The Origin of Life

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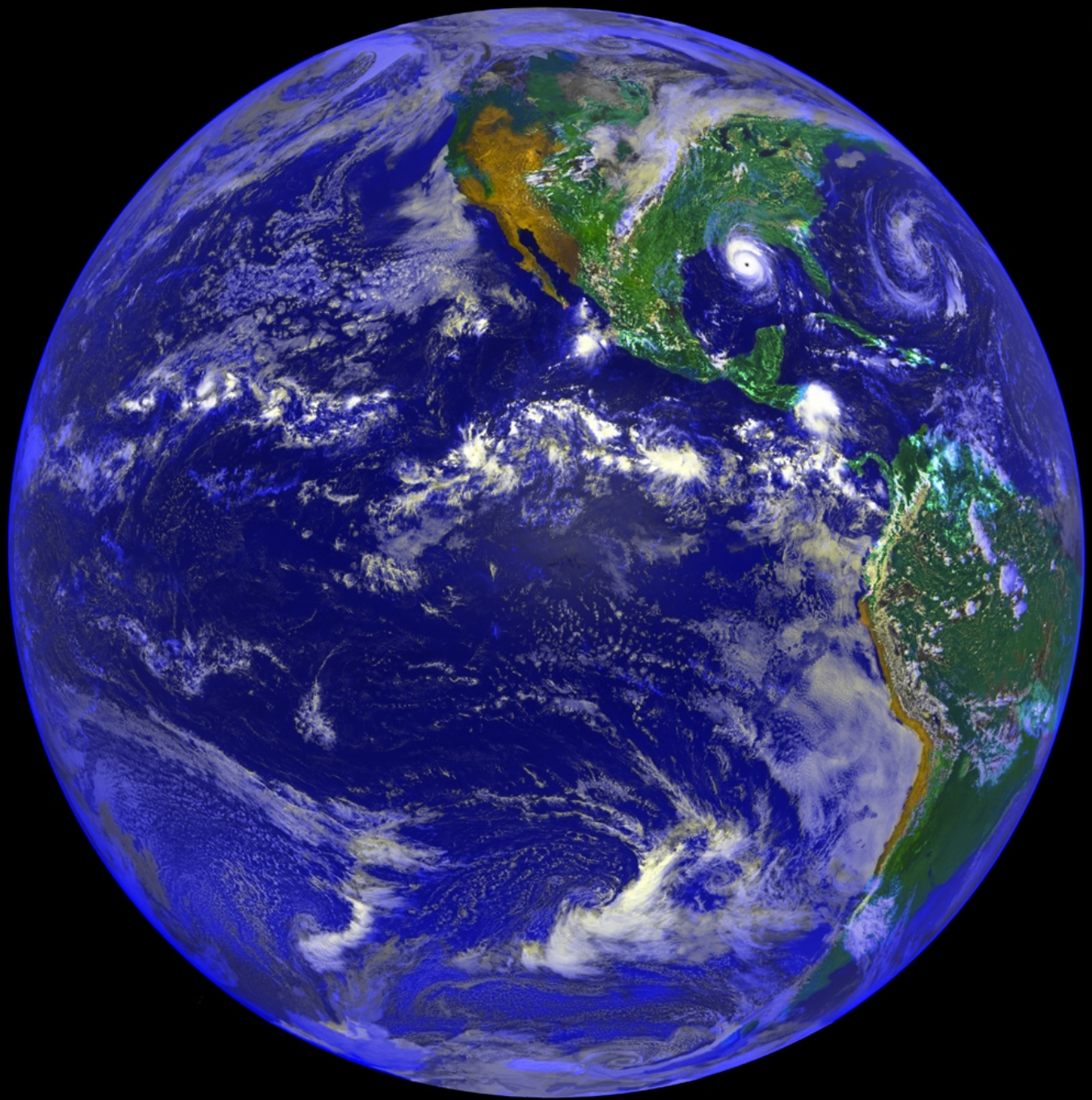
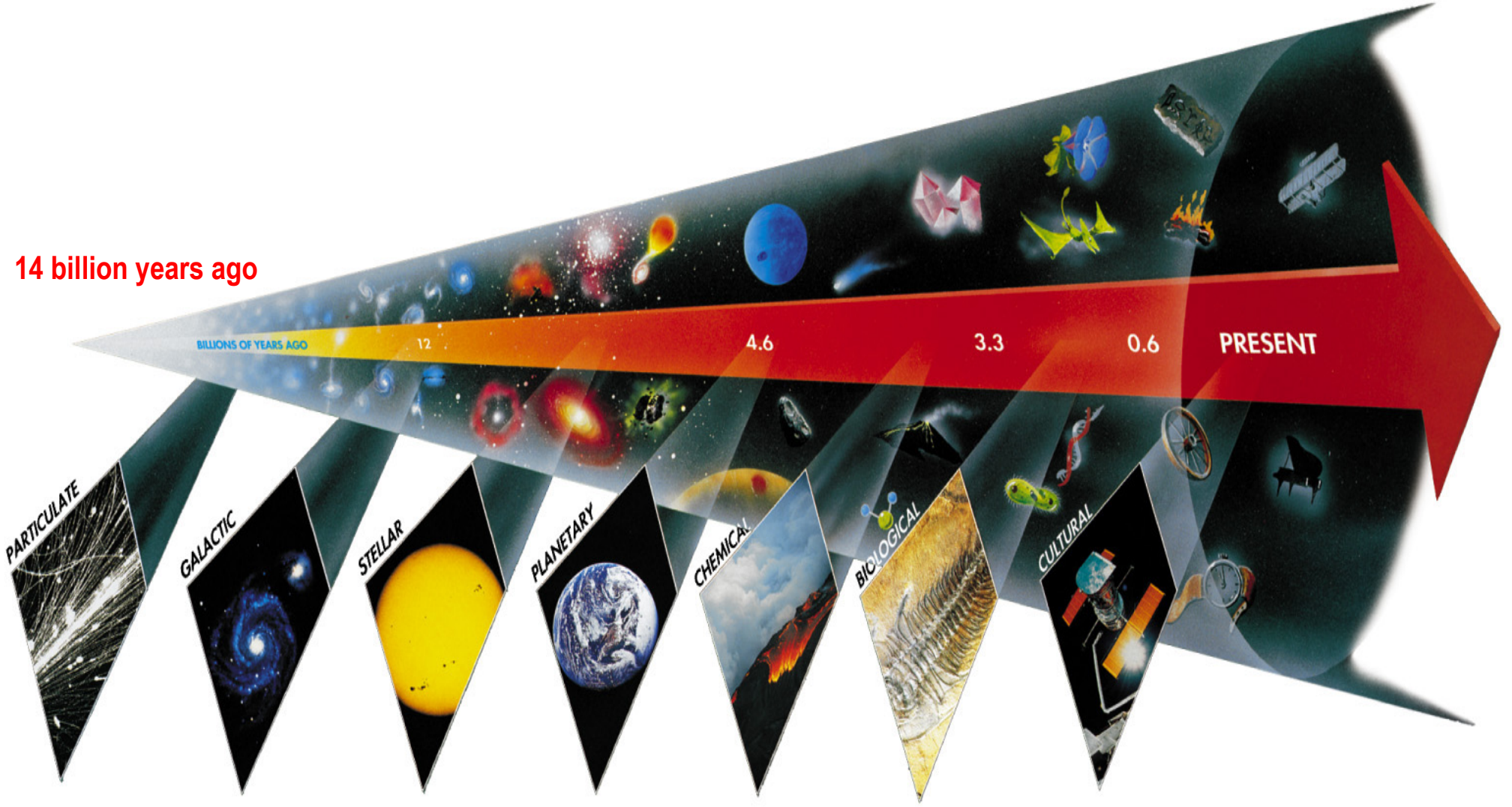


Why are we here?

Seven Phases of Cosmic Evolution



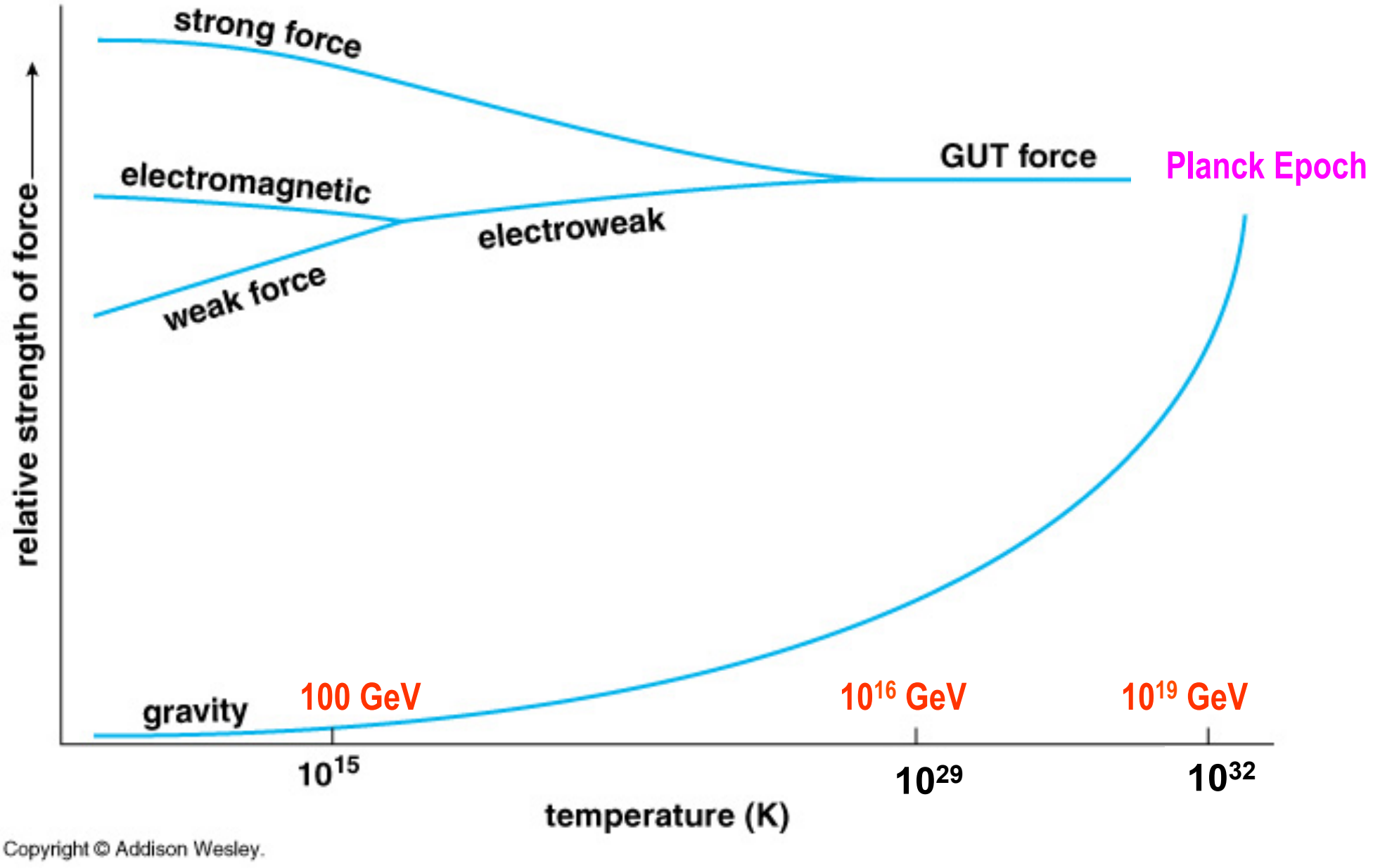
Origin of Particles

Origin of Structure

Origin of Life

Origin of Consciousness

Unification of Forces



Physicists' View of Early Universe

Fiat lux

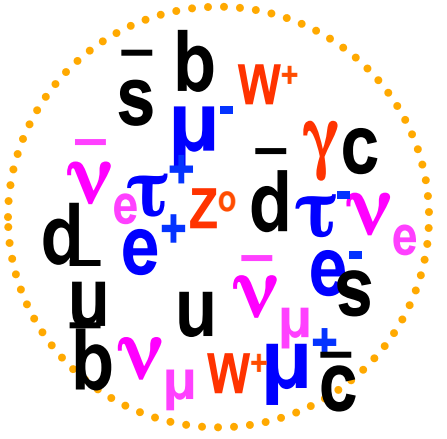
Let there be light

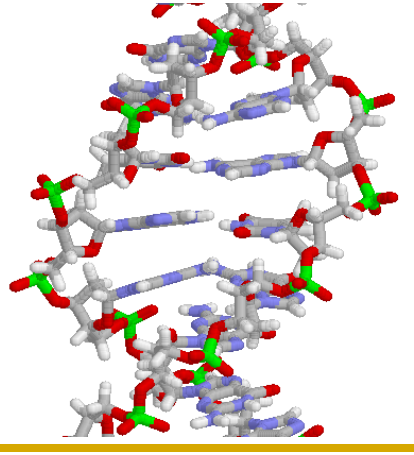
Symmetry Breaking

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

Simple

Symmetry Break Down

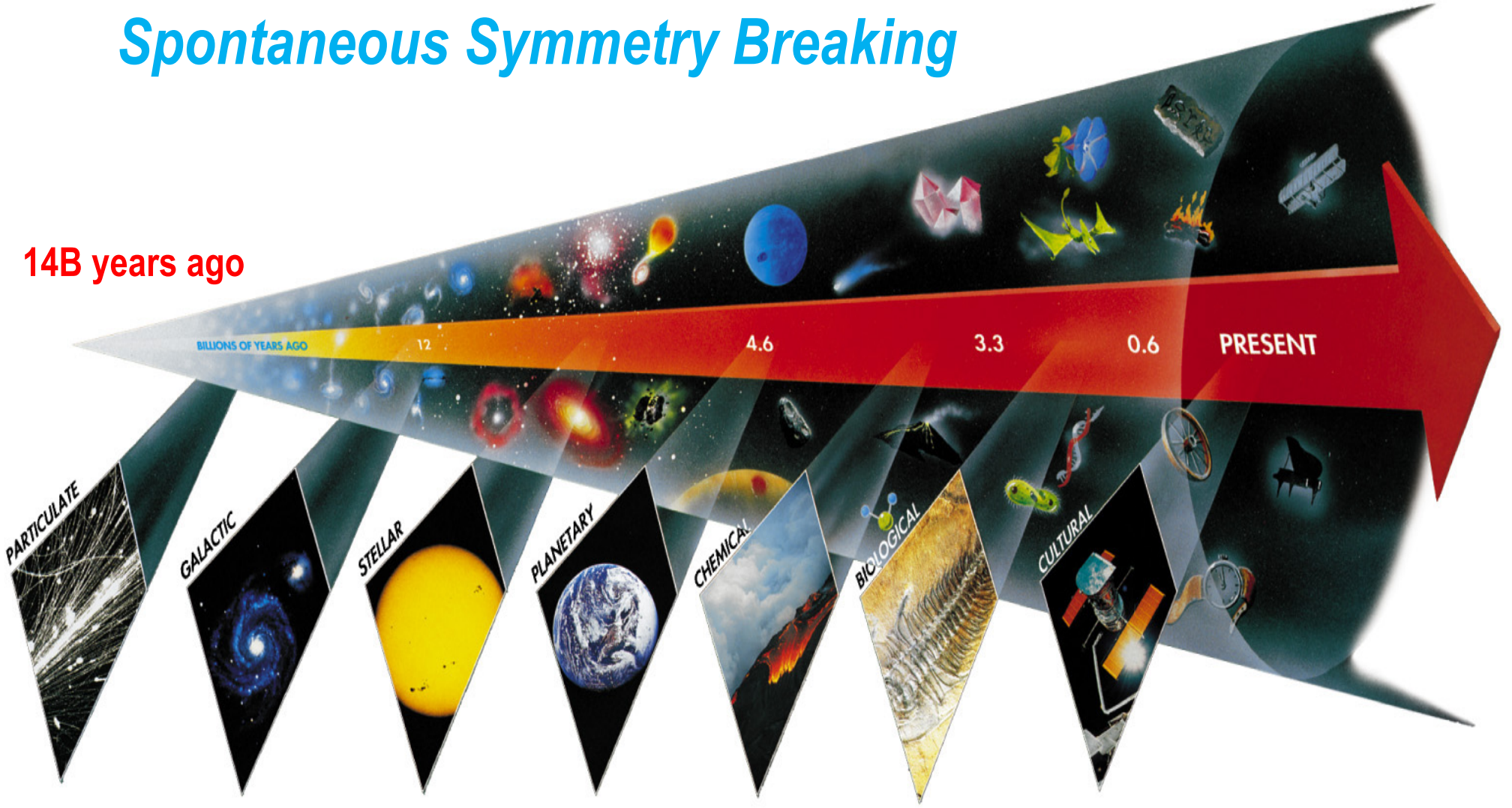




Complex

Seven steps of cosmic evolution

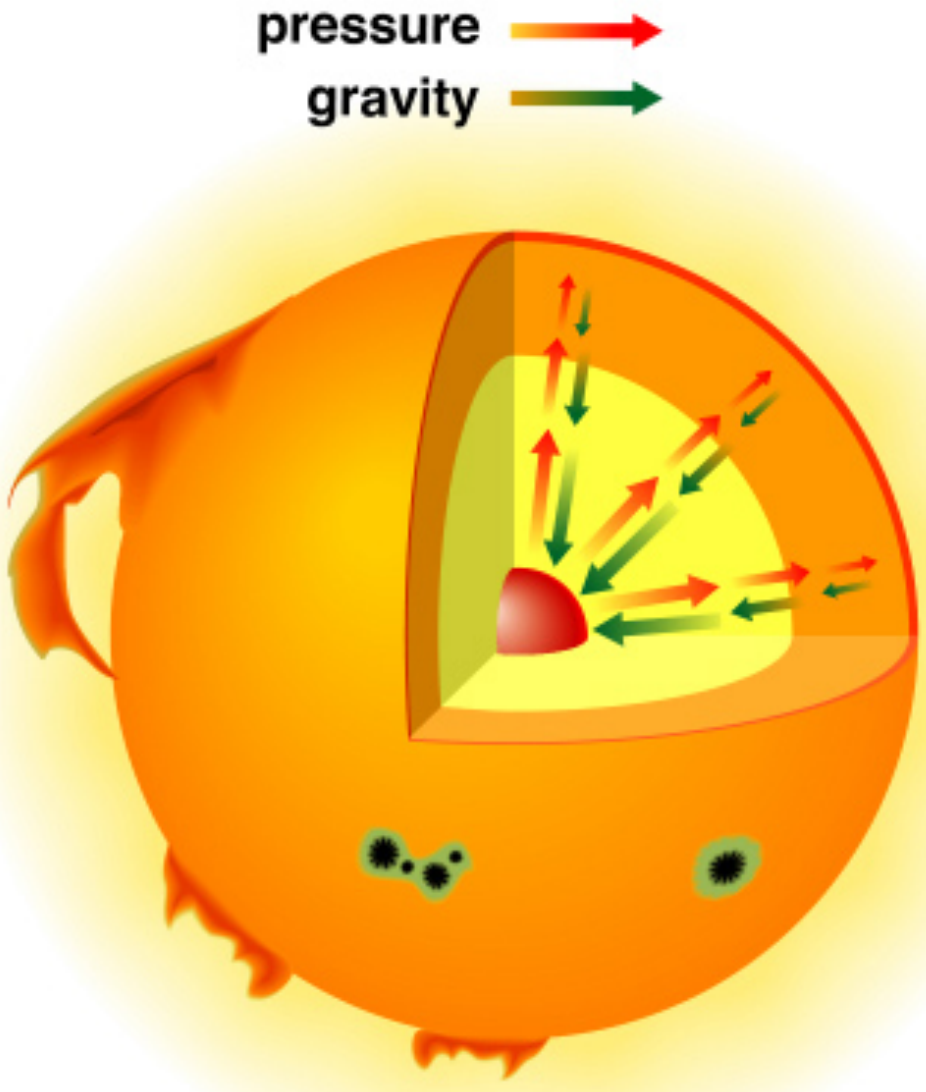
Spontaneous Symmetry Breaking



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

Origin of Elements

The Solar Interior

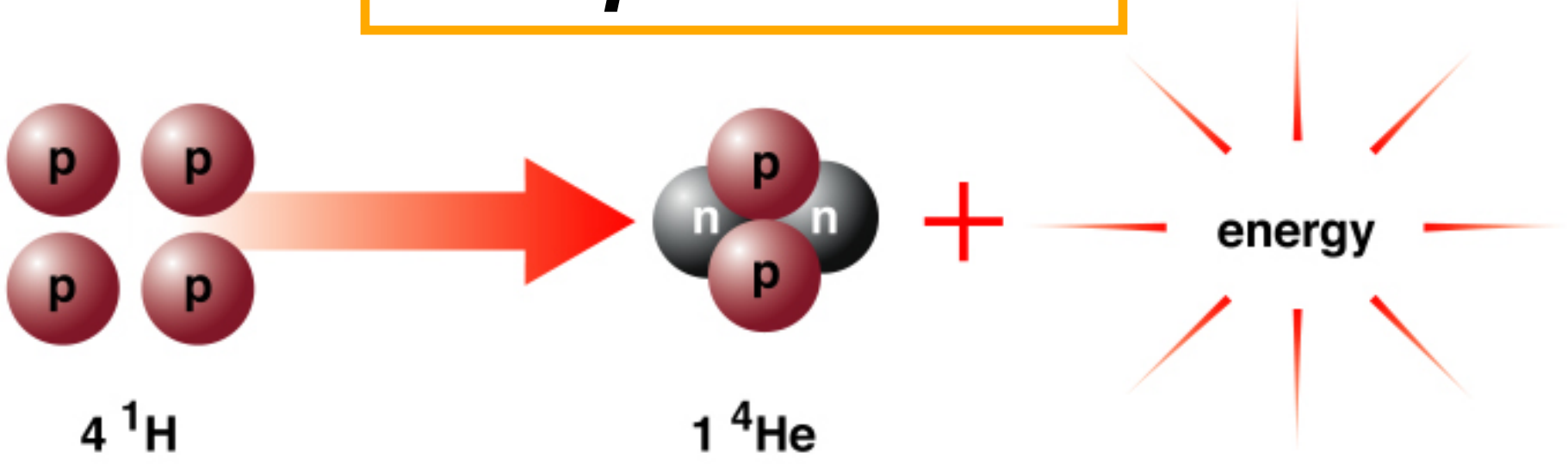


Hydrogen Gas

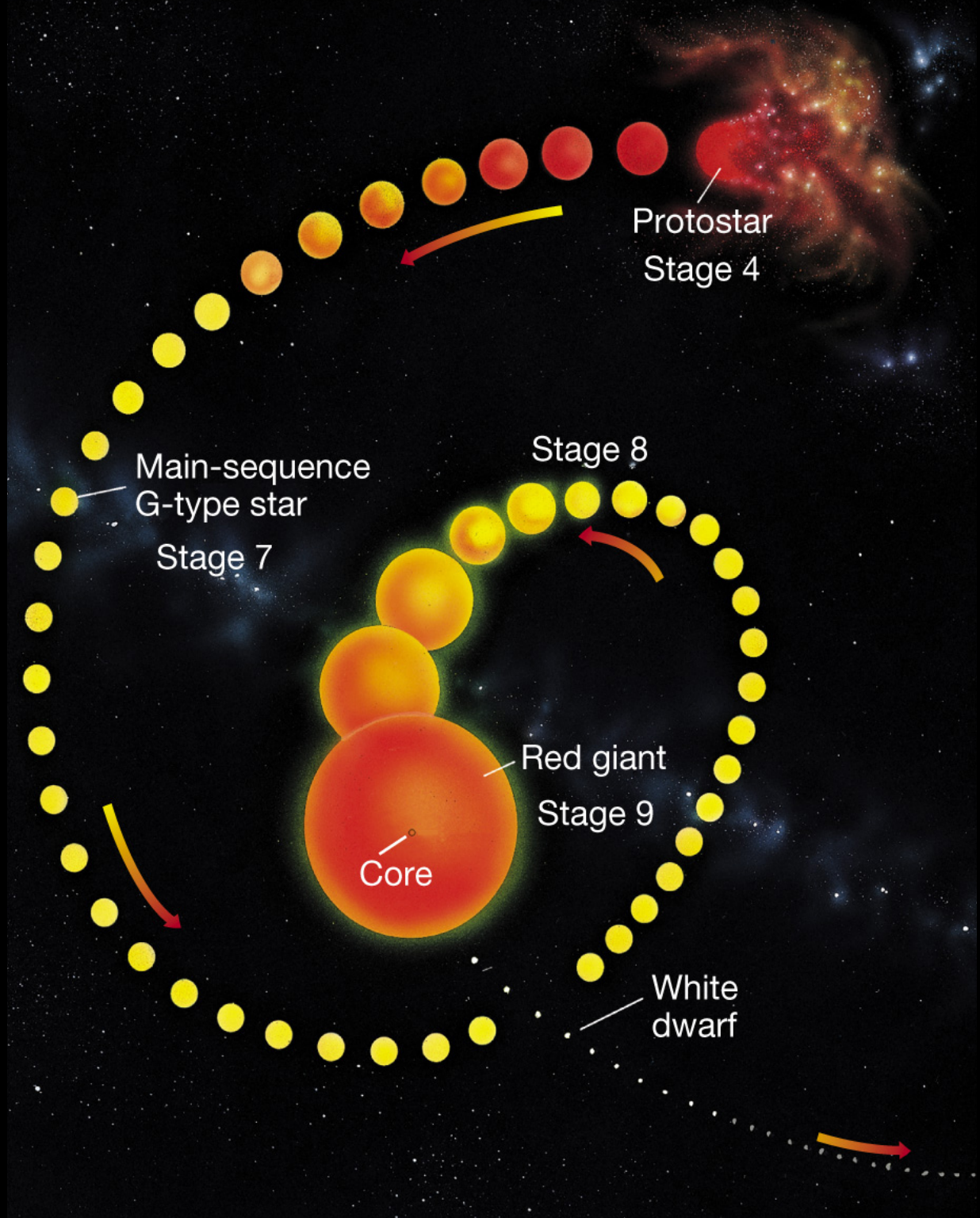
Solar Energy

$$E = mC^2$$

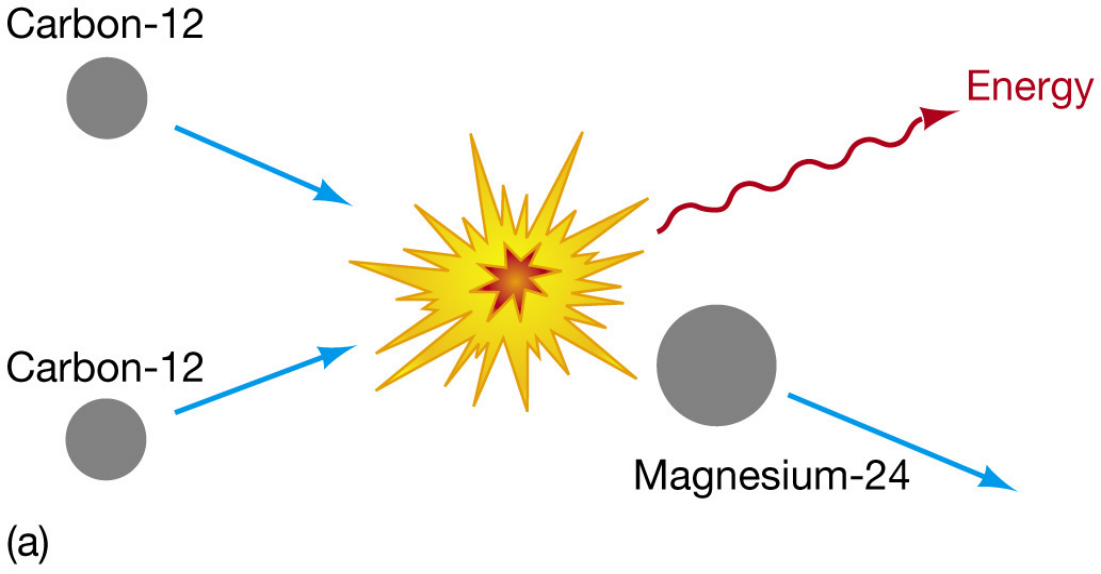
$$m_{4p} > m_{He}$$

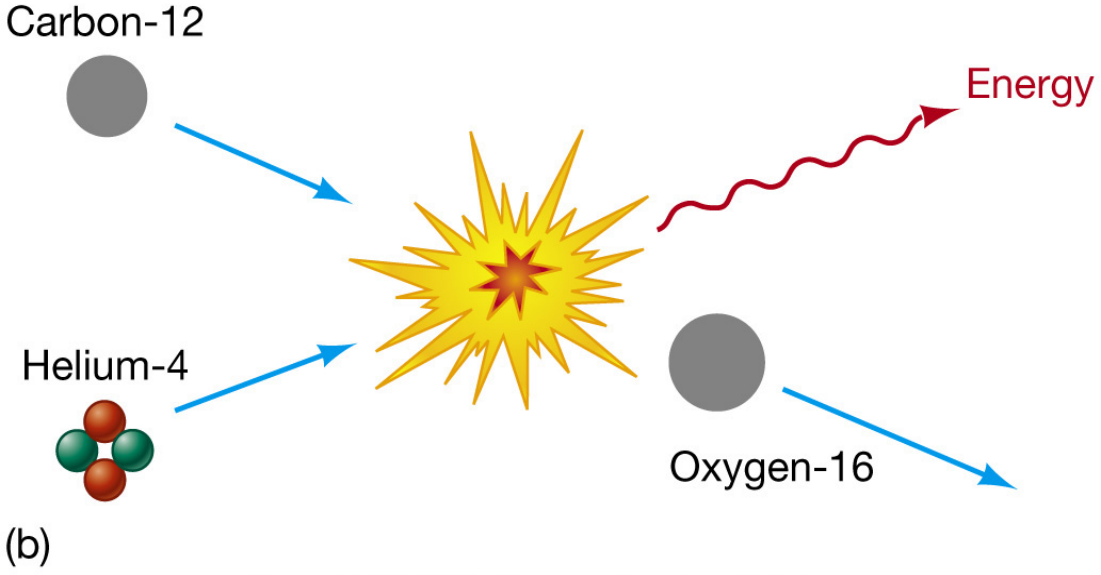


ε = = 0.007


Protostar
Stage 4
Stage 8
Main-sequence
G-type star
Stage 7
Red giant
Stage 9
Core
White
dwarf

The Formation of the Elements

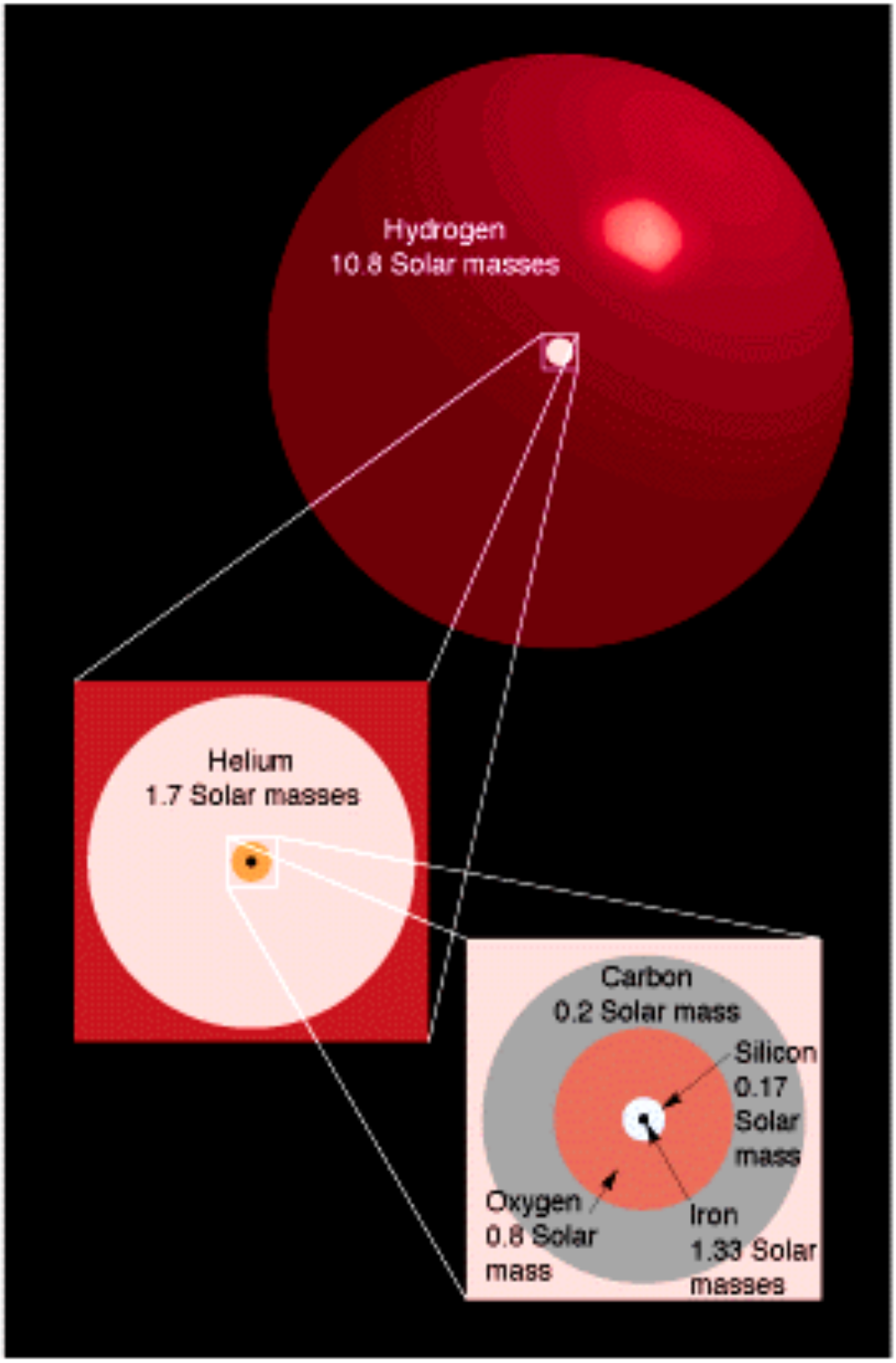




Nuclear Burning in High Mass Stars

(times for a 20 M_o star)

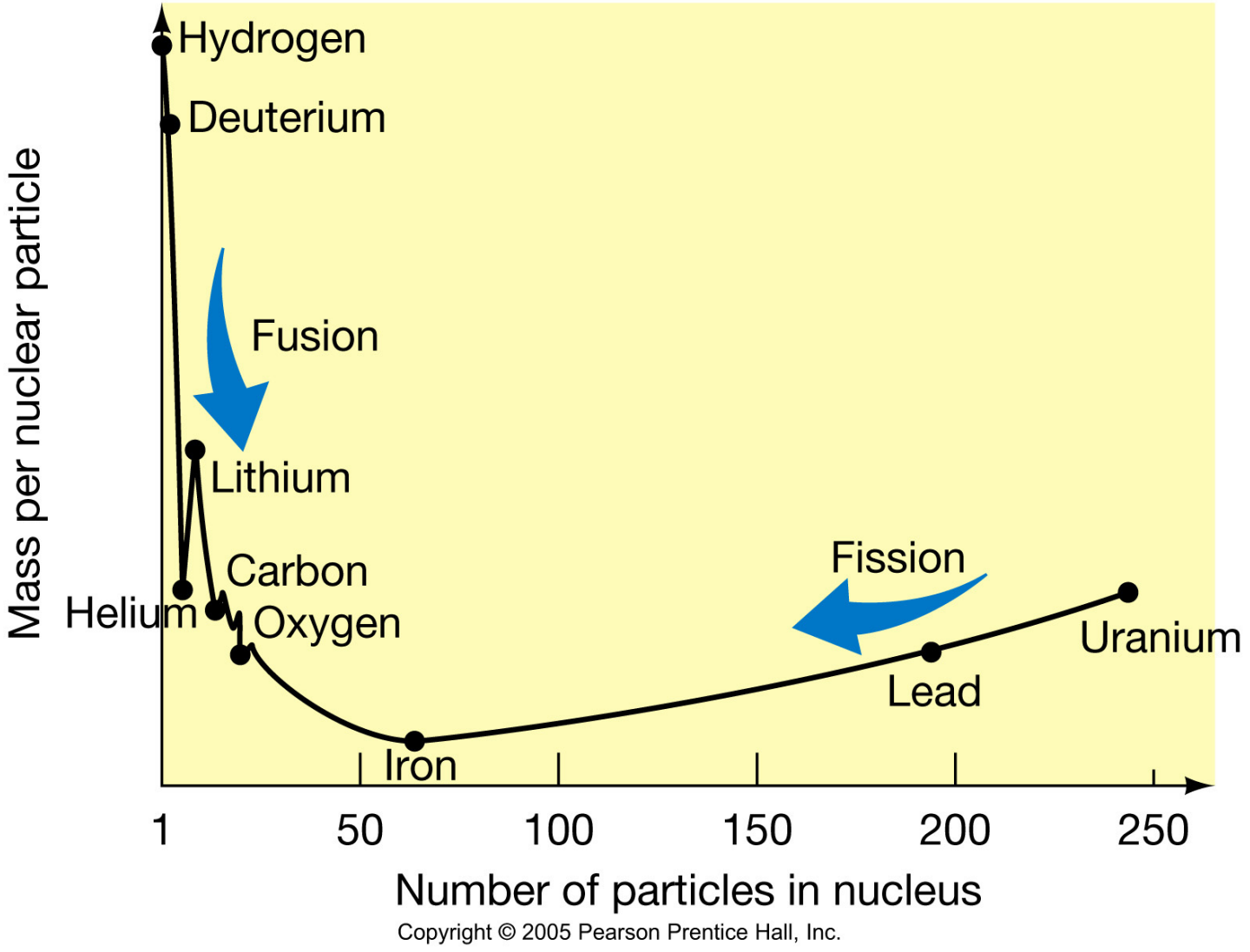
Hydrogen	10^7 yr
Helium	10^6 yr
Carbon	10^3 yr
Oxygen	1 yr
Neon	
Magnesium	
Silicon	1 week
Iron	< 1 day



The End of a High-Mass Star

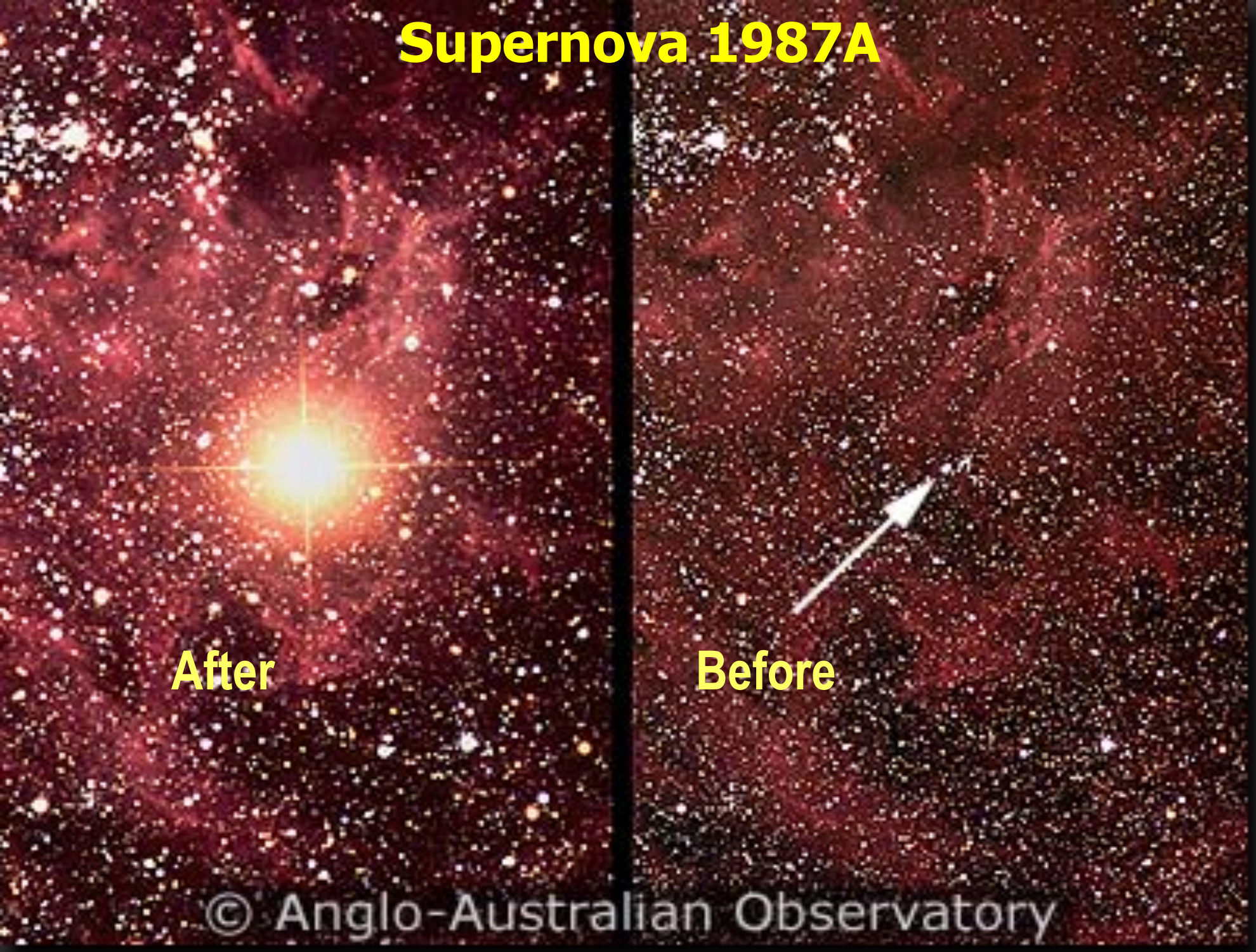
This graph shows the relative **stability** of nuclei. On the left, nuclei gain energy through **fusion**; on the right they gain it through **fission**.

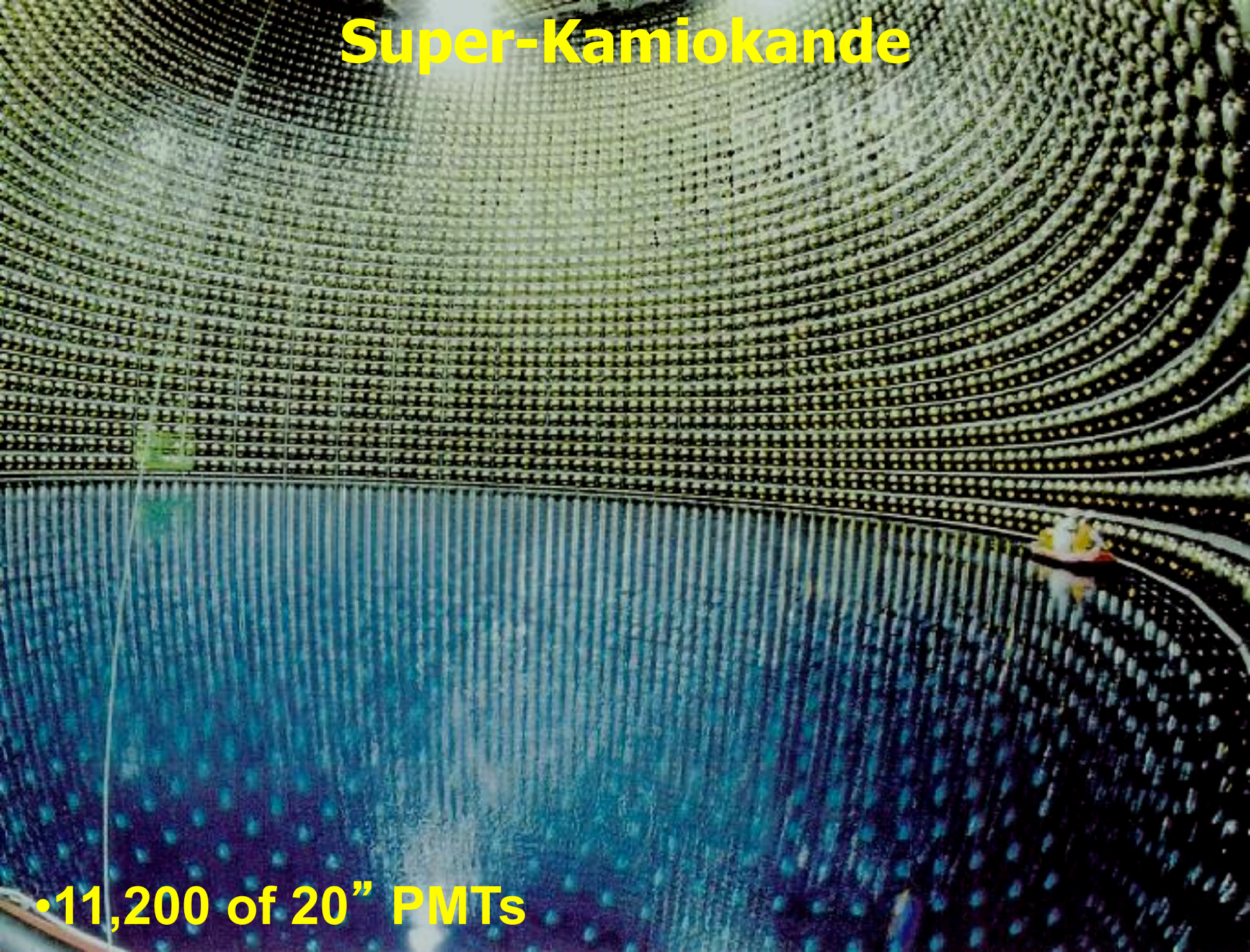
Iron is the crossing point; when the core has fused to iron, no more fusion can take place.



Power of Super Novae

- **Within a few hours**
  - one billion times solar luminosity
- **Within a few months**
  - ~ same as the Sun's total energy during 10 billion years of life
- **Not only that, > 99.99 % of energy is released by neutrino within ~ 10 seconds.**
  - First observed in 1987 by Kamiokande experiment in Japan.


Supernova 1987A
After
Before
© Anglo-Australian Observatory


Super-Kamiokande
•11,200 of 20” PMTs

Nobel Prize in 2002

The Nobel Prize in Physics 2002

"for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos"

"for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources"

Raymond Davis Jr.

Masatoshi Koshiba

Riccardo Giacconi

End Results of Stars

Initial Mass	End Results		
< 8 $M_\odot$	White Dwarf		< 1.4 $M_\odot$
8 – 20 $M_\odot$	Type II Supernova	Neutron Star	1.4 – 3 $M_\odot$
> 20 $M_\odot$		Black Hole	> 3 $M_\odot$

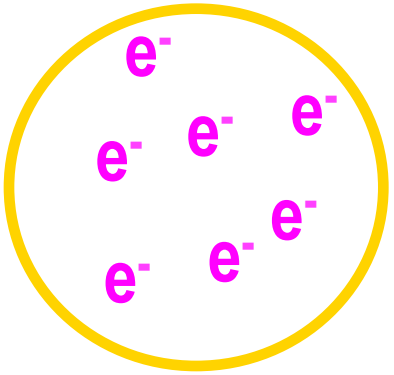
Pauli's Exclusion Principle

- **Fermi Statistics:**
  - According to quantum mechanics, each state is occupied by one particle (Fermion). Another particle can not stay in the same state.

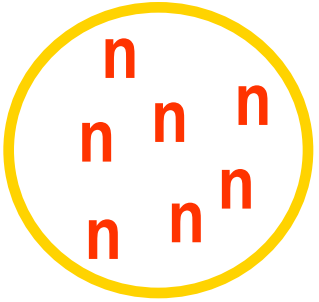
- **Degenerate matter:**
  - All possible states are occupied.

Degenerate Matter

- **White Dwarf (< 1.4 $M_\odot$)**
  - Carbon Core
  - Electrons are tightly packed



- **Neutron Star (1.4 $M_\odot$ – 3 $M_\odot$)**
  - Neutrons are tightly packed



- **Black Hole (> 3 $M_\odot$)**
  - Gravity wins

Origin of Elements

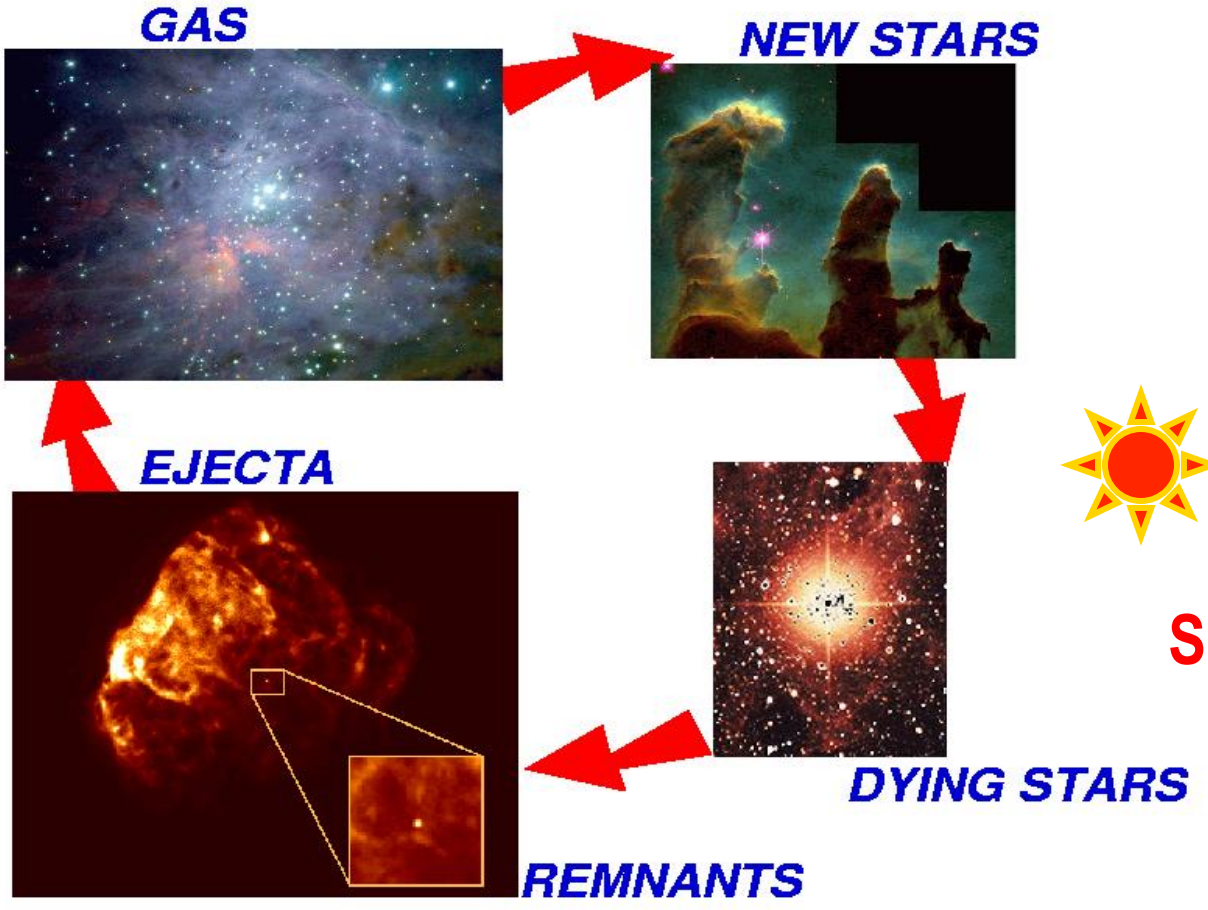
- **Hydrogen, Helium**
  - From "Big Bang"
- **Carbon – Oxygen – Iron**
  - From "Nuclear fusion" at massive stars (> 8 M_{sun})
- **Heavier than Iron (Cu, Au, Pt, Pb…)**
  - From "Supernovae"

Origin of Life

We are made from "stardust"

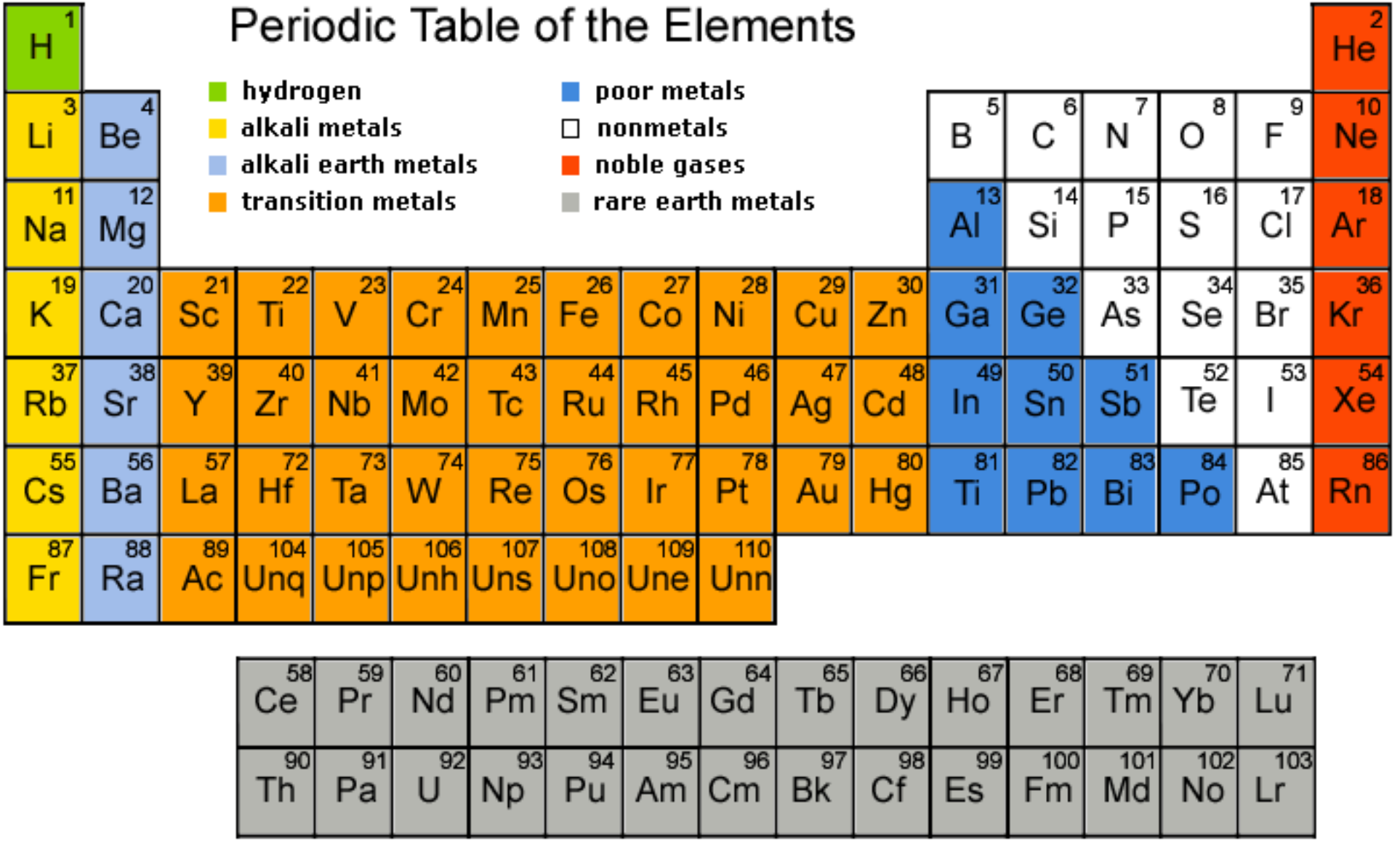
Star's Life Cycle

Big Bang! (14 B years ago)

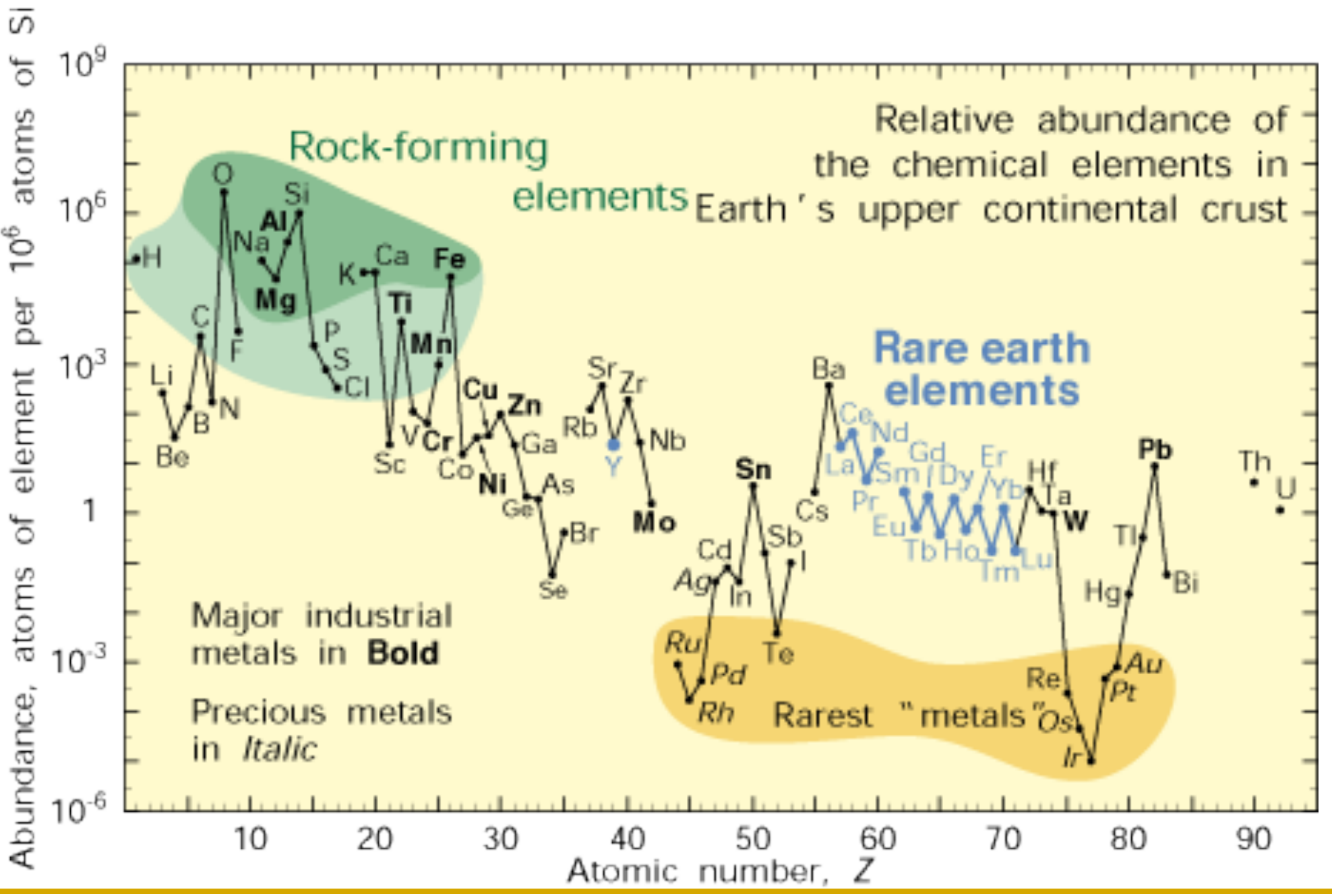


Sun (4.6 B years ago)

Periodic Table of Elements

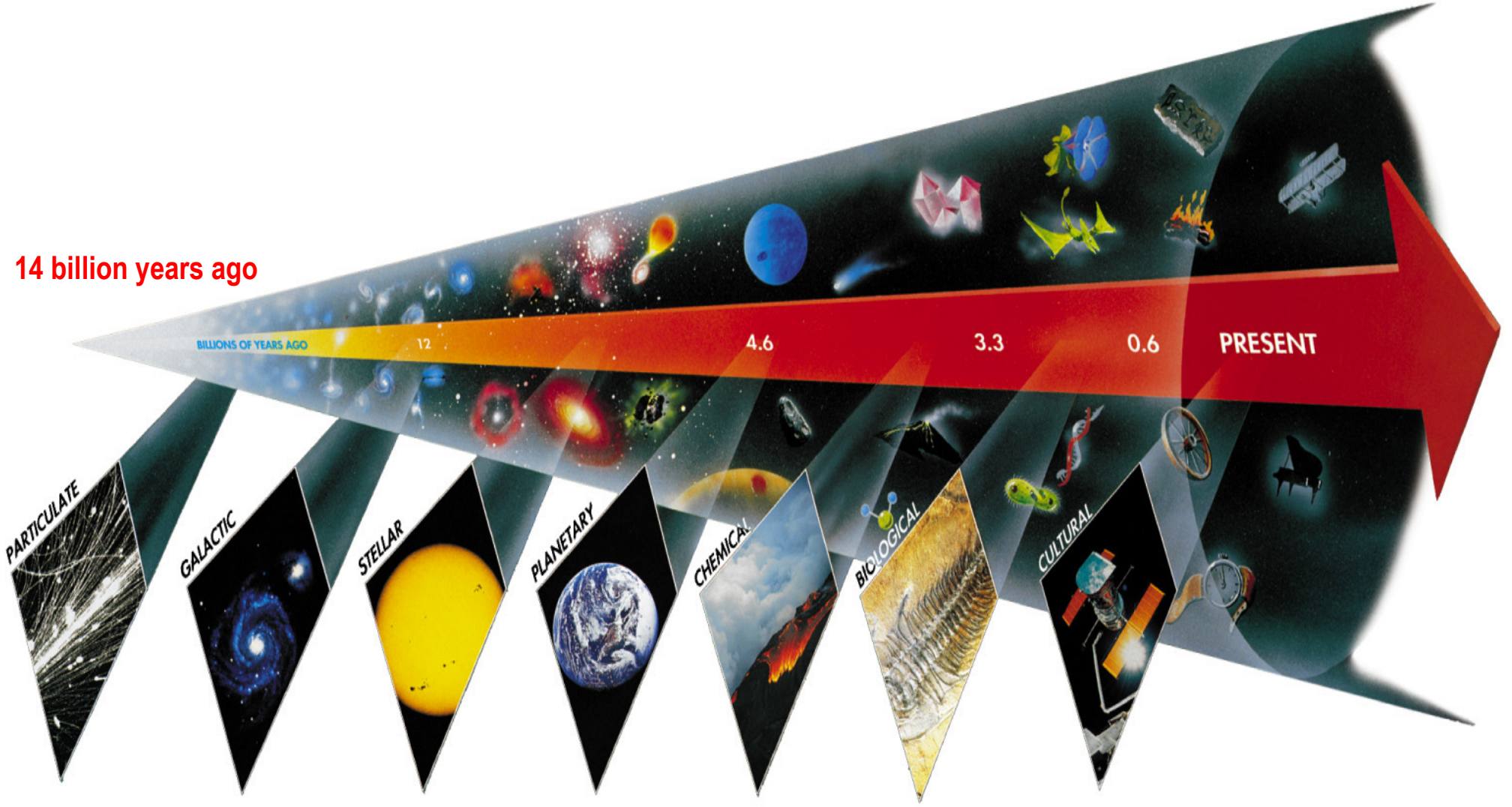


Abundance of Elements



Origin of Life

Seven Phases of Cosmic Evolution

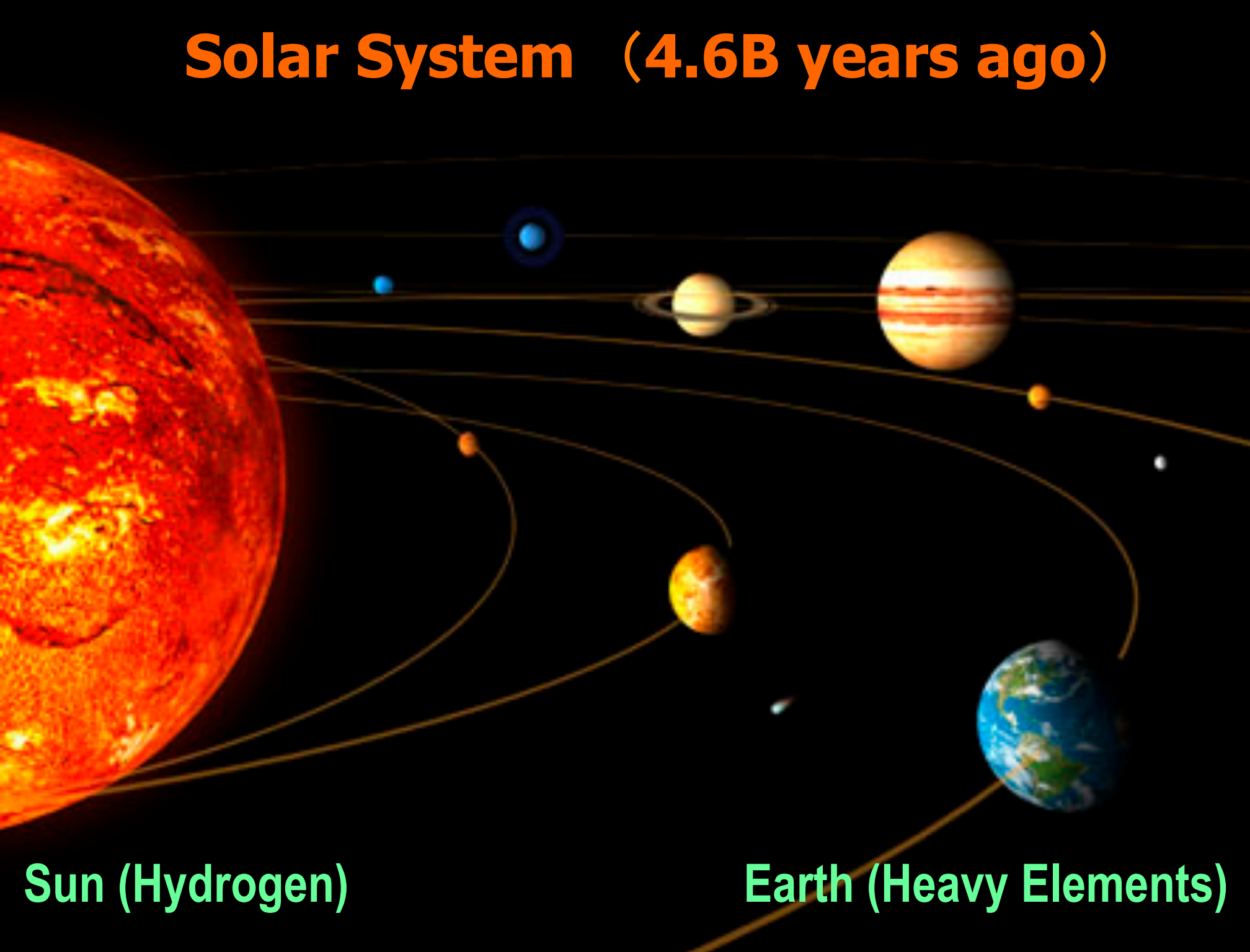


Origin of Particles

Origin of Structure

Origin of Life

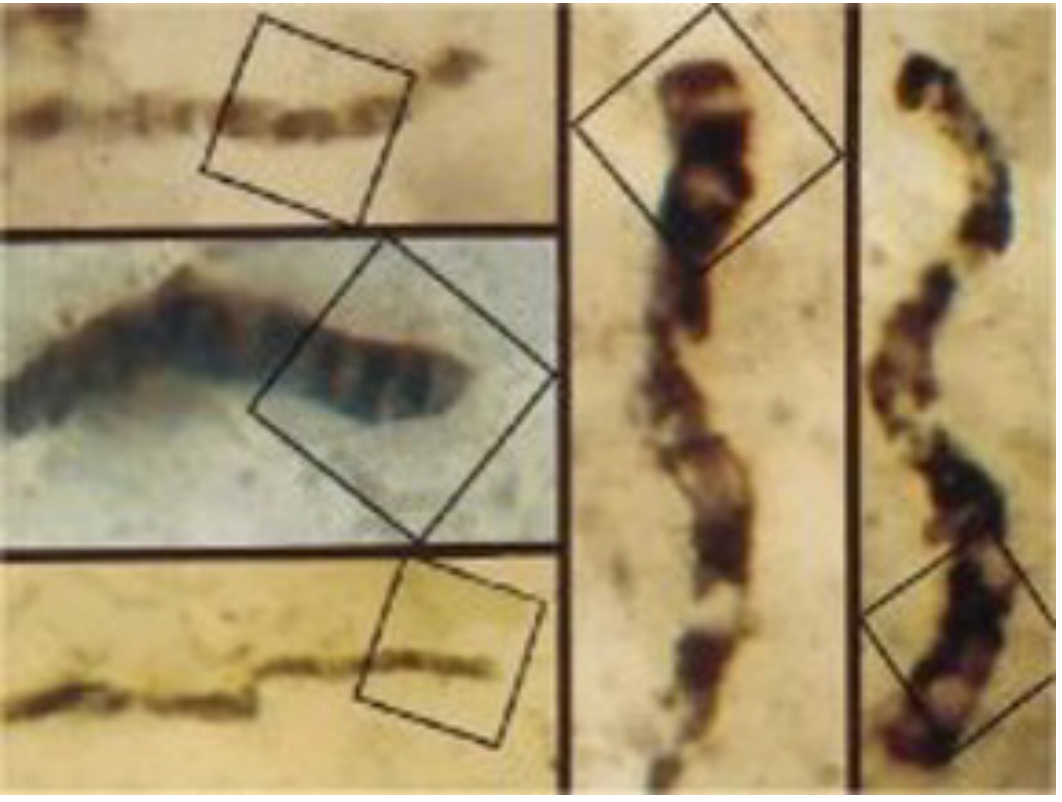
Solar System （4.6B years ago）

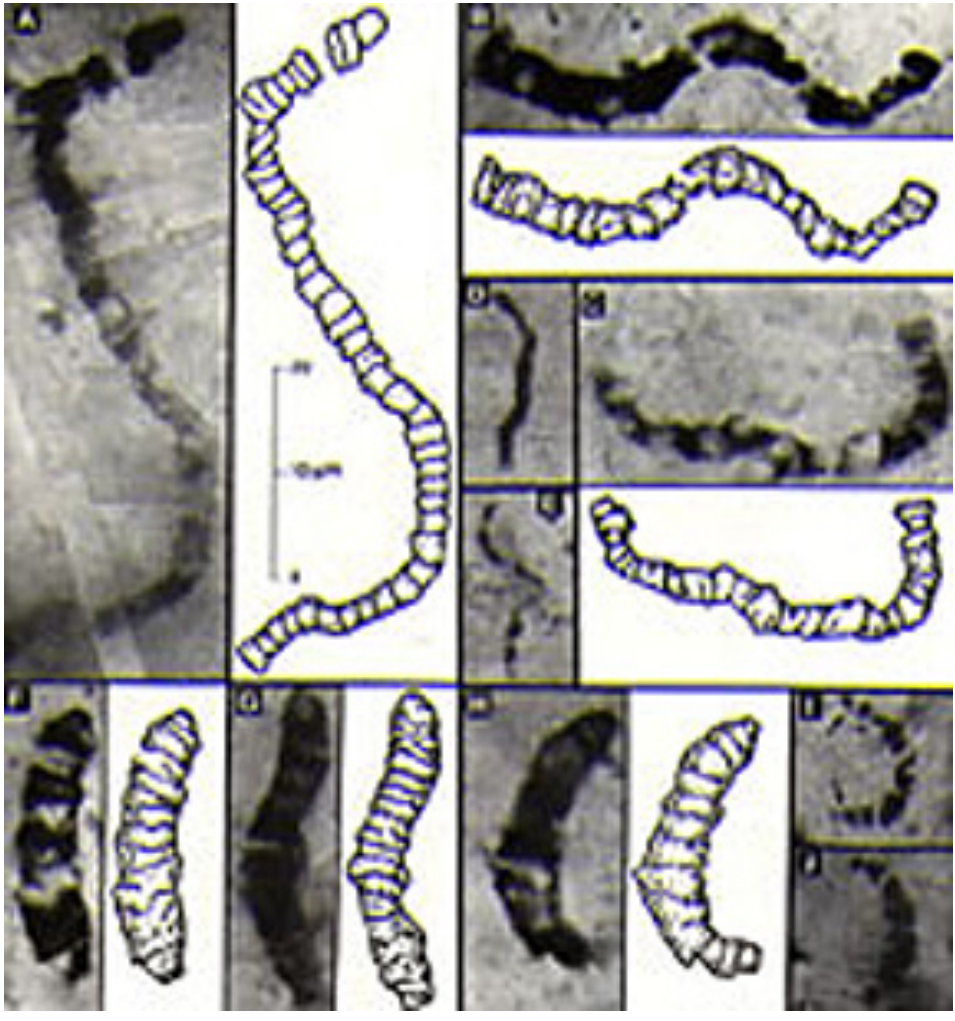


Iron Core of the Earth

The Oldest Fossil found by W. Schopf

Generally accepted evidence of bacterial life from the 3.5 Billion Year Apex Formation of Australia has been published by Bill Schopf (UCLA) and others.





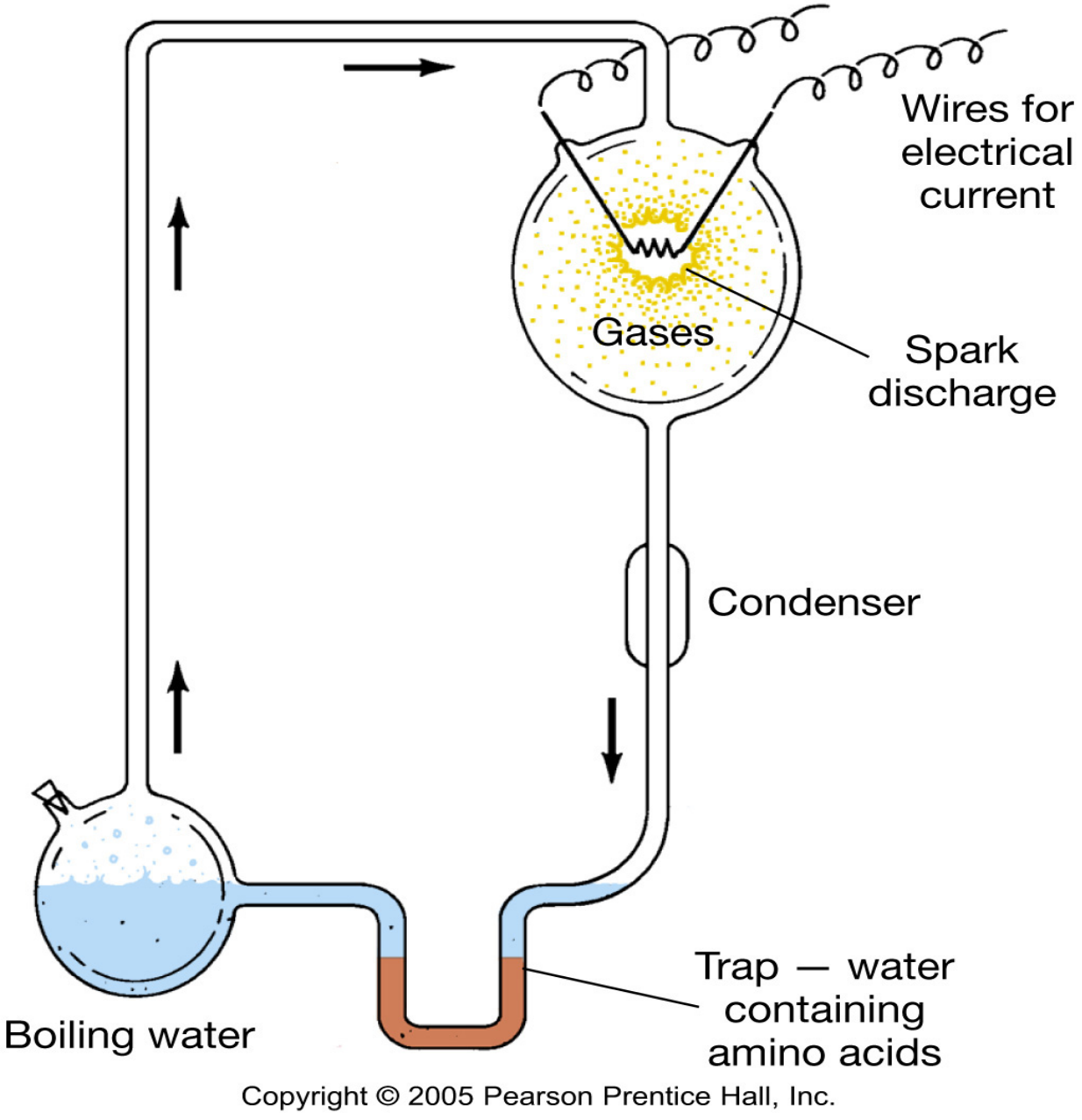
Origin of Life

Earth was subject to volcanoes, lightning, radioactivity, ultraviolet radiation, and meteoroid impacts.

Over a billion years or so, amino acids and nucleotide bases formed. The process by which this happens has been re-created in the laboratory.

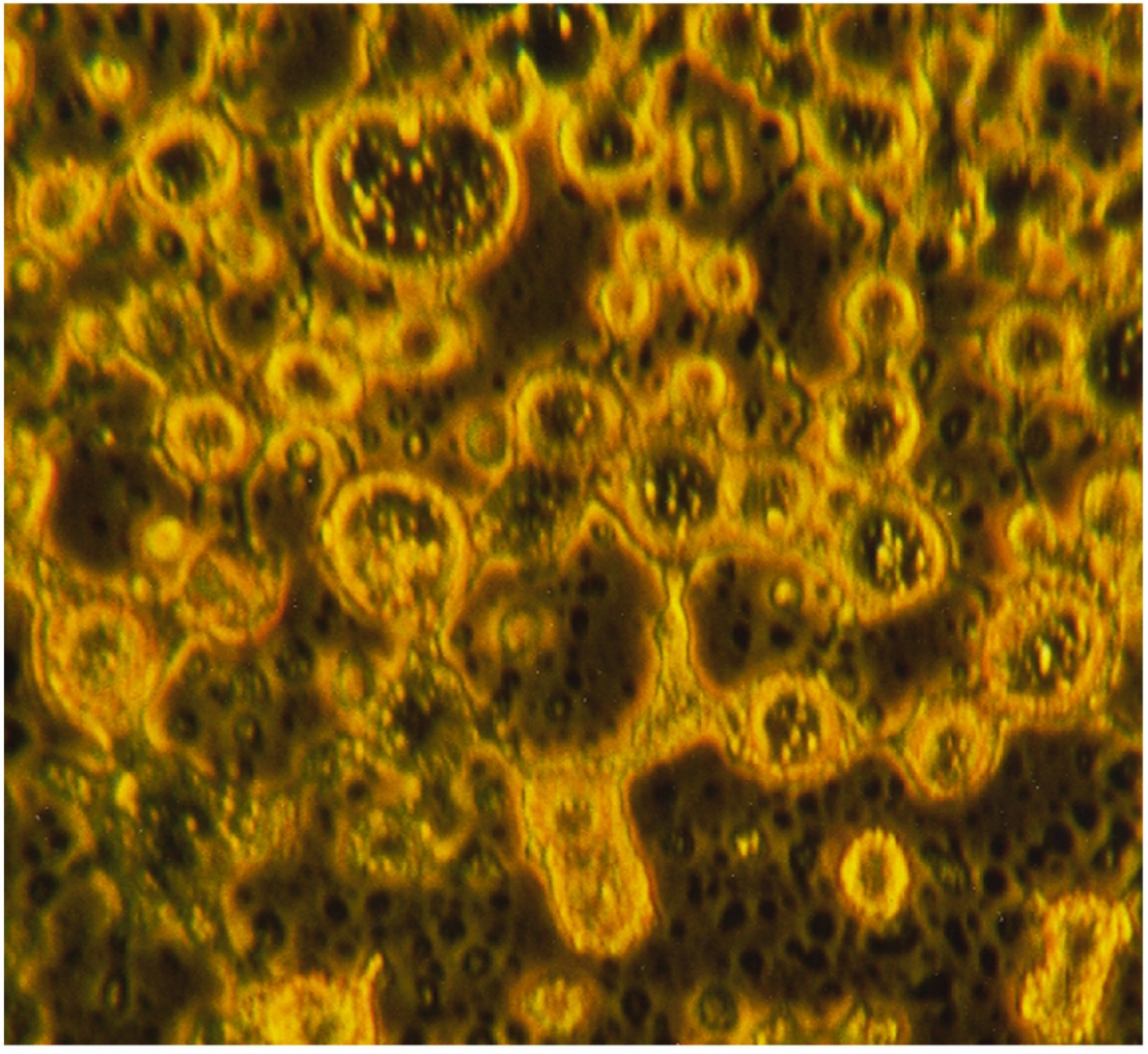
Urey-Miller Experiments

Urey-Miller Experiments



This is a schematic of the **Urey–Miller** experiment, first done in the 1950s, that demonstrated the formation of **amino acids** from the gases present in the early Earth's atmosphere, excited by lightning.

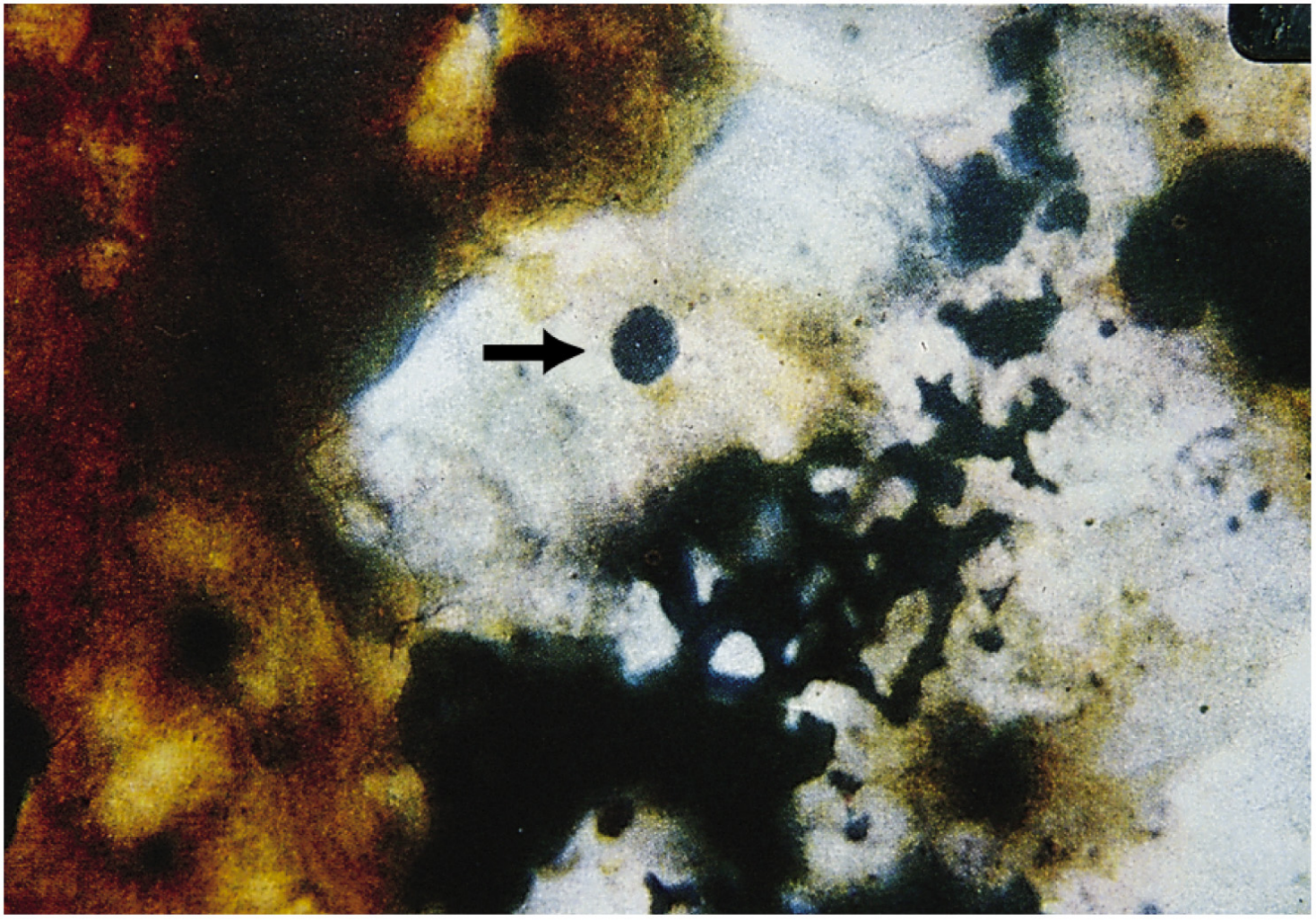
Creation of Amino Acids



It is also possible that the source of complex organic molecules could be from outside Earth, on meteorites or comets.

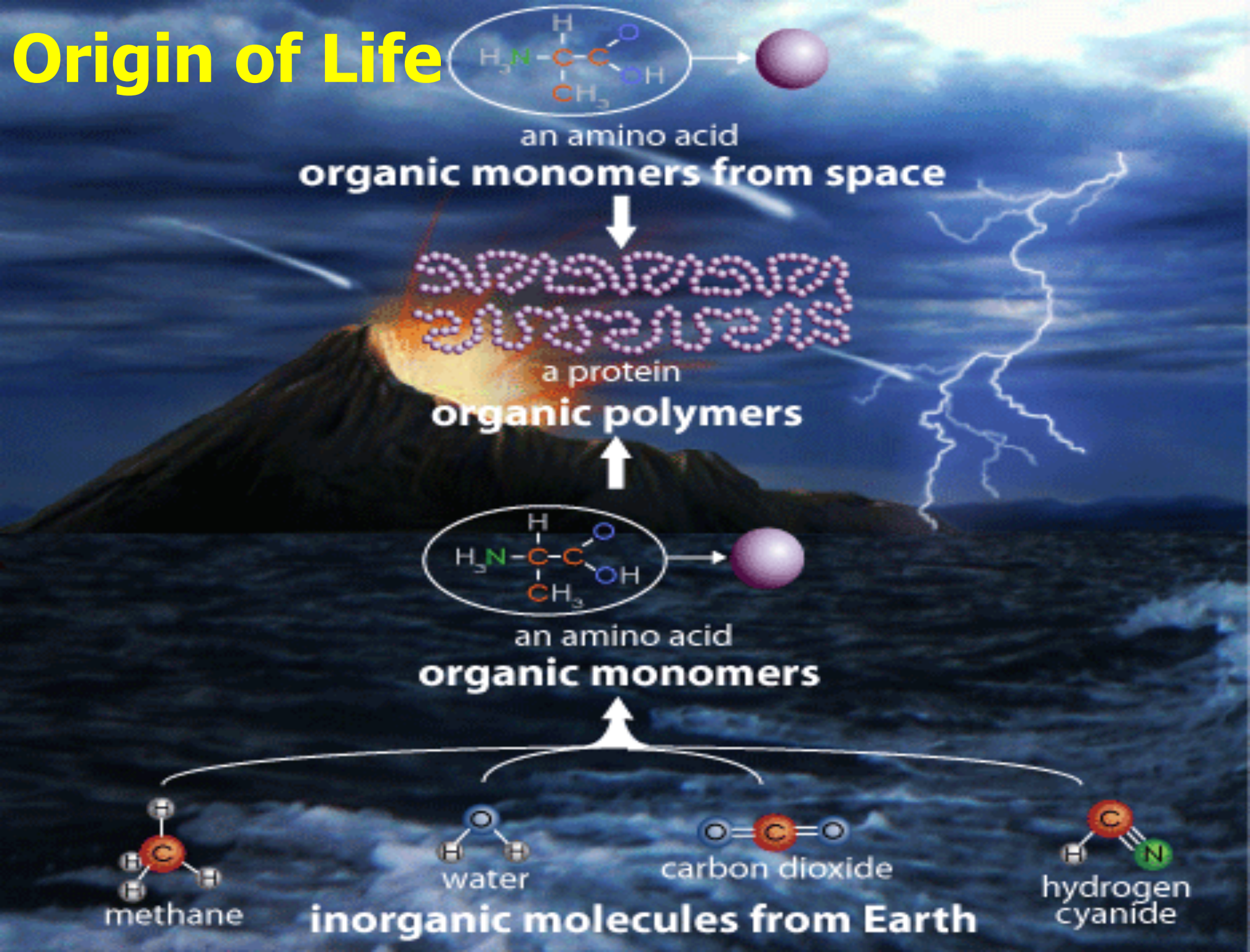
This image shows droplets rich in amino acids, formed when a freezing mix of primordial matter was subjected to harsh ultraviolet radiation.

Meteorite

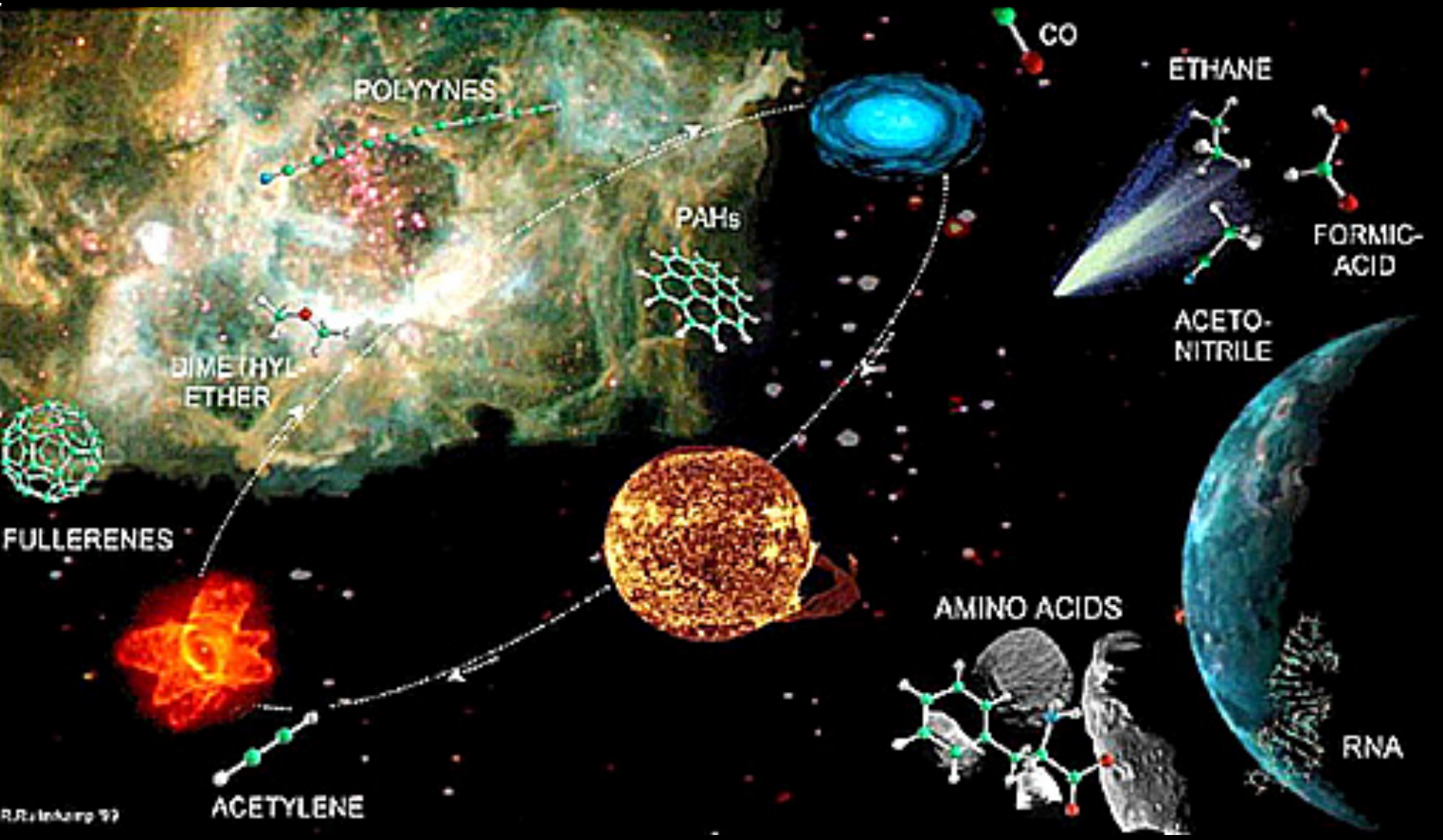


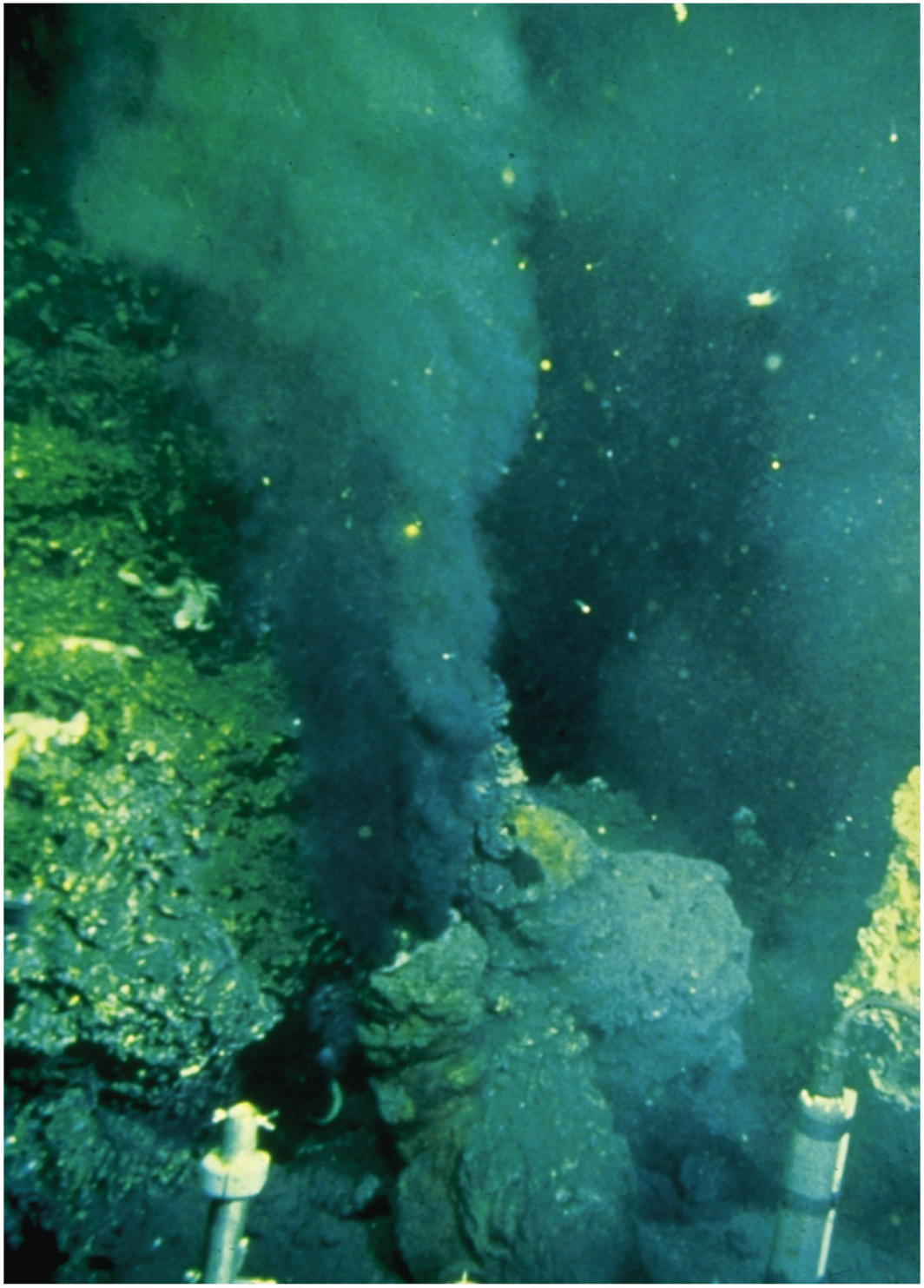
This meteorite, which fell in Australia, contains 12 different amino acids found in Earthly life, although some of them are slightly different in form.

Origin of Life



Organic molecules from outer space

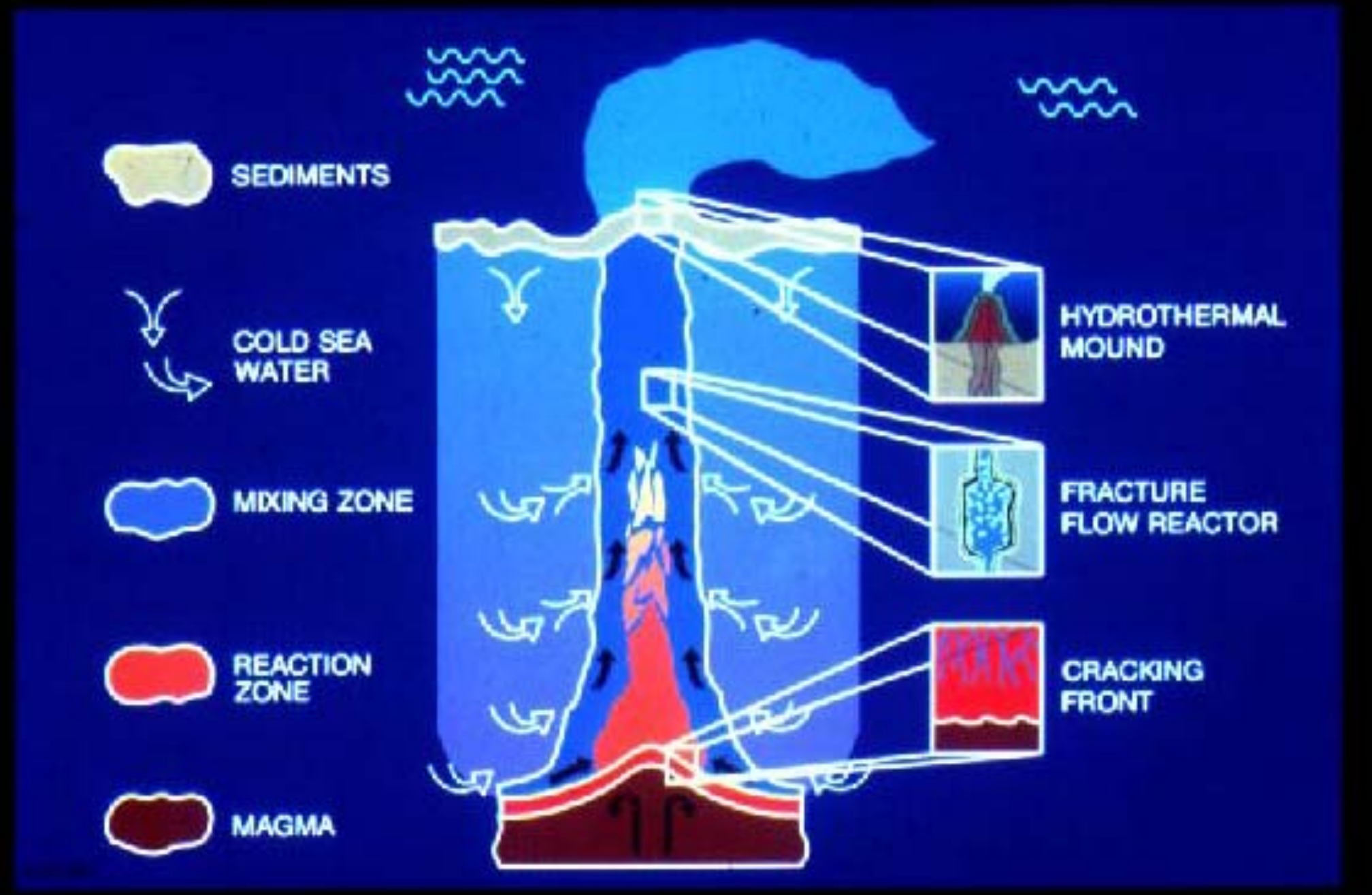




Life in Deep Ocean?

Even on Earth, organisms called **extremophiles** survive in environments long thought impossible – here, **hydrothermal vents** emitting **boiling water** rich in **sulfur**.

Volcano under deep ocean

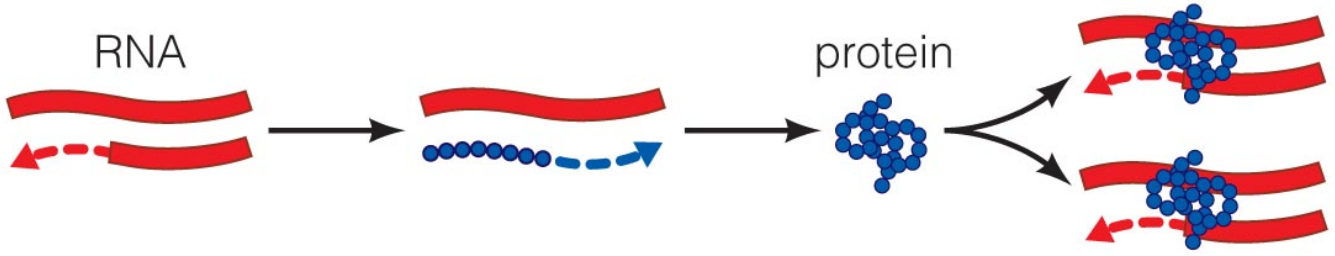


Deviation from Thermal Equilibrium

- **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

Evolution of Life

RNA World

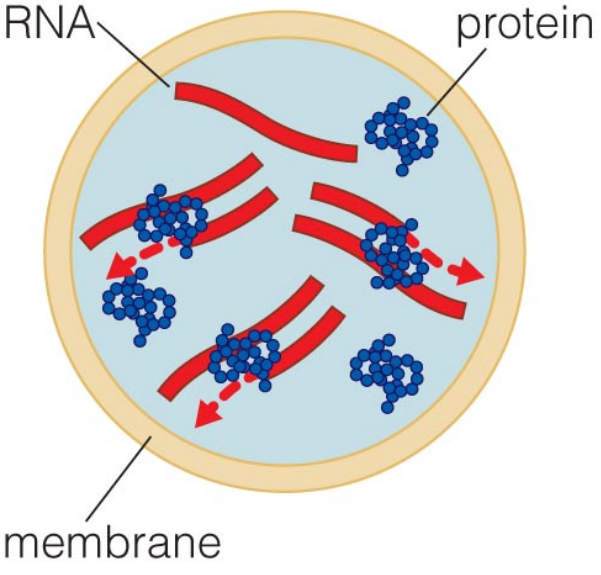


A strand of RNA serves as a template for its own replication.

Amino acids can also attach to the RNA, which links them into small proteins.

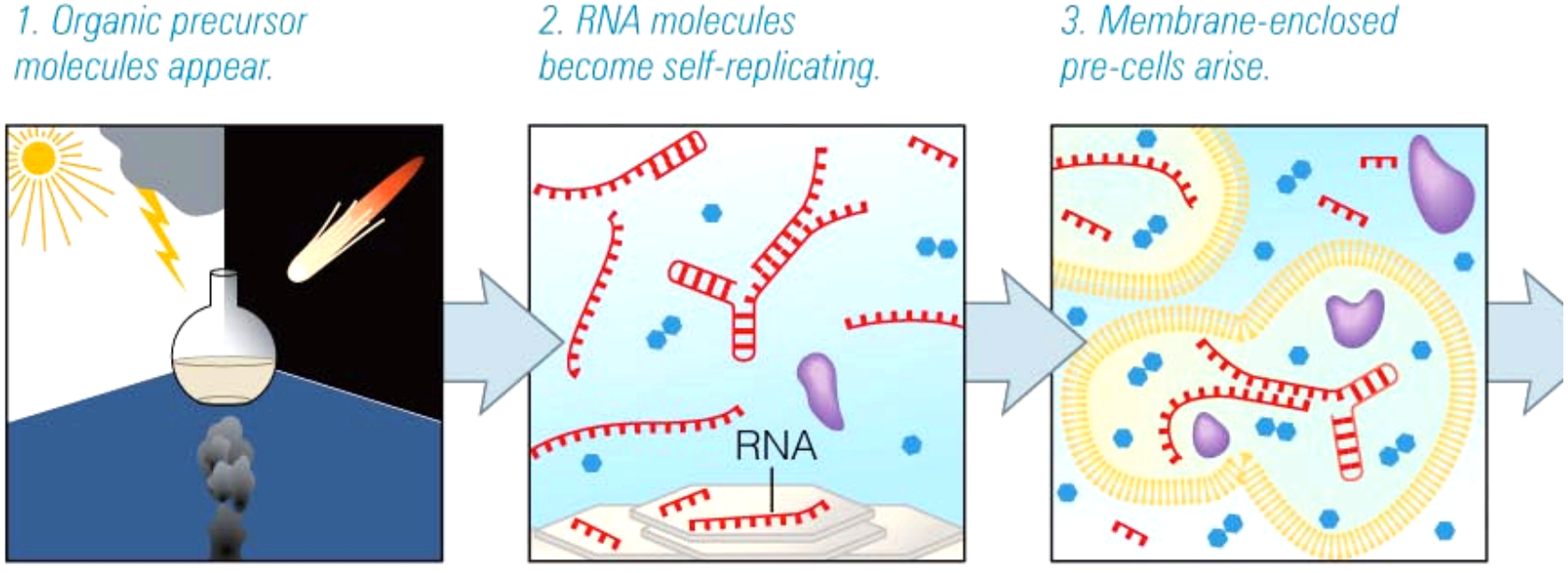
The proteins then act as simple enzymes to speed up the RNA replication.

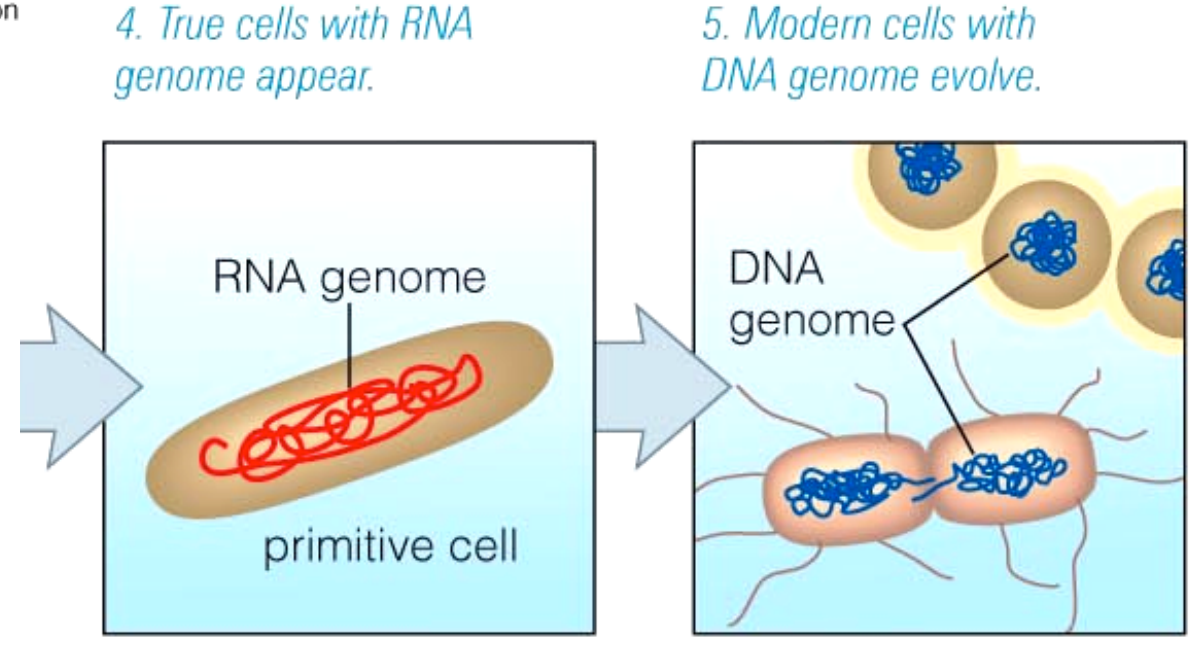
a This diagram shows a self-replicating RNA molecule that has evolved the capability to produce a primitive enzyme that helps its own replication.



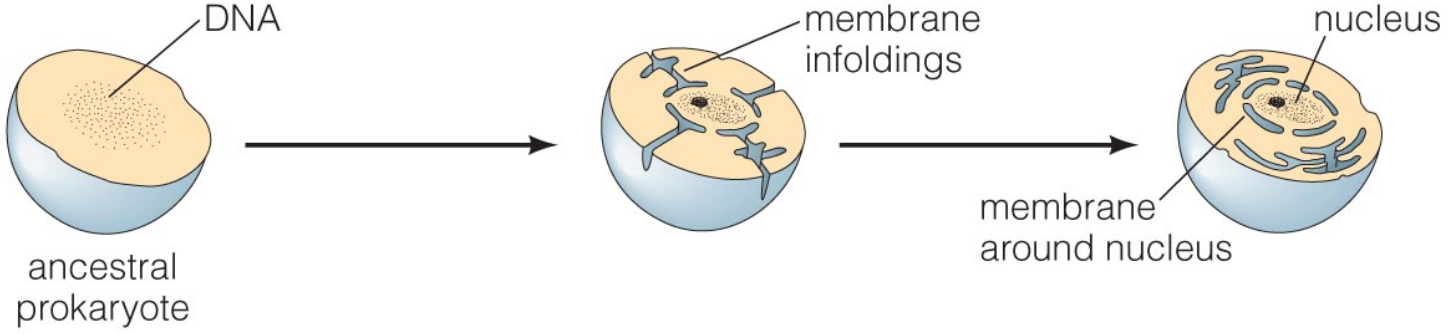
b If the RNA and the enzyme are isolated from the outside environment inside a pre-cell, then only the molecules in this particular pre-cell will benefit from the new enzyme, a fact that can speed up the molecular evolution.

RNA Word (4B → 3.5B years ago)

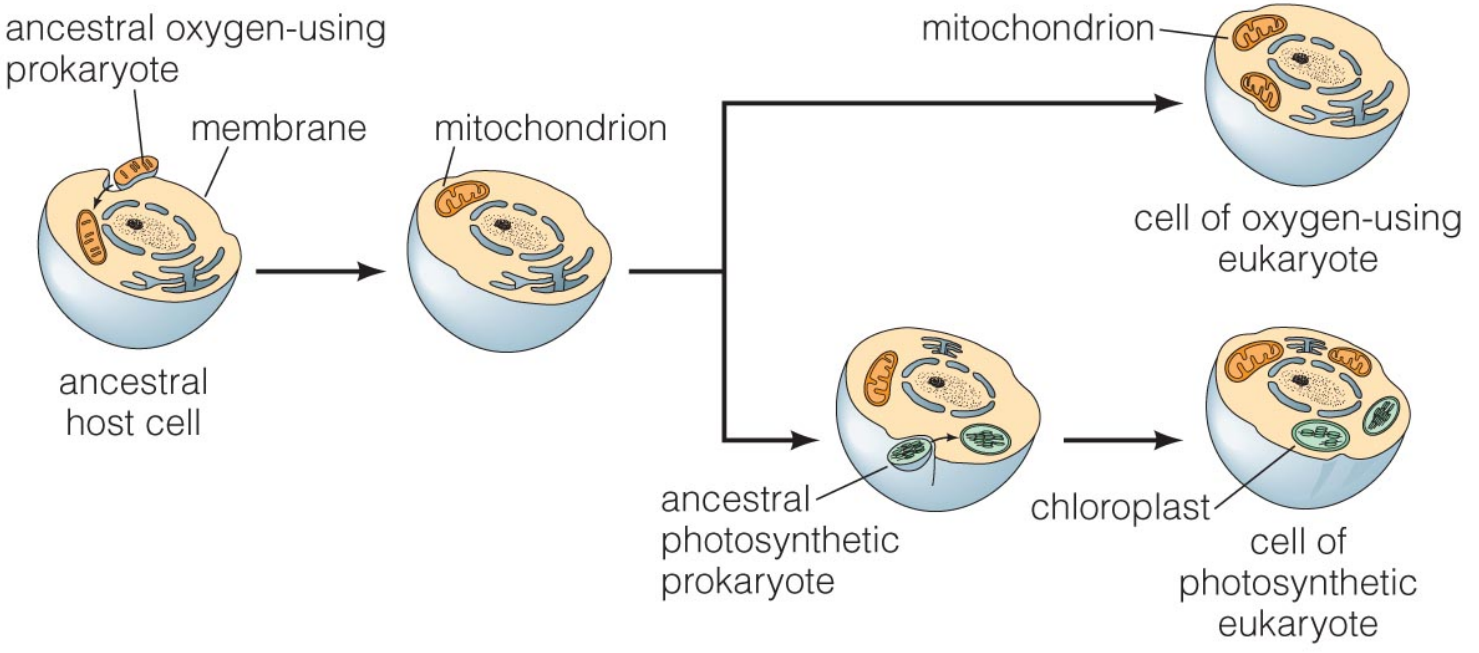




Evolution of Life



a Some large prokaryotes may have developed specialized membrane infoldings that compartmentalized certain cell functions, ultimately leading to the creation of a cell nucleus.

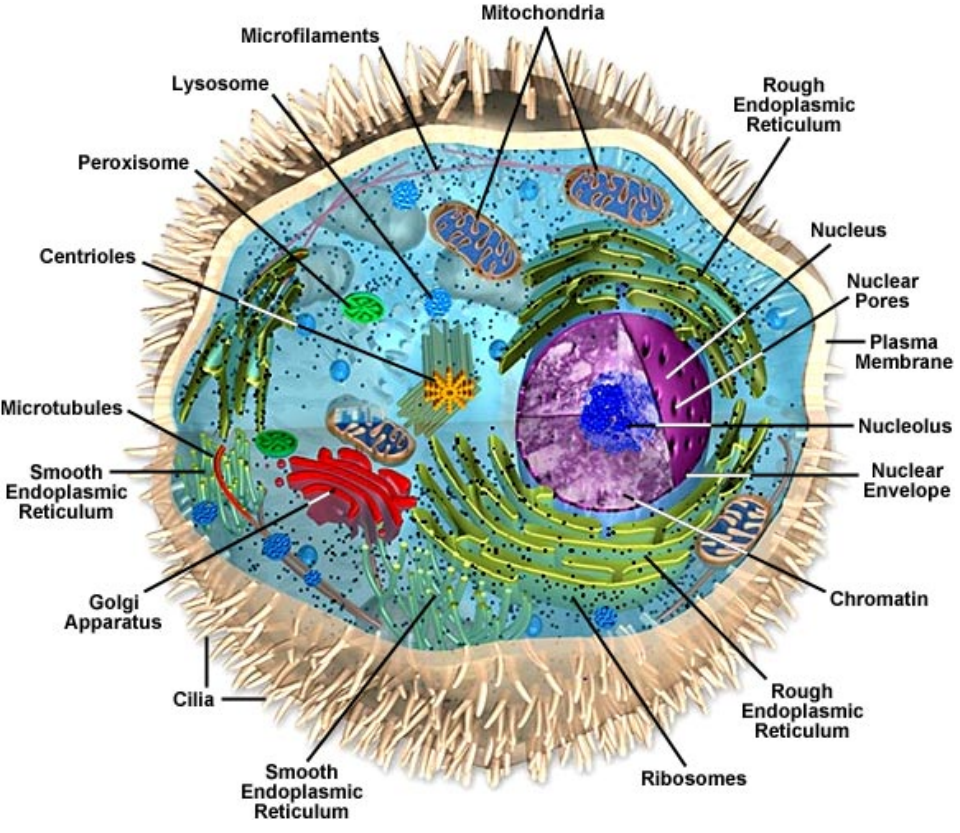


b Mitochondria and chloroplasts may have evolved as small prokaryotes invaded a larger host cell, forming a symbiotic relationship.

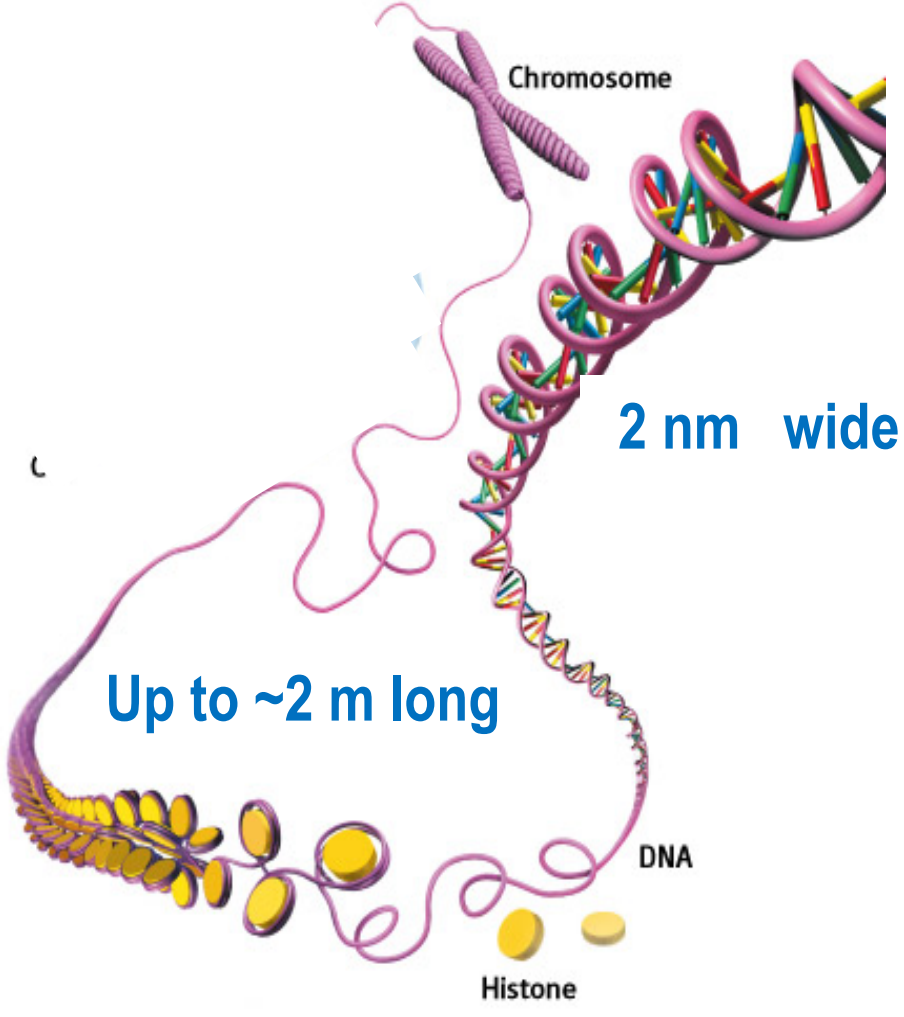
Eukaryote （~2B years ago）

Spontaneous Symmetry Breaking

Cells made by proteins ⟺ **DNA for genetic coding**



10 – 50 μm



How to observe the "Origin of Life"

- Exactly the same way as we look for the "Origin of Universe"

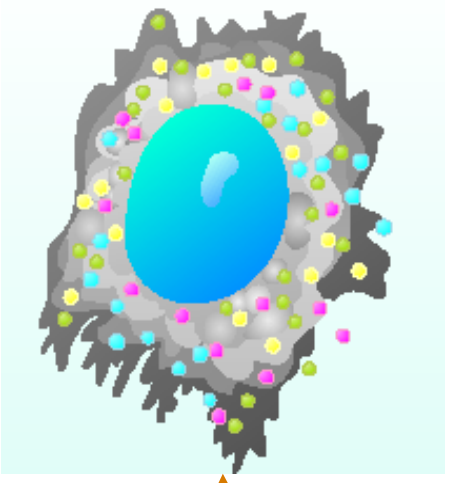
  Telescope ⇔ Microscope

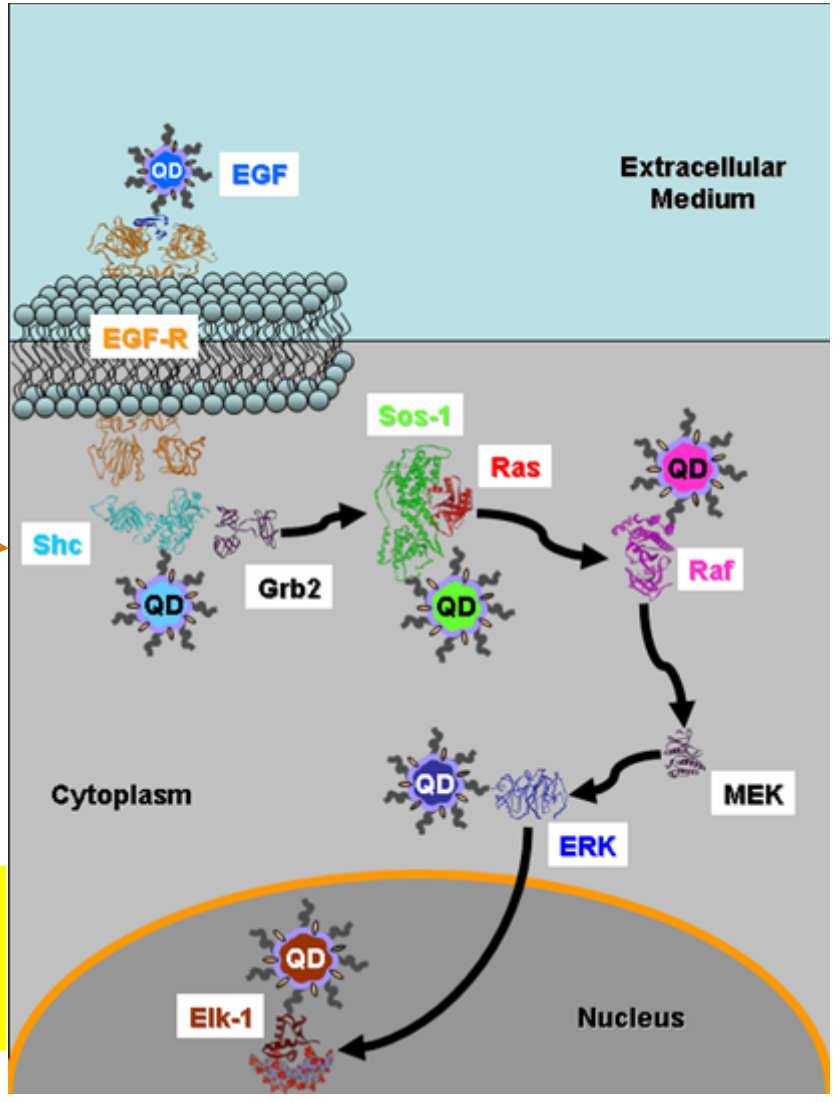
- We must look for "Live Life"

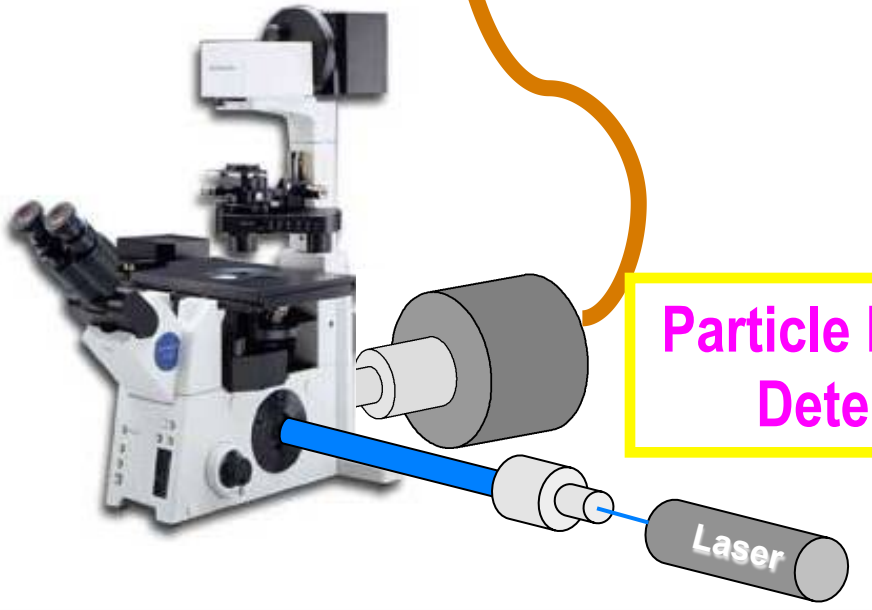
- Take advantages of the state of art "Photon Detectors" in particle physics.

Single Molecule Imaging

Nano Technology







Particle Physics Detector

How to speed up microscopes

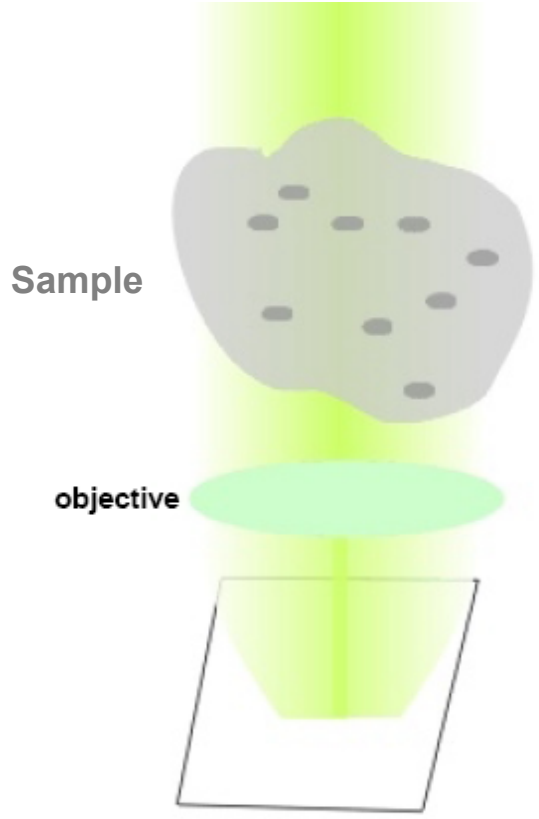
- All the existing microscopes are limited by the narrow bandwidth of readout.
  - Just one channel of FADC (Flash Analog to Digital Converter) running at 10 – 50 MHz
  - So-called Video Rate (30 frame/sec)

- 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

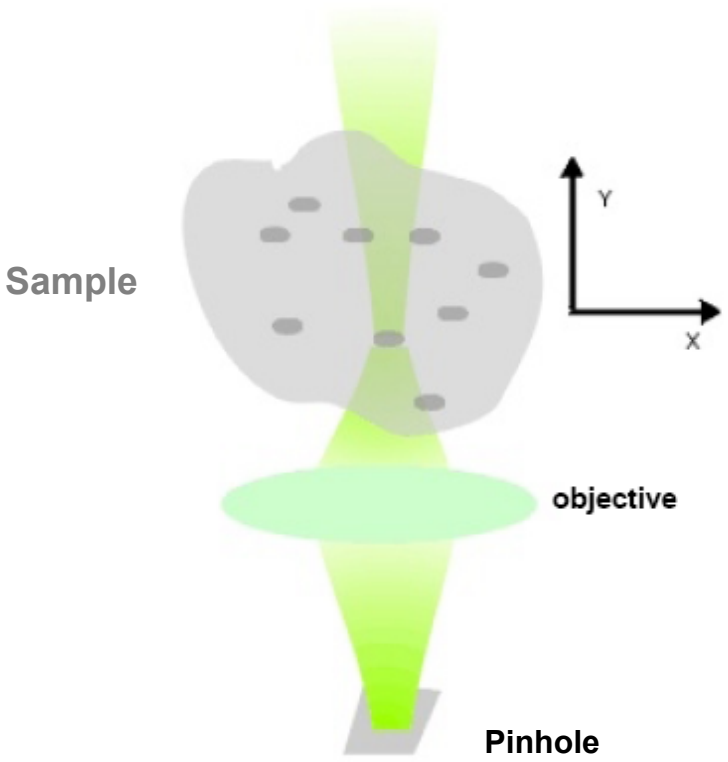


CCD + FADC (10 – 50 MHz)

⇩

CMOS [FADC (50 MHz) * 100]

Confocal

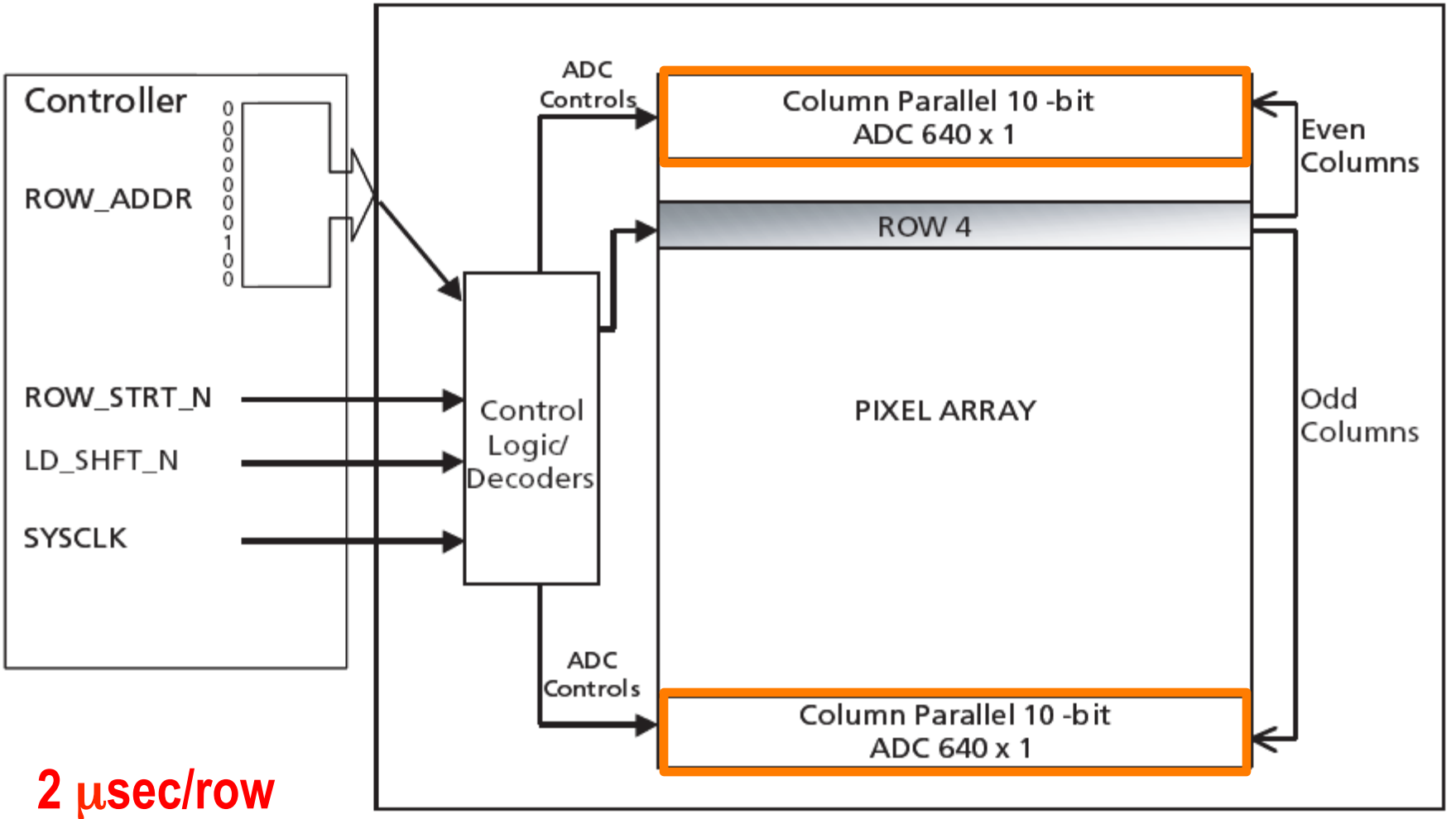


PMT + FADC (10 – 50 MHz)

⇩

[HAPD + FADC (1 GHz)] * 64

Micron 1.3M-Pixel CMOS Sensor



2 μsec/row
2 msec/frame

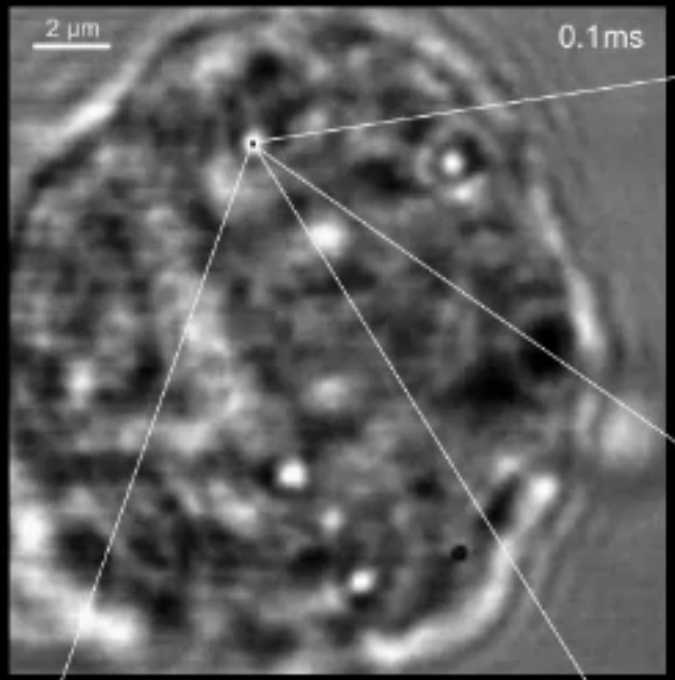
(10 bits, 66MHz)

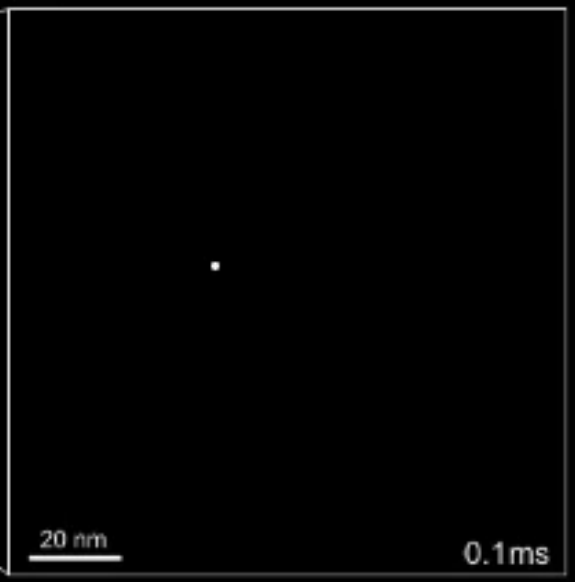
Photron SA-5 CMOS Camera

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

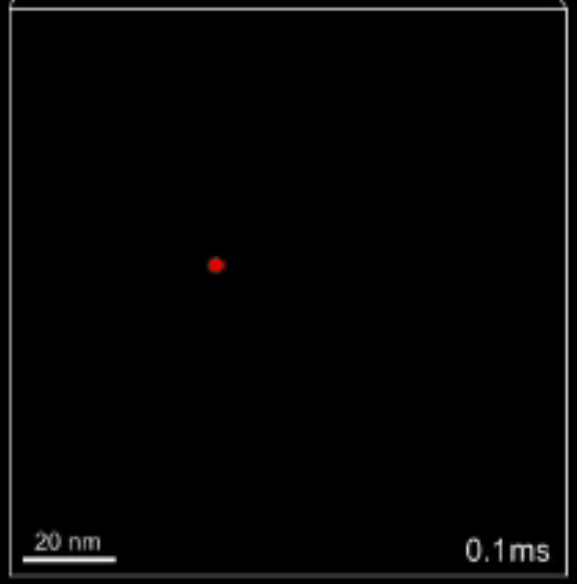
Gold nano particle (40nm) attached to Transferrin Receptor (TfR) on Cancer Cell

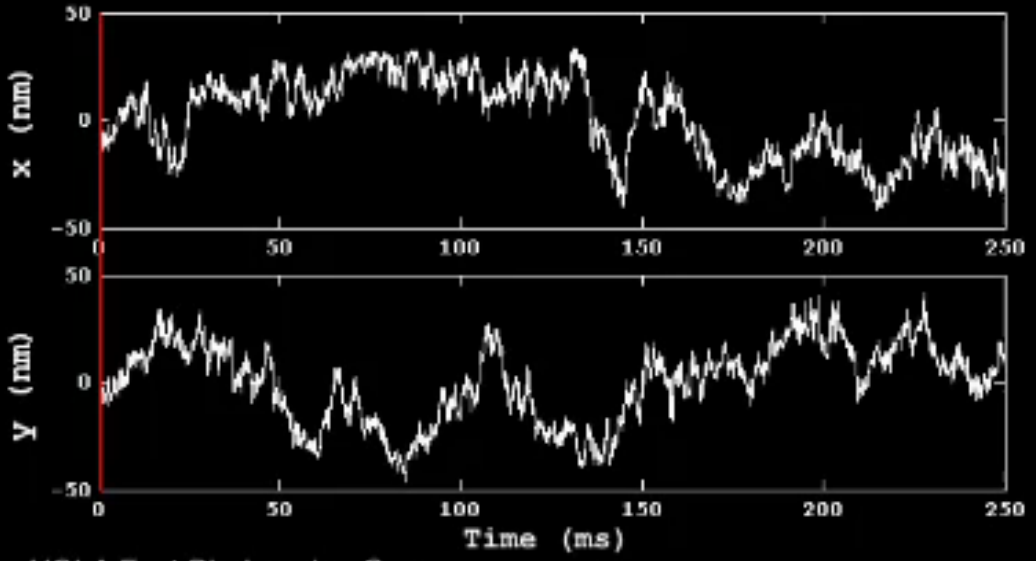
Prof. Manuel Penichet (Oncology)





(10, 000 frame/sec)

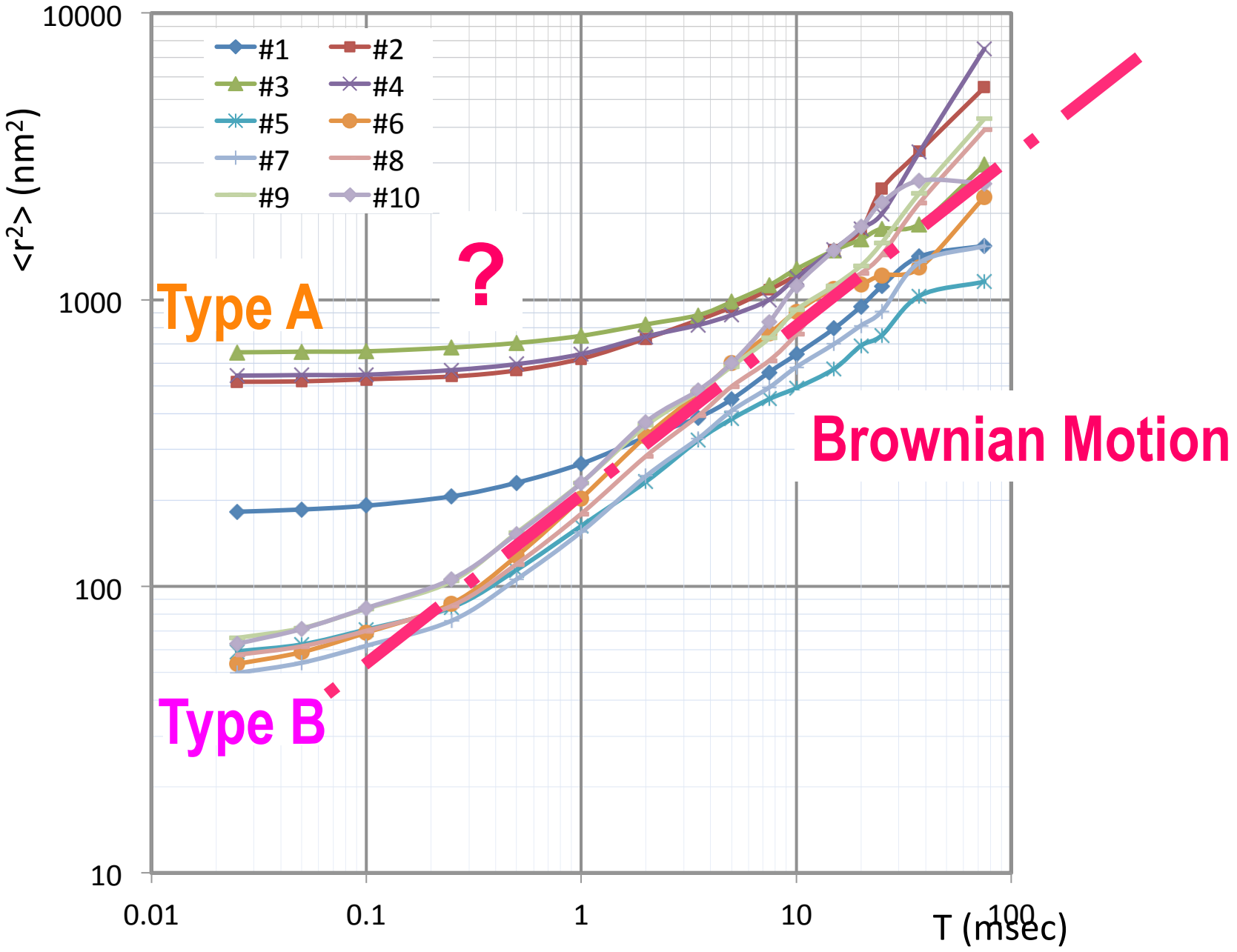




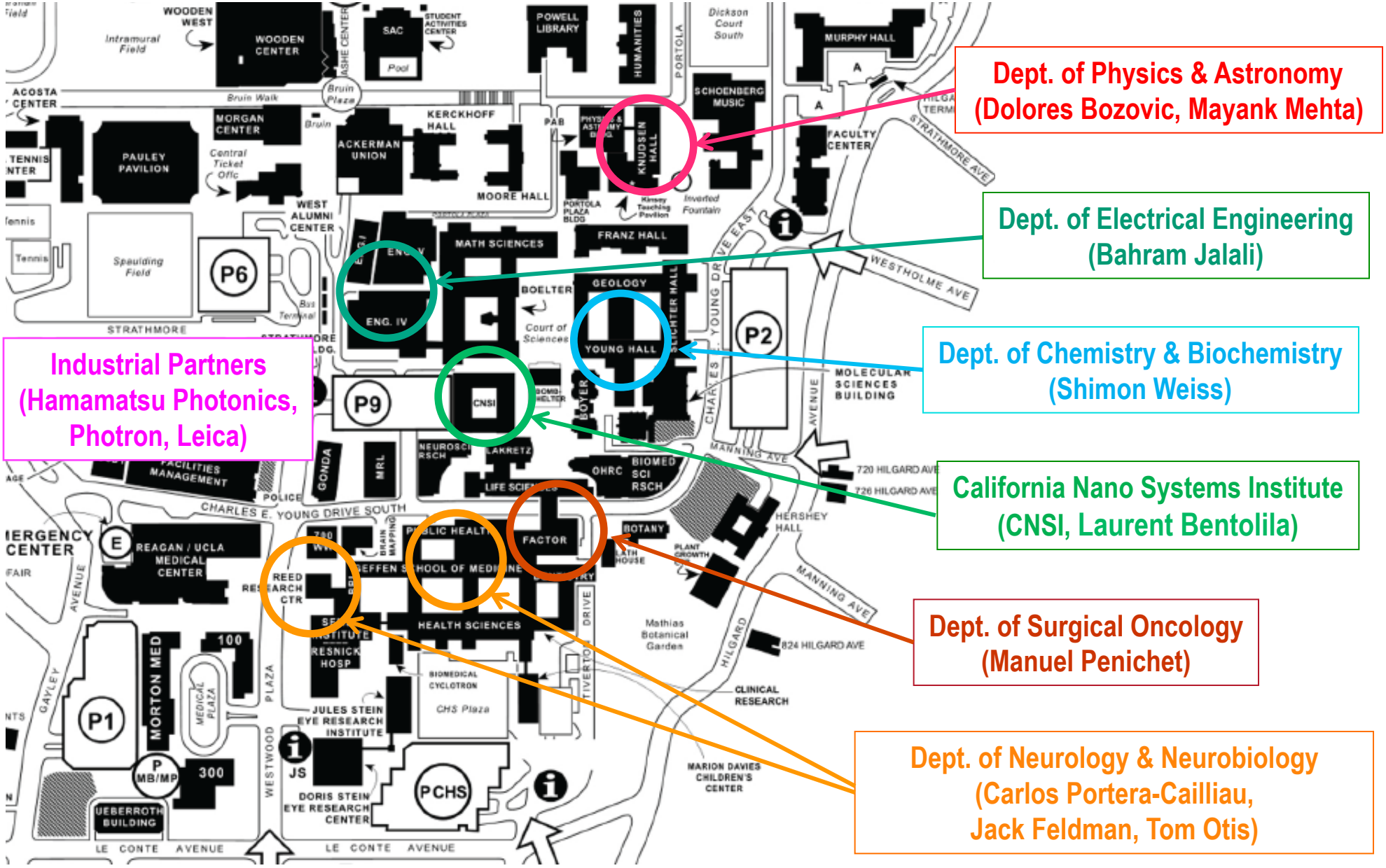
UCLA Fast Bio-Imaging Group

L. Fredrickson, J. Rodriguez, A. Cheng, K. Jewhurst, J. Miao, K. Arisaka

Mean Squire Displacement <r²> of TfR on a Human Multiple Myeloma Cell vs. Time



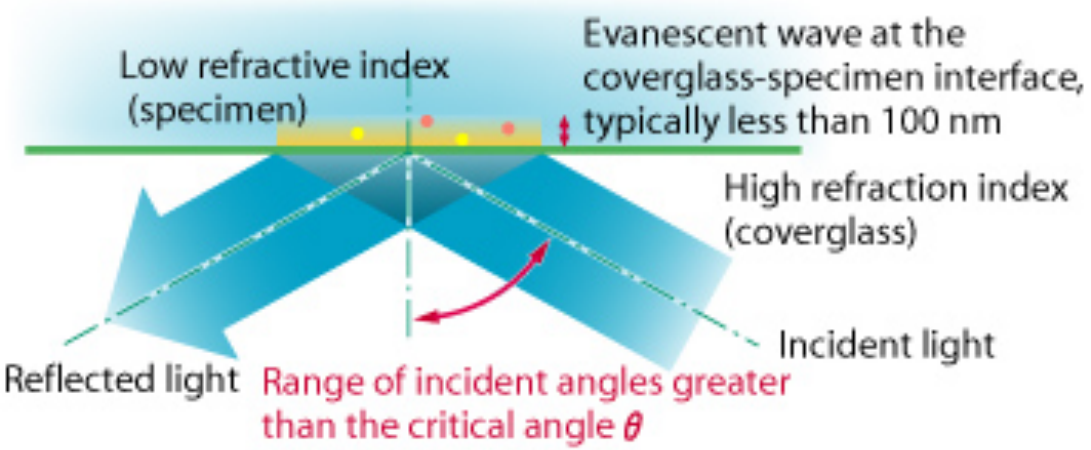
Arisaka's Campus-wide Collaborations on High-Speed Bio-imaging

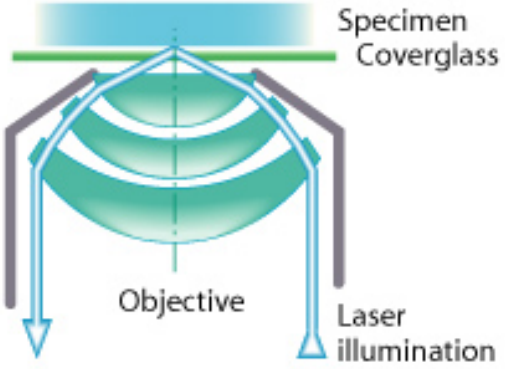


User-shared Core Facility of High-speed Microscopes at CNSI

4D Nano Biophysics

Nikon Microscope TE200E with TIRF at CNSI





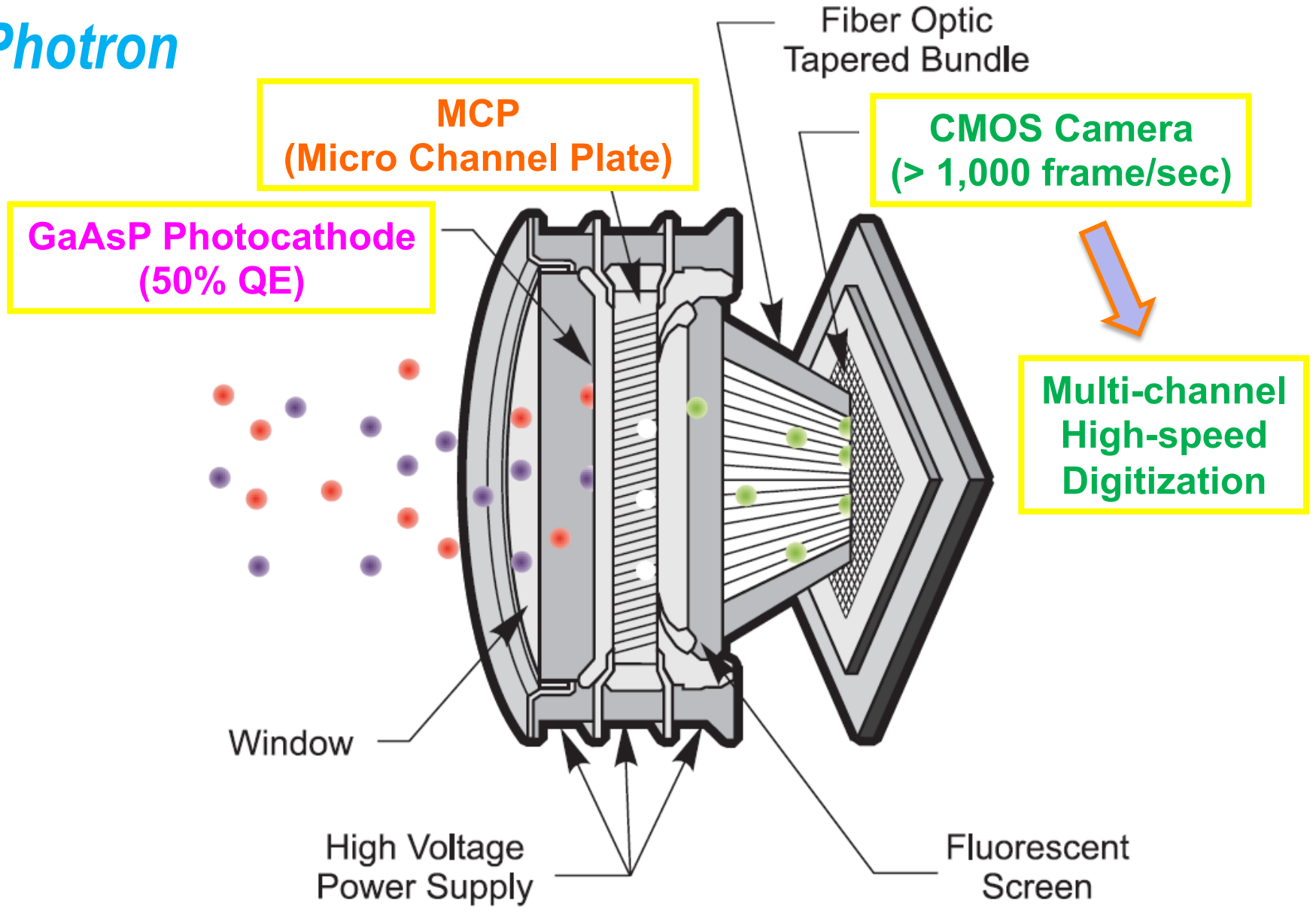
Laurent Bentolila (CNSI)

5k – 500k fps

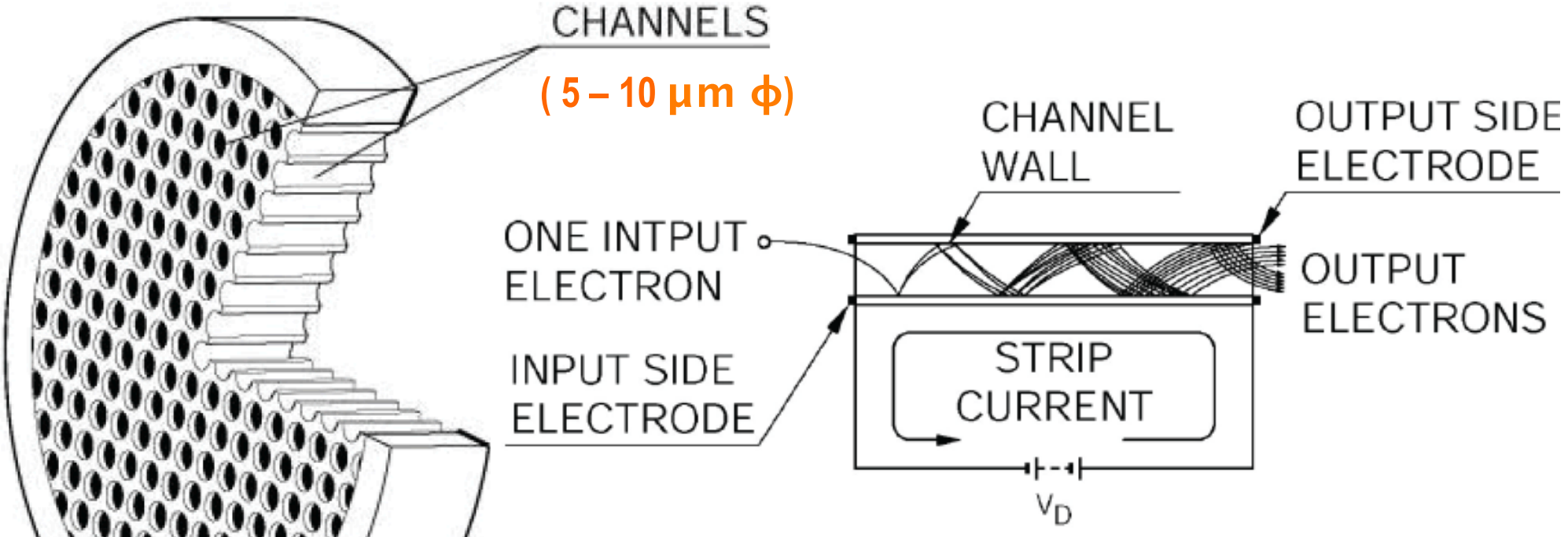
CMOS Camera
Photron SA-1

Principle of ICMOS

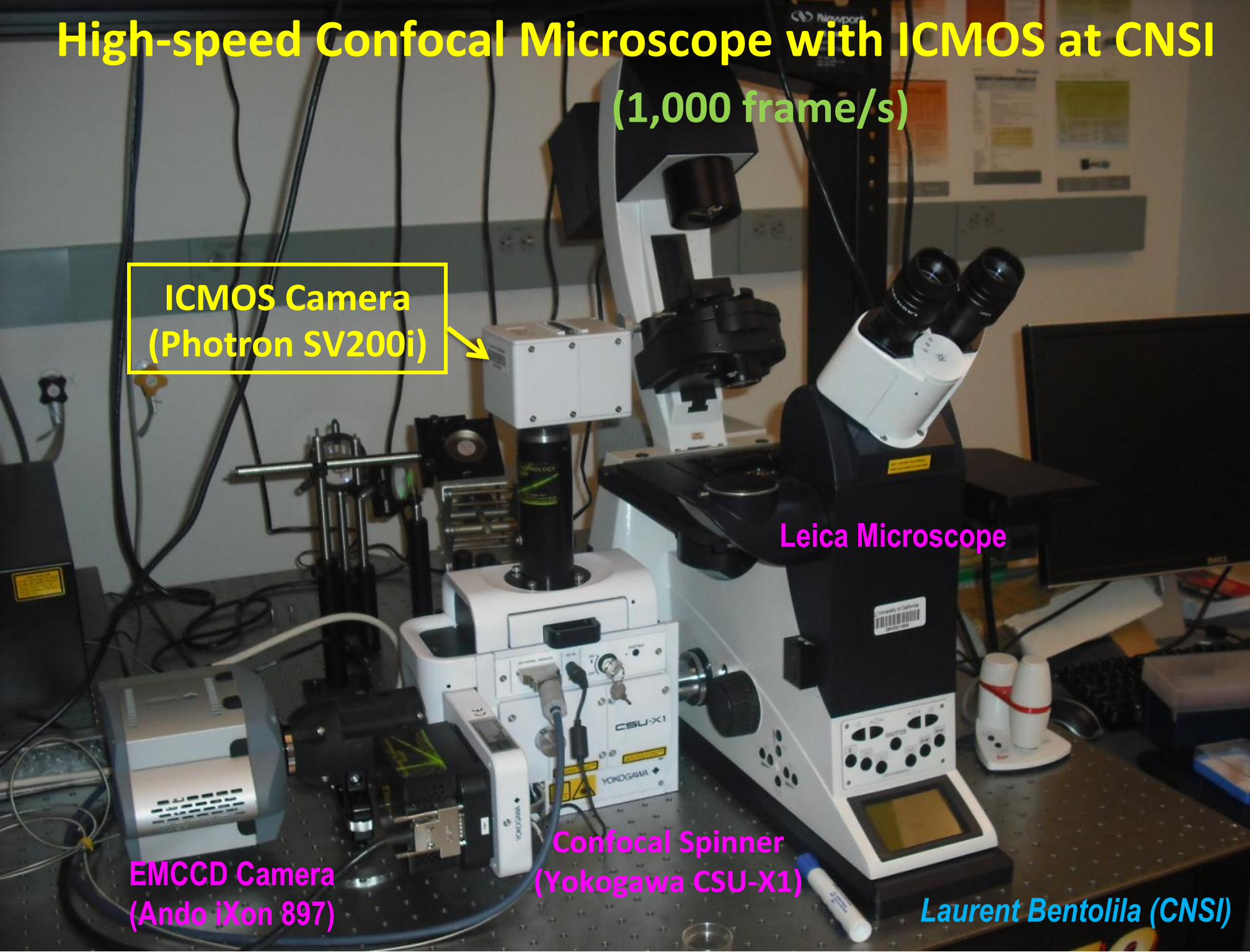
Photron



MCP (Micro Channel Plate)

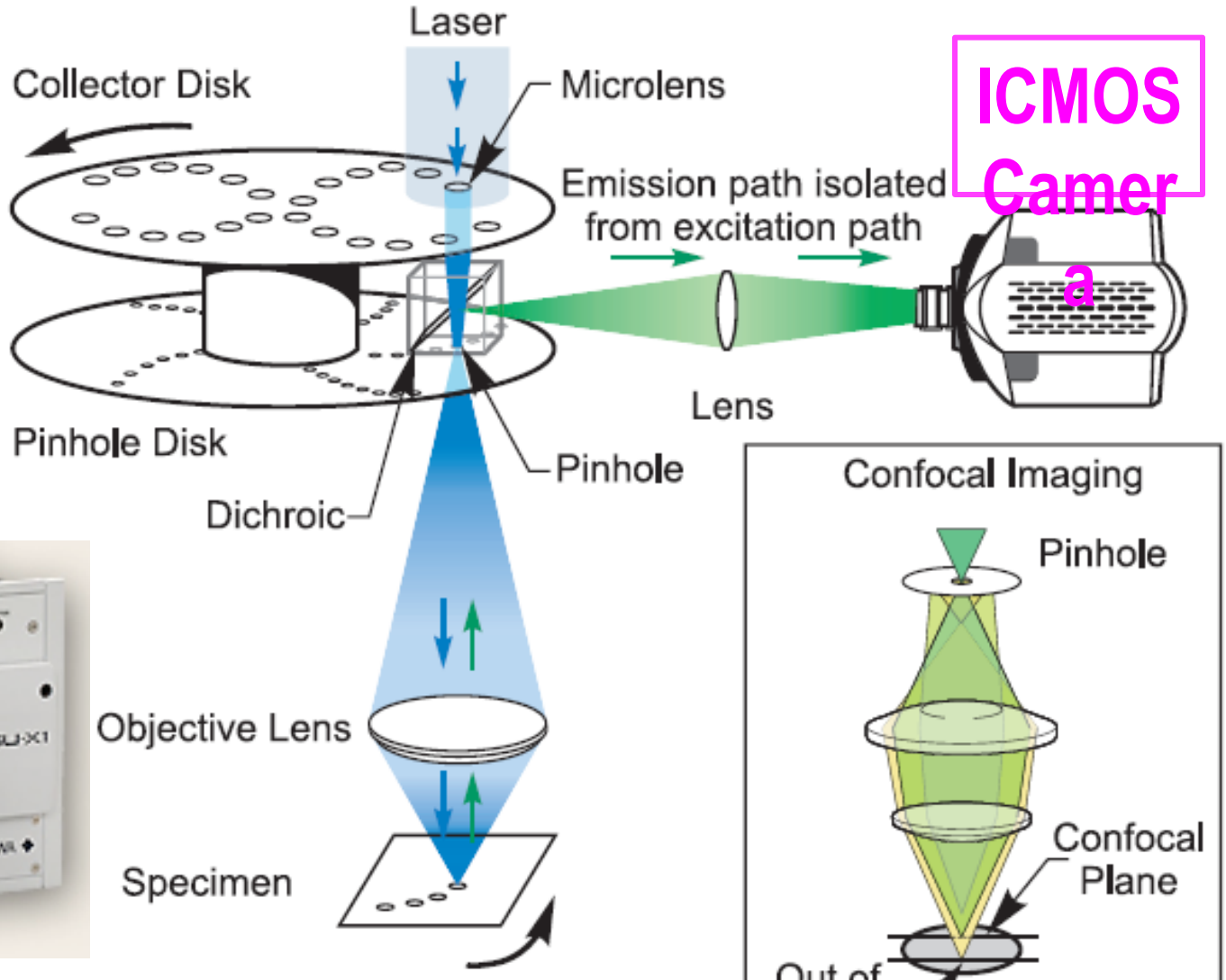


Gain = 100 - 1000


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

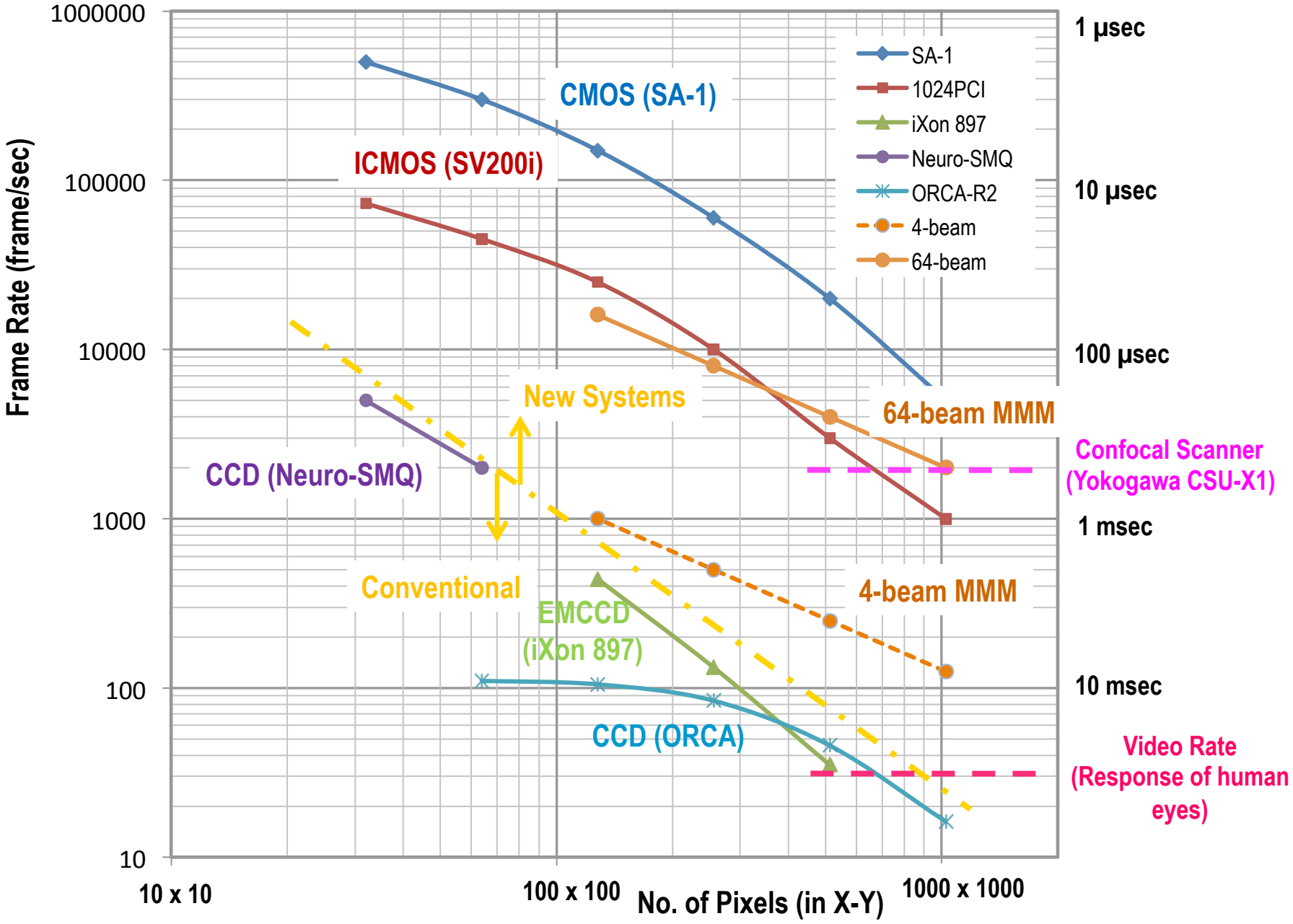
2,000 fps



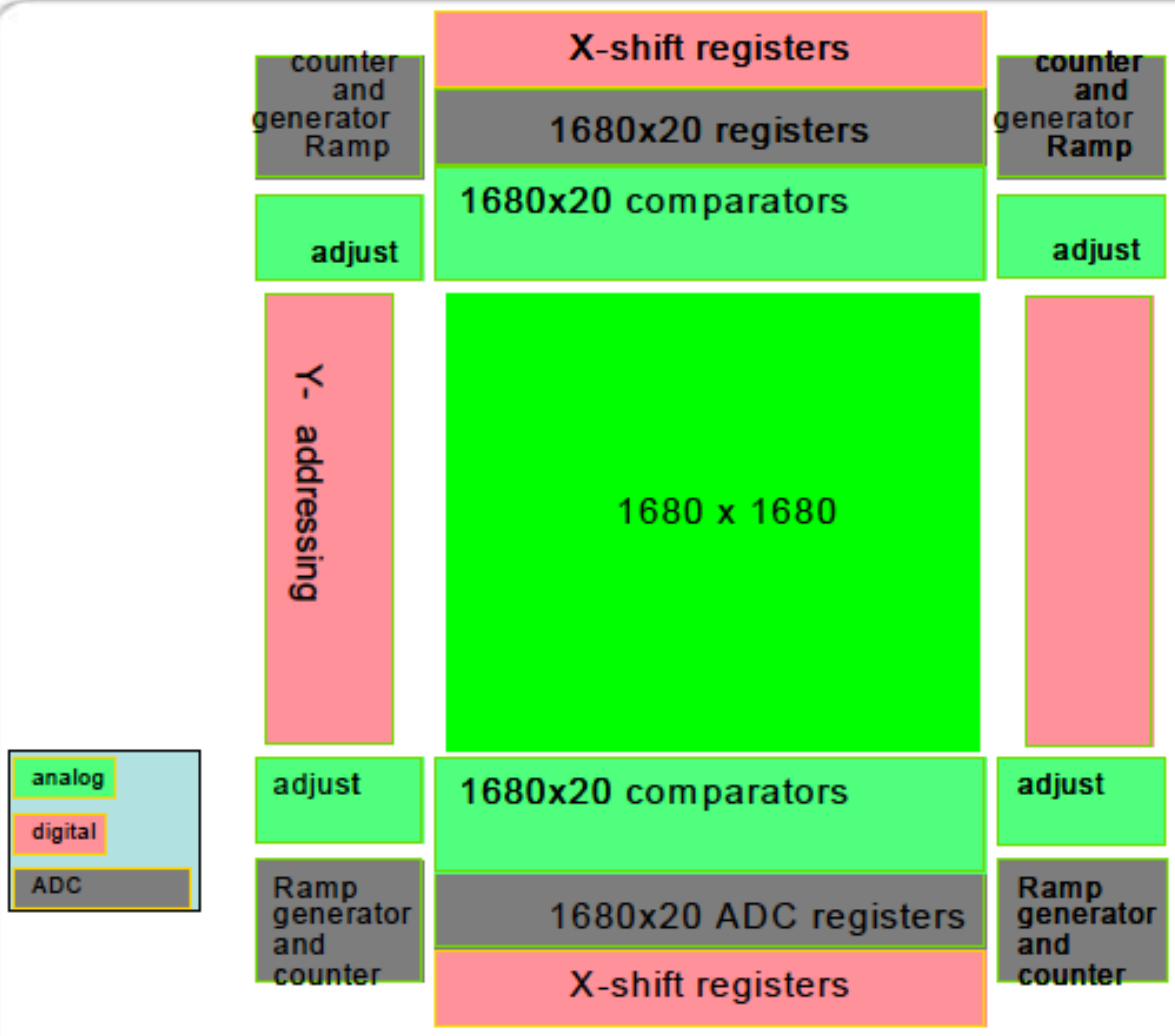
ICMOS Camera

Confocal Dual Spinning Disk

Frame Rate vs. Resolution



E2V-Caeleste scientific-CMOS (in development)



- Foorplan of the full size sensor
- Size is about 7x5cm
- Max 1000 fps
- Operating at 26Gbps
- With over 68000 ADCs running in parallel
- An ADC preamplifier gain adjustable per group of pixels
- And with a noise level of less than 3 $electrons_{RMS}$
- Electronic shutter: rolling segments of local synchronous shutter

- Packaging
  - Peltier cooler
  - > 300 pins

Photosynthesis and Breathing

Spontaneous Symmetry Breaking

Plants		Animals
Chloroplast	⟺	Mitochondria

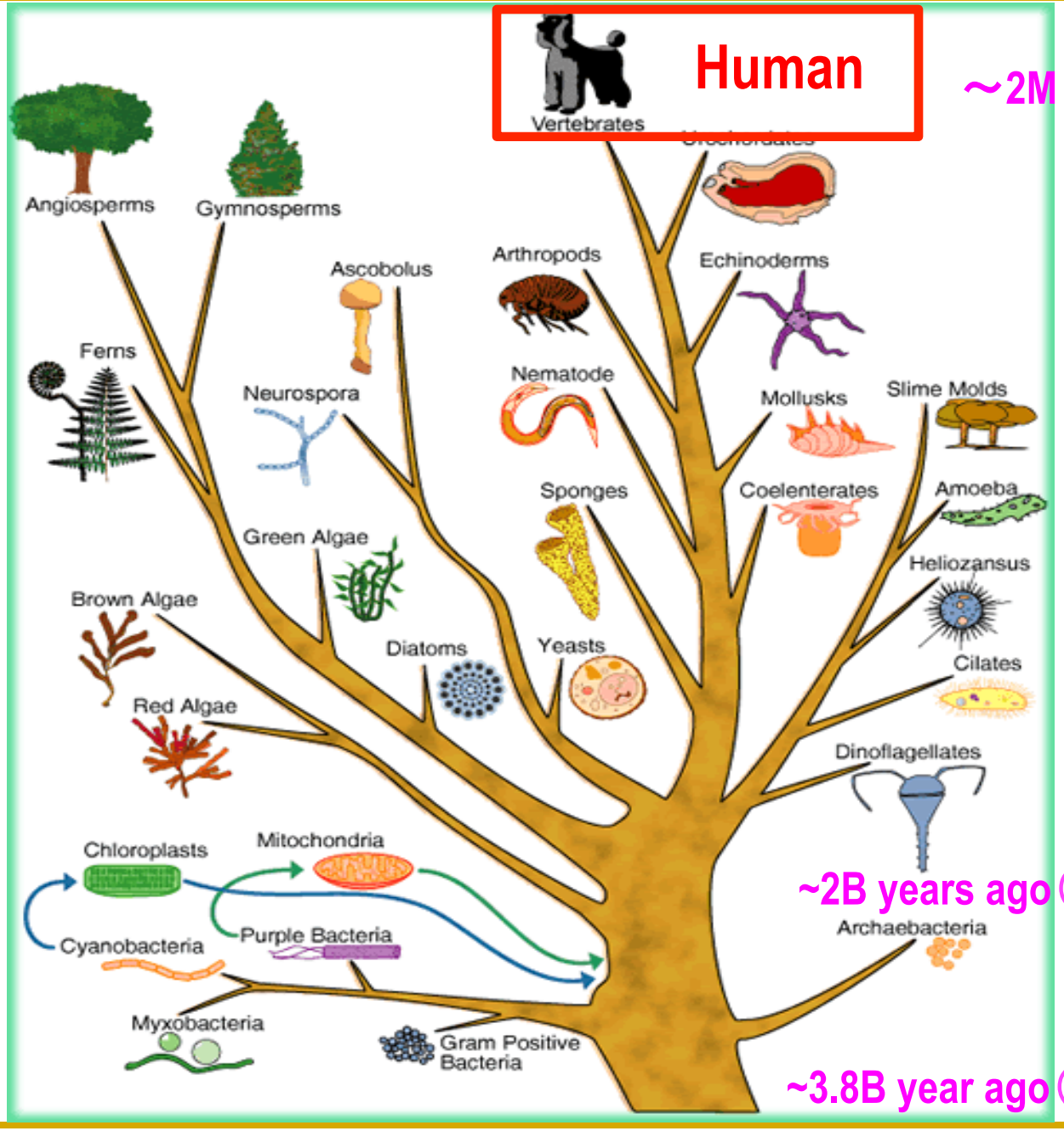
Photosynthesis

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

Breathing

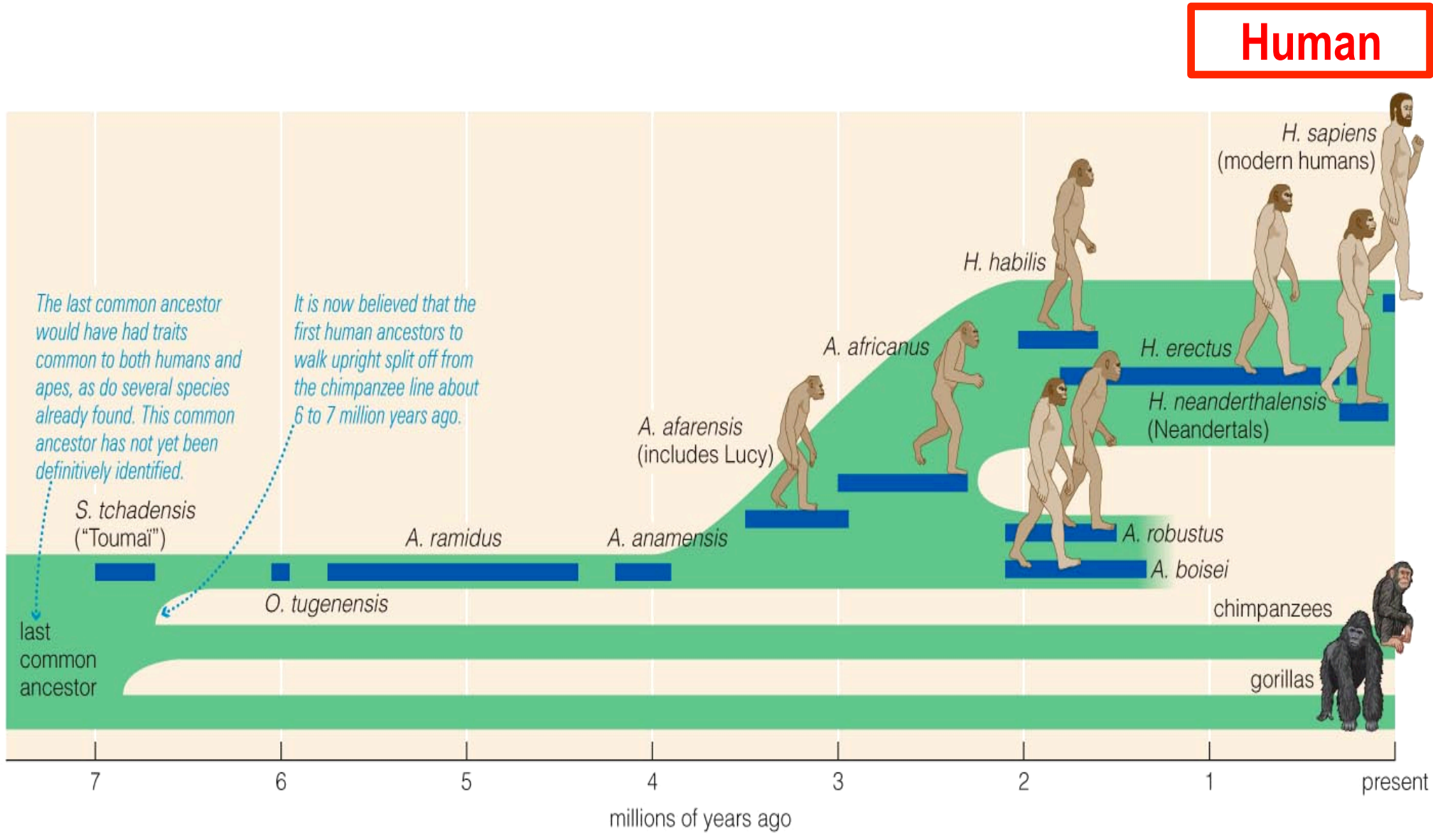
Tree diagrams of evolution

Plants



Animals

Evolution of Humans



Summary

Summary of Origin of Life

- The history of the universe can be divided into phases: particulate, galactic, stellar, planetary, chemical, biological, and cultural.

- This whole process is called cosmic evolution.

  Living organisms should be able to react to their environment, grow by taking in nutrients, reproduce, and evolve.

- Amino acids could have formed in the conditions present on the early Earth, or in space.

What is Life?

- **Emergent Property**
  - Strongly-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