Introduction to Physics Research
Origin of Universe and Ourselves

Katsushi Arisaka

University of California, Los Angeles
Department of Physics and Astronomy

arisaka@physics.ucla.edu
Why are we here?
History of Life and the Human beings

Time

- 10B years
  - Big Bang!
  - Solar System formed
- 1Billion
  - First life on the Earth
  - Plants, Fish...
- 100M
  - Mammals
- 10M
  - Homo sapiens
- 1Million
- 100,000
- 10,000
- 1,000
  - Jesus Christ was born.
- 100
  - Einstein was born.
- 10
  - You were born.
- 1 year
- 100 days
- 10 days
- 1 day
- 10 hours
- 1 hour
  - You woke up this morning.
- 10 minutes
- 1 minute
  - You saw this viewgraph.
**Brief History of Universe and Life**

- **Time**:
  - 0: *Big Bang!*
  - 1B years: *First Galaxy formed*
  - 2: *Solar System formed*
  - 3: *First life on the Earth*
  - 4: *Plants, Fish…*
  - 5: *Homo sapiens*
  - 6: *You were born.*

**Telescopes**

**Fossils**
Andromeda

~100 Billions Stars in a Galaxy
Hubble Deep Field

~100 Billion Galaxies
Red shift up to ∼10
Hubble’s Law: Expansion of the Universe

Big Bang!

Sun/Earth

Horizon of Universe

14 Billion Light Years Moving Away at Speed of Light
Expansion of Universe

Size of Universe $\propto \sqrt{\text{Time}}$

Horizon $\propto cT$
Temperature of Universe

Temperature

Temperature = 1/Size

2.7°C

Beginning

Today

Size
Tevatron at Fermi Lab near Chicago
(1980 – 2010)

6km Circumference
Elementary Particles

ATOM

NUCLEUS

PARTICLE

QUARK

ELECTRON
Elementary Particles

<table>
<thead>
<tr>
<th>Charge</th>
<th>Fermion</th>
<th>Boson</th>
</tr>
</thead>
<tbody>
<tr>
<td>+2/3</td>
<td>u up</td>
<td>γ photon</td>
</tr>
<tr>
<td>-1/3</td>
<td>d down</td>
<td>g gluon</td>
</tr>
<tr>
<td>0</td>
<td>c charm</td>
<td>b bottom</td>
</tr>
<tr>
<td>-1</td>
<td>e electron</td>
<td>W photon</td>
</tr>
<tr>
<td></td>
<td>μ muon</td>
<td>Z Z boson</td>
</tr>
<tr>
<td></td>
<td>τ tau</td>
<td>W W boson</td>
</tr>
</tbody>
</table>

Three Families of Matter

+ Anti-particles

Charge

0

0

±1
Elementary Particles and Forces

**Strong**
- Gluons (8)
- Quarks
- Mesons
- Baryons
- Nuclei

**Weak**
- Bosons ($W, Z$)
- Neutron decay
- Beta radioactivity
- Neutrino interactions
- Burning of the sun

$10^{-13}$

**Electromagnetic**
- Photon
- Atoms
- Light
- Chemistry
- Electronics

$10^{-2}$

**Gravitational**
- Graviton ?
- Solar system
- Galaxies
- Black holes

$10^{-38}$
Unification of Forces (1980)

The diagram illustrates the relative strength of various forces as a function of temperature. The forces are categorized as strong, electromagnetic, weak, and gravitational. The graph shows that at high temperatures, the electromagnetic and weak forces unify into the electroweak force, while at lower temperatures, the gravitational force is still separate.

Key points:
- **Gravitational force** at 100 GeV
- **Electromagnetic force** and **Weak force** at 10^16 GeV
- **Strong force** at 10^19 GeV
- **Electroweak force** at 10^32 K

The diagram suggests a scale from 10^15 to 10^32 K, emphasizing the grand unification at higher temperatures.
Unification of Forces (1980)

- Strong force
- Electromagnetic
- Weak force
- Electroweak
- GUT force

Plank Epoch

Relative strength of force

Temperature (K)

- 100 GeV
- $10^{16}$ GeV
- $10^{19}$ GeV

Copyright © Addison Wesley.
Physicists’ View of Early Universe

Fiat lux
Let there be light
Structure of DNA

3 billion base pairs
Symmetry Breaking

Simple

Symmetry Break Down

Complex
The Beginning

- Everything was the same ↔ Perfect symmetry.
  - All the particles are the same as photons.
  - All four forces are the same.

- The Universe was 10 dimension.
Spontaneous Symmetry Breakdown at a Dinner Table

by Nambu Yoichiro
Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking

14 billion years ago

Origin of Particles
CERN and LHC in Geneva

27km Circumference
7+7=14 TeV
LHC Tunnel with Magnets
CMS Collaboration (1993 ~)

(144 Institutions with about 1700 scientists)

ARATNA
- Yerevan Physics Inst., Yerevan

AUSTRIA
- HEPHY, Vienna

BELARUS
- Institute of Nuclear Problems, Minsk
- National Centre of Part. and HEP, Minsk
- Res. Inst. of Applied Physical Probl., Minsk
- Byelorussian State Univ., Minsk

BELGIUM
- Univ. Instelling Antwerpen, Wilrijk
- Univ. Libre de Bruxelles, Brussels
- Vrije Universiteit Brussel, Brussels
- Univ. Catholique de Louvain, Louvain-la-Neuve
- Univ. de Mons-Hainaut, Mons

BULGARIA
- Inst. for Nucl. Res. and Nucl. Energy, Sofia
- Univ. of Sofia, Sofia

CHINA, PR
- Inst. of High Energy Physics, Beijing
- Peking Univ., Beijing
- Univ. for Science & Tech. of China, Hefei, Anhui

CROATIA
- Tech. Univ. of Split, Split
- Univ. of Split, Split

CYPRUS
- Univ. of Cyprus, Nicosia

ESTONIA
- Inst. of Chemical Phys. and Biophys., Tallinn

FINLAND
- Helsinki Institute of Physics, Helsinki
- Optofys., Univ.of Helsinki, Helsinki
- Univ. of Jyväskylä, Jyväskylä
- Helsinki University of Technology, Helsinki
- Univ. of Oulu, Oulu
- Tampere Univ. of Tech., Tampere

FRANCE
- LAPP, IN2P3-CNRS, Annecy-le-Vieux
- IPN, IN2P3-CNRS, Univ. Lyon I, Villeurbanne
- LPNHE, Ecole Polytech., IN2P3-CNRS, Palaiseau
- DSM/DAPNIA, CEA/Saclay, Gif-sur-Yvette
- IRES, IN2P3-CNRS - ULP, UHA, LEPSI, Strasbourg

GEORGIA
- Inst. of Physics Academy of Science, Tbilisi

GERMANY
- RWTH, I. Physik. Inst., Aachen
- RWTH, III. Physik. Inst. A, Aachen
- RWTH, III. Physik. Inst. B, Aachen
- Humboldt-Univ. zu Berlin, Berlin
- Inst. für Exp. Kernphysik, Karlsruhe
- Univ. of Athens, Athens
- Inst. of Nucl. Phys. "Democritos", Attiki
- Univ. of Ioannina, Ioannina

HUNGARY
- KFKI Res. Inst. for Part. & Nucl. Phys., Budapest
- Kossuth Lajos Univ., Debrecen
- Institute of Nuclear Research ATOMKI, Debrecen
- Panjab Univ., Chandigarh
- Bhabha Atomic Res. Centre, Mumbai
- Univ. of Delhi South Campus, New Delhi
- TIFR - HEPI, Mumbai
- TIFR - HECR, Mumbai

INDIA
- Univ. di Bari e sez. dell'INFN, Bari
- Univ. di Bologna e sez. dell'INFN, Bologna
- Univ. di Catania e sez. dell'INFN, Catania
- Univ. di Firenze e sez. dell'INFN, Firenze
- Univ. di Genova e sez. dell'INFN, Genova
- Univ. di Padova e sez. dell'INFN, Padova
- Univ. di Pavia e sez. dell'INFN, Pavia
- Univ. di Perugia e sez. dell'INFN, Perugia
- Univ. di Pisa e sez. dell'INFN, Pisa
- Univ. di Roma 1 e sez. dell'INFN, Roma
- Univ. di Torino e sez. dell'INFN, Torino

KOREA
- Cheju National University, Cheju
- Chonnam National University, Kwangju
- Chonbuk National University, Chongju
- Dongguk University, Naju
- Kangnung National University, Kangnung
- Kangwon National University, Chuncheon
- Kon-Kuk University, Seoul
- Korea University, Seoul
- Kyungpook National University, Taegu
- Pohang University of Science and Technology, Pohang
- Gyeongsang National University, Jinju
- Seoul National Univ., Seoul
- Sejong University, Seoul
- Sungkyunkwan University, Suwon
- Seoul National Univ. of Education, Seoul
- Wonkwang University, Iri

PAKISTAN
- Quaid-I-Azam Univ., Islamabad
- Ghulam Ishaq Khan Institute, Swabi

POLAND
- Inst. of Exp. Phys., Warsaw
- Soltan Inst. for Nucl. Studies, Warsaw

PORTUGAL
- ULP, Lisboa

RUSSIA
- JINR, Dubna
- Inst. for Nucl. Res., Moscow
- Inst. for Theoretical and Exp. Phys., Moscow
- P.N. Lebedev Phys. Inst., Moscow
- Moscow State Univ., Moscow
- Budker Inst. for Nucl. Phys., Novosibirsk
- Petersburg Nucl. Phys. Inst., Gatchina (St Petersburg)

SLOVAK REPUBLIC
- Slovak University of Technology, Bratislava

SPAIN
- CIEMAT, Madrid
- Univ. Autonoma de Madrid, Madrid
- Univ. de Oviedo, Oviedo
- IFCA, CSIC-Univ. de Cantabria, Santander

SWITZERLAND
- Univ. Basel, Basel
- CERN, Geneva
- Paul Scherrer Inst., Villigen
- Inst. für Teilchenphysik, ETH, Zurich
- Univ. Zürich, Zurich

TURKEY
- Cultureva Univ., Adana
- Middle East Technical Univ., Ankara

Ukraine
- Inst. of Single Crystals of Nat. Acad. of Science, Kharkov
- Kharkov Inst. of Phys. and Tech., Kharkov
- Kharkov State Univ., Kharkov

UNITED KINGDOM
- Univ. of Bristol, Bristol
- Brunel Univ., Uxbridge
- Imperial College, Univ. of London, London
- RAL, Didcot

USA
- Univ. of Alabama, Tuscaloosa
- Iowa State Univ., Ames
- Boston Univ., Boston
- California Inst. of Tech., Pasadena
- Carnegie Mellon Univ., Pittsburgh
- Univ. of Illinois at Chicago, Chicago
- Fairfield Univ., Fairfield
- Fermi National Accelerator Lab., Batavia
- Florida State Univ. - HEPG, Tallahassee
- Florida State Univ. - SCRI, Tallahassee
- Univ. of Florida, Gainesville
- The Univ. of Iowa, Iowa City
- Johns Hopkins Univ., Baltimore
- LLNL, Livermore
- Los Alamos Nat. Lab., Los Alamos
- Univ. of Maryland, College Park
- Univ. of Minnesota, Minneapolis
- Univ. of Mississippi, Oxford
- Massachusetts Inst. of Tech., Cambridge
- Univ. of Nebraska-Lincoln, Lincoln
- Northeastern Univ., Boston
- Northwestern Univ., Evanston
- Univ. of Notre Dame, Notre Dame
- The Ohio State Univ., Columbus
- Princeton Univ., Princeton
- Purdue Univ., West Lafayette
- Rice Univ., Houston
- Univ. of California, Riverside
- Univ. of Rochester, Rochester
- Rutgers, the State Univ. of New Jersey, Piscataway
- Texas Tech Univ., Lubbock
- Univ. of Texas at Dallas, Richardson
- Univ. of California at Davis, Davis
- UCLA, Los Angeles
- Univ. of California San Diego, La Jolla
- Virginia Polytech. Inst. and State Univ., Blacksburg
- Univ. of Wisconsin, Madison

UZBEKISTAN
- Inst. of Nucl. Phys. of the Uzbekistan Acad. of Sciences, Tashkent
Installing muon Detectors
Particle detectors constructed at Westwood, now at LHC, CERN
First Event at LHC – Recreation of the Big Bang! (Nov 7, 2009)
Physicists find 'tantalizing hints' of Higgs boson 'God particle'

December 13, 2011 | By Eryn Brown, Los Angeles Times

Physicists announced Tuesday that they had detected "tantalizing hints," but not definitive proof, of the long-sought Higgs boson, the so-called God particle that is crucial to physicists' understanding of why mass exists in the universe.

Two large teams of scientists based at the Large Hadron Collider near Geneva separately saw what they believe are telltale tracks of the maddeningly elusive particle in the aftermath of about 400 trillion proton collisions carried out since January.
Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking

14 billion years ago

Origin of Particles

Origin of Structure
Dark Matter is required!
Formation of Structure in the Universe

Dark Matter is required!

Katsushi Arisaka, UCLA
What is Dark Matter?

- **Must be a heavy particle**
  - Only weakly interacting.
  - Gravitationally attracted.

- **Candidates**
  - “**MACHO**” (Massive Compact Halo Objects)  \(\times\)
    - \(\rightarrow\) Baryonic Dark Matter
  - **Heavy Neutrino**  \(\times\)
    - \(\rightarrow\) Hot Dark Matter
  - “**WIMP**” (Weakly Interacting Massive Particle)  
    - \(\rightarrow\) Cold Dark Matter
SUSY Particles and Neutralino

**Standard particles**

- Quarks (u, c, t, d, s, b)
- Leptons (e, μ, τ, ν_e, ν_μ, ν_τ)
- Force particles (γ, Z, W, H)

**Spin**
- 1/2
- 1
- 0

Katsushi Arisaka, UCLA
SUSY Particles and Neutralino

Super Symmetry

Neutralino

Standard particles

SUSY particles

Spin

Quarks
Leptons
Force particles

Squarks
Sleptons
SUSY force particles

$\frac{1}{2}$
1
0

0
1/2
1/2

6/26/2012
Katsushi Arisaka, UCLA
XENON100 Detector

170 kg
(50 kg)
XENON100 Detector (2009)
Where backgrounds come from?

Ultimately **photon detectors** are the major source of backgrounds.

- Underground or Under high mountains
- Cosmic Rays
- Radio Activities (U, Th, K...)
- Water Tank (Liquid Scintillator)

Detector
Structure and Electron Trajectories of 3” QUPID
Mechanical Samples on Base plate
Comparison of Detector Size

- **ZEPLIN-II**: 31 kg (7.2 kg)
  - 14 cm
  - 30 cm
  - 2006

- **XENON10**: 14 kg (5.4 kg)
  - 15 cm
  - 30 cm
  - 2007

- **XENON100**: 170 kg (50 kg)
  - 30 cm
  - 60 cm
  - 2009

- **XENON100+**: 250 kg (100 kg)
  - 60 cm
  - 1 m
  - 2011

- **XENON1ton**: 2.7 ton (1 ton)
  - 1 m
  - 2 m
  - 2014

- **XAX**: 19 ton (10 ton)
  - 2 m
  - 2017

-XENON100+|2011
-XENON1ton|2014
-ZEPLIN-II|2006
-XENON10|2007
-XAX|2017
MAX Detector (G3)

Xe
20 ton
(10 ton)

40Ar
70 ton
(50 ton)

2 m

4 m

3” QUPID x 595 (Top)
3” QUPID x 595 (Bottom)

3” QUPID x 2644 (Top)
3” QUPID x 2644 (Bottom)
Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking

14 billion years ago

Origin of Particles
Origin of Structure
Origin of Life
Organic Polymers (4.5B → 4B years)

an amino acid

organic monomers from space

a protein

organic polymers

an amino acid

organic monomers

inorganic molecules from Earth

methane

water

carbon dioxide

hydrogen cyanide
RNA Word (4B $\rightarrow$ 3.5B years ago)


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

Up to ~2 m long

2 nm wide

Cell made by proteins

Gene made by DNA
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.
The H33D detector attaches to a standard fluorescence microscope. Laser. It will permit to track multicolor qdot-labeled proteins in live cells virtually background-free.

Single Molecule Imaging

Nano Technology

Particle Physics Detector

Prof. Shimon Weiss
Gold nano particle (40nm) attached to Transferrin Receptor (TfR) on Cancer Cell

Prof. Manuel Penichet (Oncology)

(10,000 frame/sec)
Arisaka’s Campus-wide Collaborations on High-Speed Bio-imaging

California Nano Systems Institute (CNSI, Laurent Bentolila)

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

Dept. of Electrical Engineering (Bahram Jalali)

Dept. of Chemistry & Biochemistry (Shimon Weiss)

Dept. of Surgical Oncology (Manuel Penichet)

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

Industrial Partners (Hamamatsu Photonics, Photron, Leica, Spectra Physics)
User-shared Core Facility of High-speed Microscopes at CNSI

Tour in July

4D Nano Biophysics
High-speed Confocal Microscope with ICMOS at CNSI

ICMOS Camera
(Photron SV200i)

EMCCD Camera
(Ando iXon 897)

Confocal Spinner
(Yokogawa CSU-X1)

Leica Microscope

Laurent Bentolila (CNSI)
Seven Phases of Cosmic Evolution

Spontaneous Symmetry Breaking

14 billion years ago

Origin of Particles
Origin of Structure
Origin of Life
Origin of Consciousness
Ca\textsuperscript{2+} Signal in cultivated Rat’s Brain
Assembly of cortical circuits during development

Sensory (afferent) Neurons

SENSORY INPUT

INTEGRATION

Interneurons

Brain and spinal cord

Motor output

Motor (efferent) Neurons

Peripheral nervous system (PNS)

Central nervous system (CNS)

Effector

Sensory receptor
Human Eyes

- Sclera
- Choroid
- Retina
- Cornea
- Pupil
- Lens
- Iris
- Ciliary body
- Optic nerve

6/26/2012
Katsushi Arisaka, UCLA
How can I recognize a woman so far away?

- Genetically encoded?
- Learning and memory?
The Cerebral Cortex

Conscious

Unconscious

Thalamus

Subcortical areas

Conscious

Unconscious

Thalamus

Subcortical areas
Nature vs. Nurture

Nature

Nurture

Katsushi Arisaka, UCLA
Mutiphoton Microscope

Conventional Confocal

Two Photon Excitation

440 nm

500 – 600 nm

880 nm

500 – 600 nm

pinhole

dichroic mirror

scattering tissue

objective lens

DETECTOR

Katsushi Arisaka, UCLA
In vivo calcium imaging of neuronal activity

Katsushi Arisaka, UCLA
3D Structure of Barrel Cortex of Mouse

Fluo-4 AM labeled astrocytes are colabeled with sulforhodamine 101 to eliminate background (yellow).

Sulforhodamine 101 labeled astrocytes (orange).

Layer 5 pyramidal neuron soma and apical dendrite from a transgenic animal demonstrates imaging depth (blue).

Glass microelectrode for dye injection and electrophysiology
- cell-attached voltage follower
- whole-cell voltage/current clamp
- $10^{15}$ Ohm input impedance, < 150 fA input current bias.

150 µm deep

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

6/26/2012 Katsushi Arisaka, UCLA
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)

Beam 1
(0 ns)

Beam 2
(+3 ns)

Beam 3
(+6 ns)

Beam 4
(+9 ns)

6/26/2012
Katsushi Arisaka, UCLA

300 µm
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 billions neurons in our brain)

6/26/2012 Katsushi Arisaka, UCLA
How can we recognize and memorize the space?

Mayank Mehta (Physics, Neurology)
Activity of (excitatory) pyramidal neurons in CA depends on rat’s position: place cells

Hippocampus has a cognitive map of space

Mayank Mehta (Physics, Neurology)
Learning and Memory by Hippocampus

Motion Direction

After learning

Before learning
Virtual Reality Experiment on Awake Rats

Two Photon Excitation Microscope

Ti:Sa Laser

Spherical Screen for Virtual Vision

Speakers

Tetrodes

Olfactory Stimulator

Whisker Stimulator

Floating Ball

Optical Mice

Pressurized air

Mayank Mehta
Daniel Aharoni
Bernard Willers
A rat running in a Virtual Reality
Seven Phases of Cosmic Evolution

Origin of Particles
Origin of Structure
Origin of Life
Origin of Consciousness

14 billion years ago
Why are we here?
Cyclic Model

“bang”
radiation
matter
dark energy
“contraction”
“crunch”

M theory

Shadow Universe
Our Universe
Are there more than one Universe?
Linde’s Multiverse by Chaotic Inflation
There may be ~100 Billion Universes.
Four Major Science

Origin of Particles
Particle Physics

Origin of Universe
Cosmology

Origin of Life
Molecular Biology

Origin of Consciousness
Neurophysics
Welcome to Physics World at UCLA

- Feel free to stop by my office any time.
  - Katsushi Arisaka
  - Knudsen 4-145
  - (310) 825-4925
  - arisaka@physics.ucla.edu

- This talk available at:
  - http://www.physics.ucla.edu/~arisaka/REU

- Lab Tours:
  - Today ➔ Dark Matter Lab
  - In July ➔ CNSI (California Nano System Institute)