of neural networks	Neurology	Carlos Portera-Cailliau	Adrian Cheng, Tiago Goncalves	Phuc Hoang	Mouse	2PE	NIH Rec. Act	2008 - Now
High-speed Imaging Flow Cytometer	Electrical Engineering	Bahram Jalali			Cells	ICMOS		2009 - Now
Core facility of High-speed Bio-imaging	CNSI	Shimon Weiss	Laurent Bentolila		Anything	CMOS, ICMOS, EMCCD	CNSI internal	2008 - Now
Multi-channel HAPD, LCOS	Hamamatsu	Suyama Motohiro				2PE, EMCCD	EMCCD, LCOS donated	2006 - Now
CMOS Cemera	Photron	Tak Takimizu				CMOS, ICMOS	3 CMOS donated	2007 - Now
High-speed Microscope	Nikon, Leica	Jeff Huber, Thomas Zhapf				CMOS, ICMOS, 2PE	Microscope discounted	2009 - Now

Talk Outline

- **Today: Bio-imaging and Neuro-physics**
  - Part I ~30 min.
    - Introduction to High-speed Bio-imaging
    - Single Molecule: Origin of Life
  - Part II ~30 min.
    - Neurophysics: Origin of Consciousness
- **Next week : Particle Physics & Cosmology**
  - Part I ~30 min.
    - Introduction to Cosmology: Origin of Universe
    - CMS at CERN: Origin of Particles
  - Part II ~30 min.
    - Detection of Dark Matter: Origin of Structure in Universe
  - Lab Tour ~10 min.