

Frontier Science and the ILC

US-Japan Advanced Science and Technology Symposium

Hitoshi Murayama

UC Berkeley, Lawrence Berkeley Laboratory, U.Tokyo

April 30, 2013

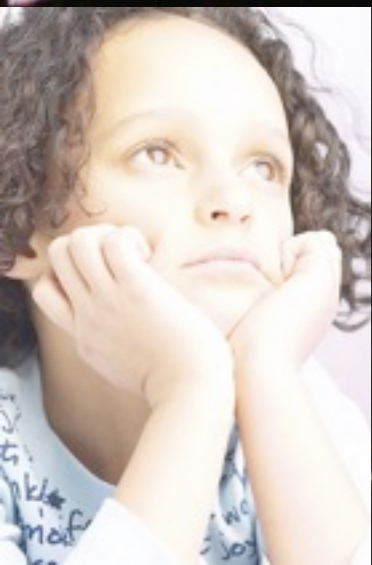
How did the Universe begin?

What is its fate?

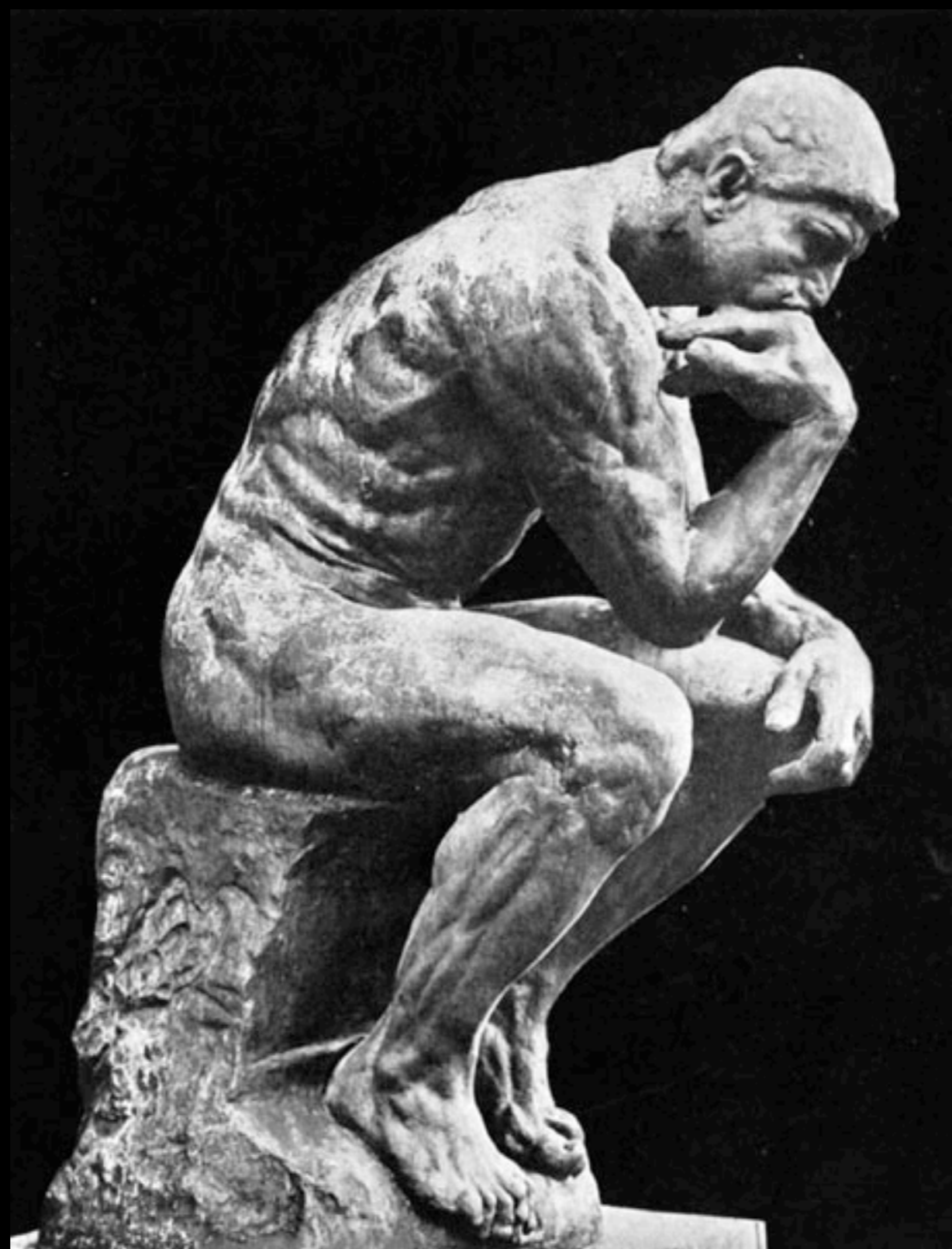
What is it made of?

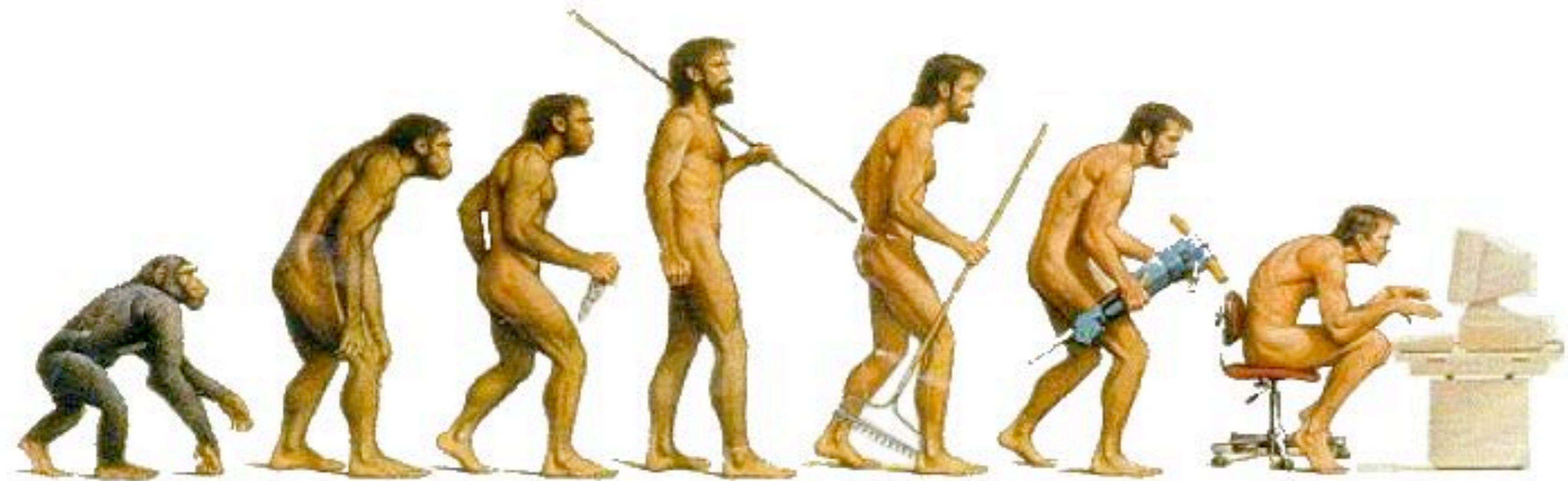
What are its fundamental laws?

Why do we exist?

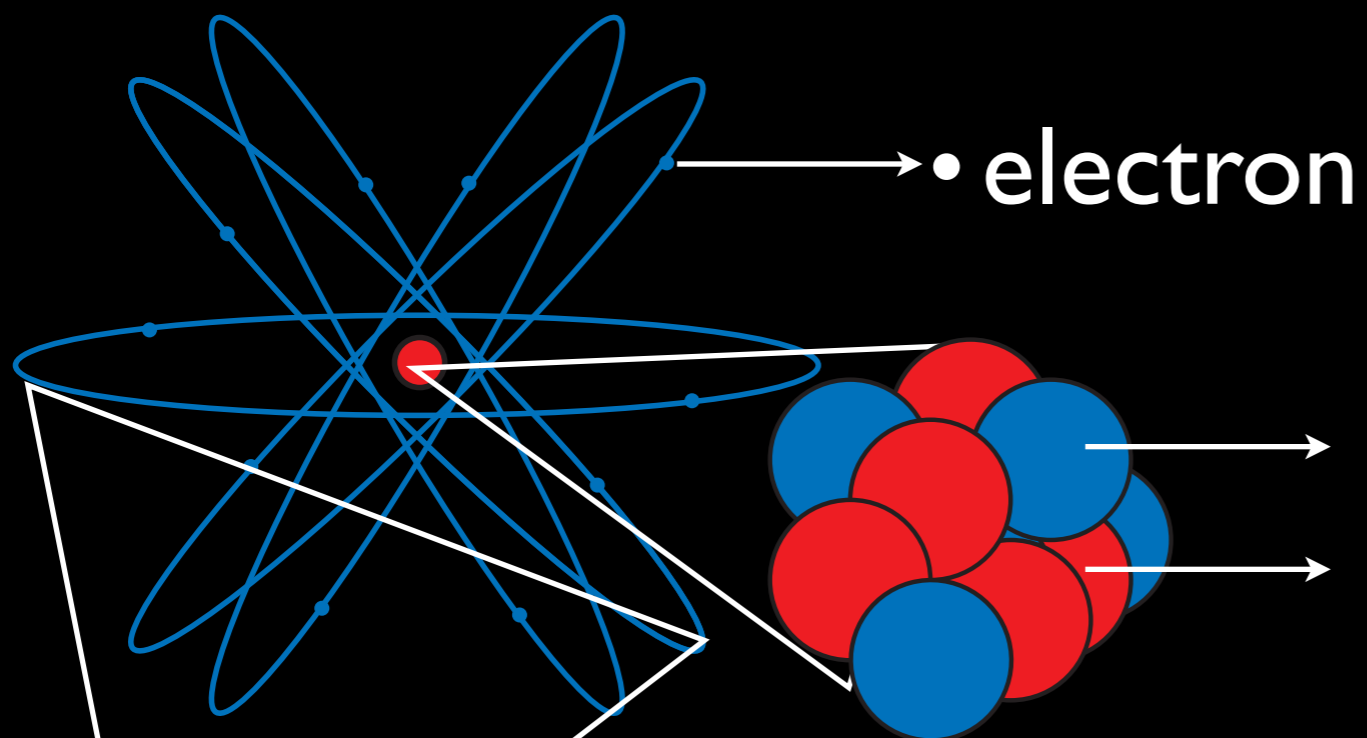




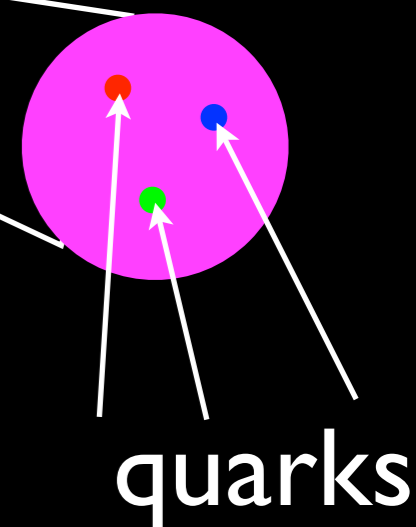
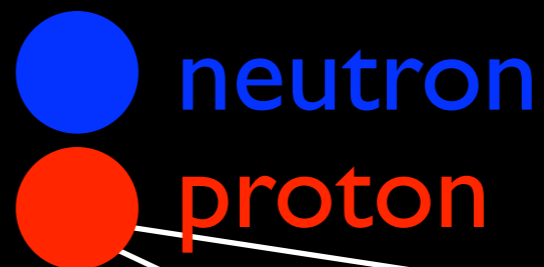




atom



nucleus



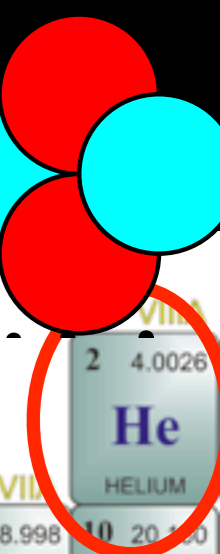
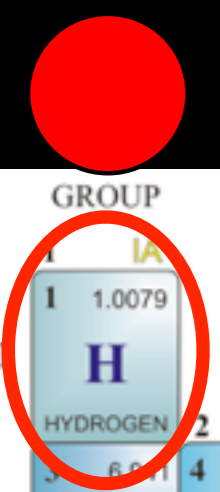
number of protons determines
the chemical element

only hydrogen and helium right after the Big Bang

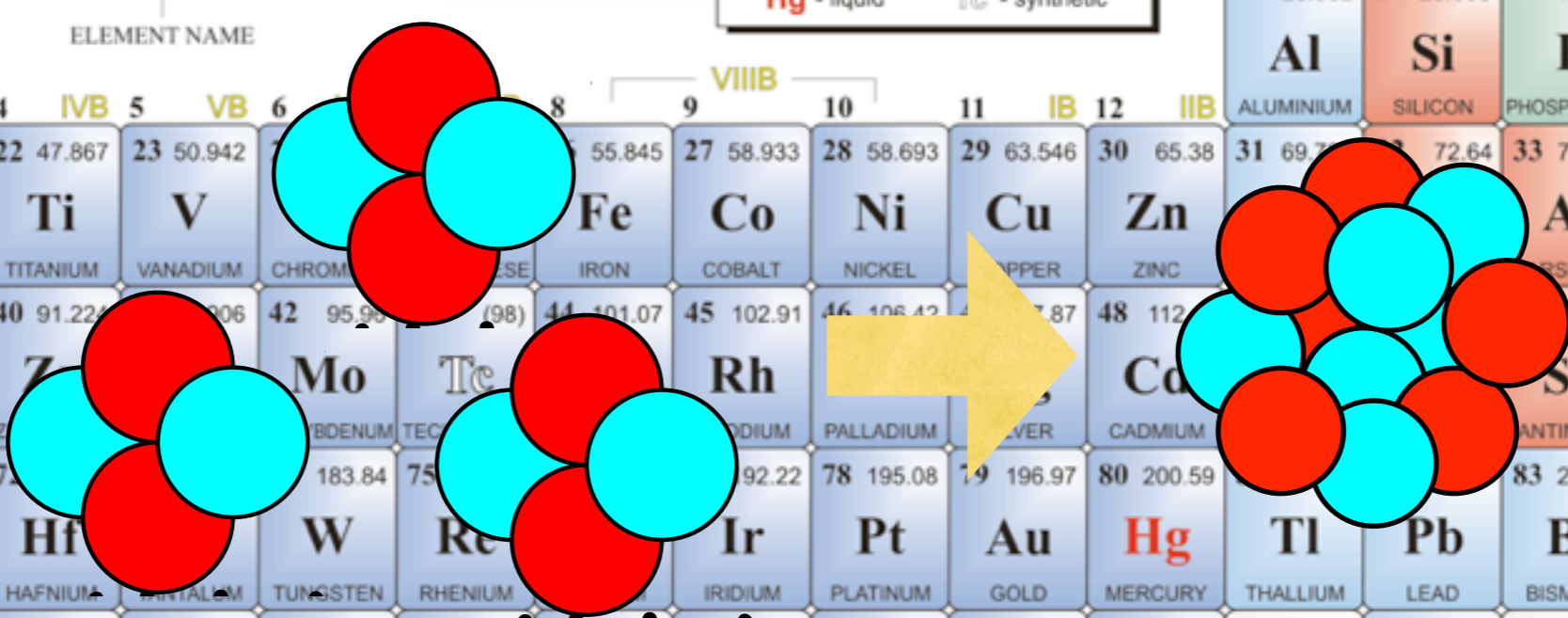
PERIODIC TABLE OF THE ELEMENTS

<http://www.periodni.com>

| PERIOD | GROUP I A | GROUP II A | GROUP III A | GROUP IV A | GROUP V A | GROUP VI A | GROUP VII A | GROUP VIII A | GROUP IX A | GROUP X A |
|--------|---------------------------------|----------------------------------|---------------------|------------|-----------|------------|-------------|--------------|------------|-----------------------------------|
| 1 | 1.0079 H HYDROGEN | | | | | | | | | 4.0026 He HELIUM |
| 2 | 6.941 Li LITHIUM | 9.0122 Be BERYLLIUM | | | | | | | | 18.998 Ne NEON |
| 3 | 22.990 Na SODIUM | 24.305 Mg MAGNESIUM | | | | | | | | 39.948 Ar ARGON |
| 4 | 39.098 K POTASSIUM | 40.078 Ca CALCIUM | | | | | | | | 83.798 Kr KRYPTON |
| 5 | 85.468 Rb RUBIDIUM | 87.62 Sr STRONTIUM | | | | | | | | 131.29 Xe XENON |
| 6 | 132.91 Cs CAESIUM | 137.33 Ba BARIUM | La-Lu Lanthanide | | | | | | | 222 Rn RADON |
| 7 | (223) Fr FRANCIUM | (226) Ra RADIUM | Ac-Lr Actinide | | | | | | | (...) Uuo UNUNOCTIUM |



built inside stars



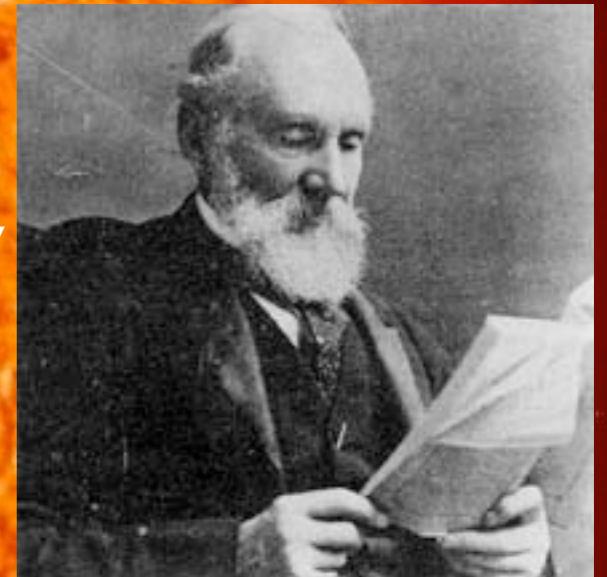
LANTHANIDE

| | | | | | | | | | | | | | | |
|-------------------------------------|----------------------------------|--|-------------------------------------|-------------------------------------|------------------------------------|------------------------------------|--------------------------------------|-----------------------------------|--------------------------------------|-----------------------------------|----------------------------------|-----------------------------------|------------------------------------|------------------------------------|
| 57 138.91 La LANTHANUM | 58 140.12 Ce CERIUM | 59 140.91 Pr PRASEODYMIUM | 60 144.24 Nd NEODYMIUM | 61 (145) Pm PROMETHIUM | 62 150.36 Sm SAMARIUM | 63 151.96 Eu EUROPIUM | 64 157.25 Gd GADOLINIUM | 65 158.93 Tb TERBIUM | 66 162.50 Dy DYSPROSIUM | 67 164.93 Ho HOLMIUM | 68 167.26 Er ERBIUM | 69 168.93 Tm THULIUM | 70 173.05 Yb YTTERIUM | 71 174.97 Lu LUTETIUM |
|-------------------------------------|----------------------------------|--|-------------------------------------|-------------------------------------|------------------------------------|------------------------------------|--------------------------------------|-----------------------------------|--------------------------------------|-----------------------------------|----------------------------------|-----------------------------------|------------------------------------|------------------------------------|

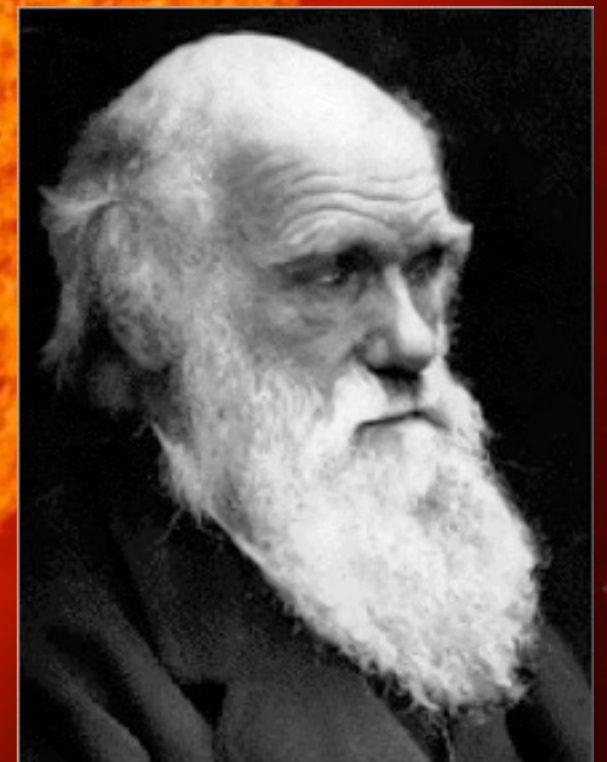
(1) Pure Appl. Chem., 81, No. 11, 2131-2156 (2009)
Relative atomic masses are expressed with five significant figures. For elements that have no stable nuclides, the value enclosed in parentheses is the mass number of the longest-lived isotope.

Why does the Sun shine?

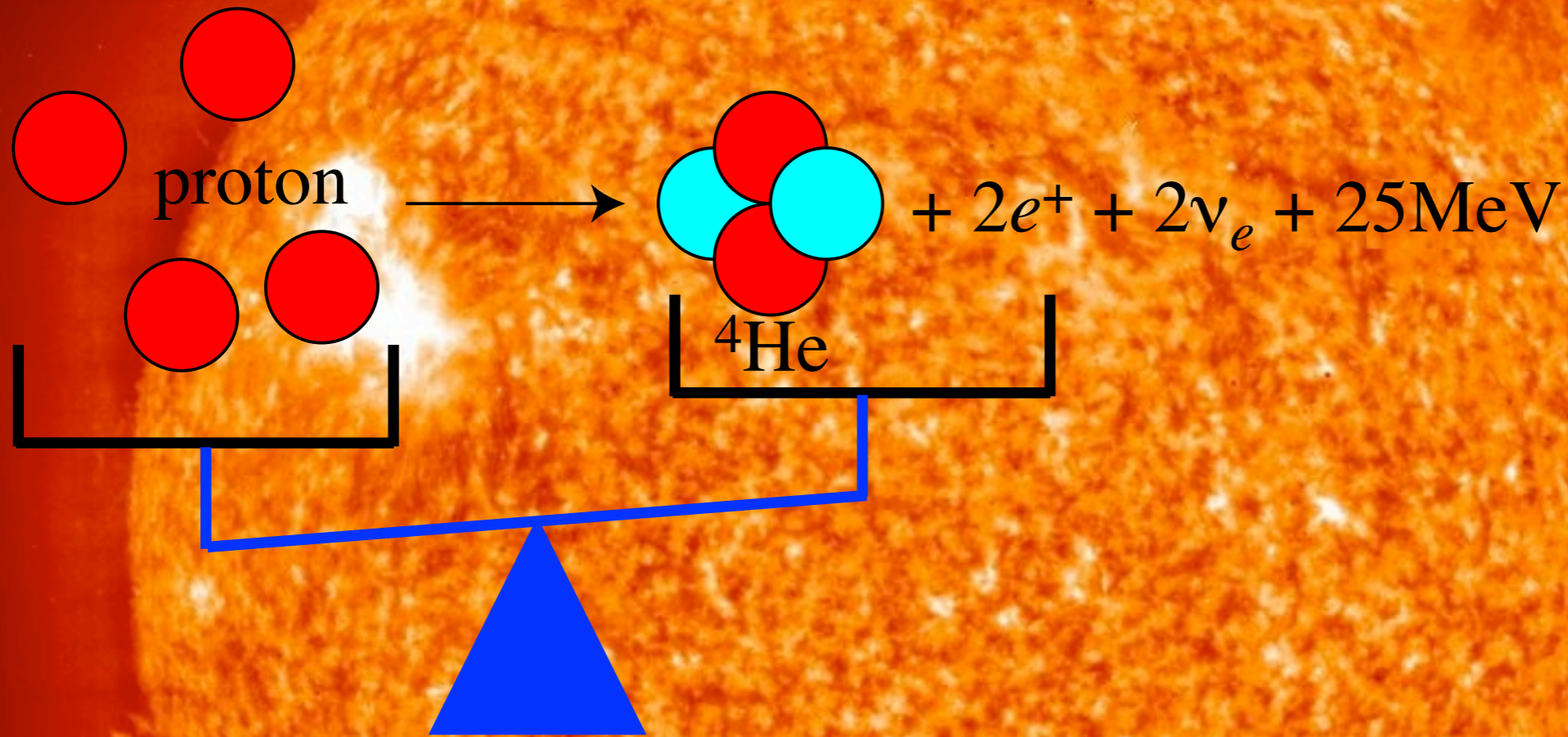
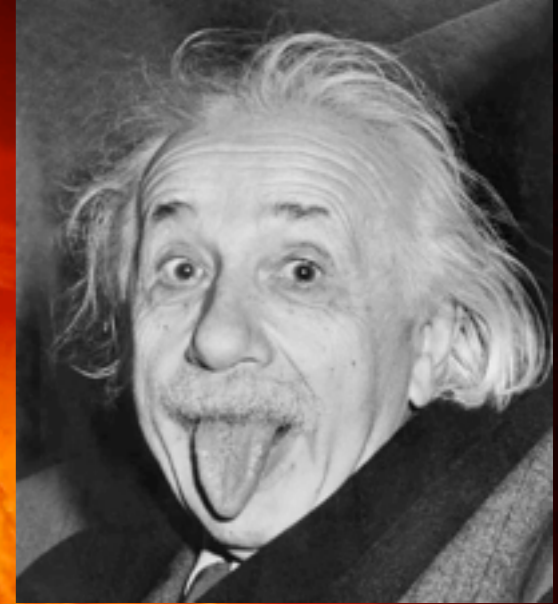
Lord Kelvin:
the Sun can't possibly
shine more than
20 thousand years



Darwin:
given geological
information and evolution
of life, it must be older
than 300 million years



burning atoms?

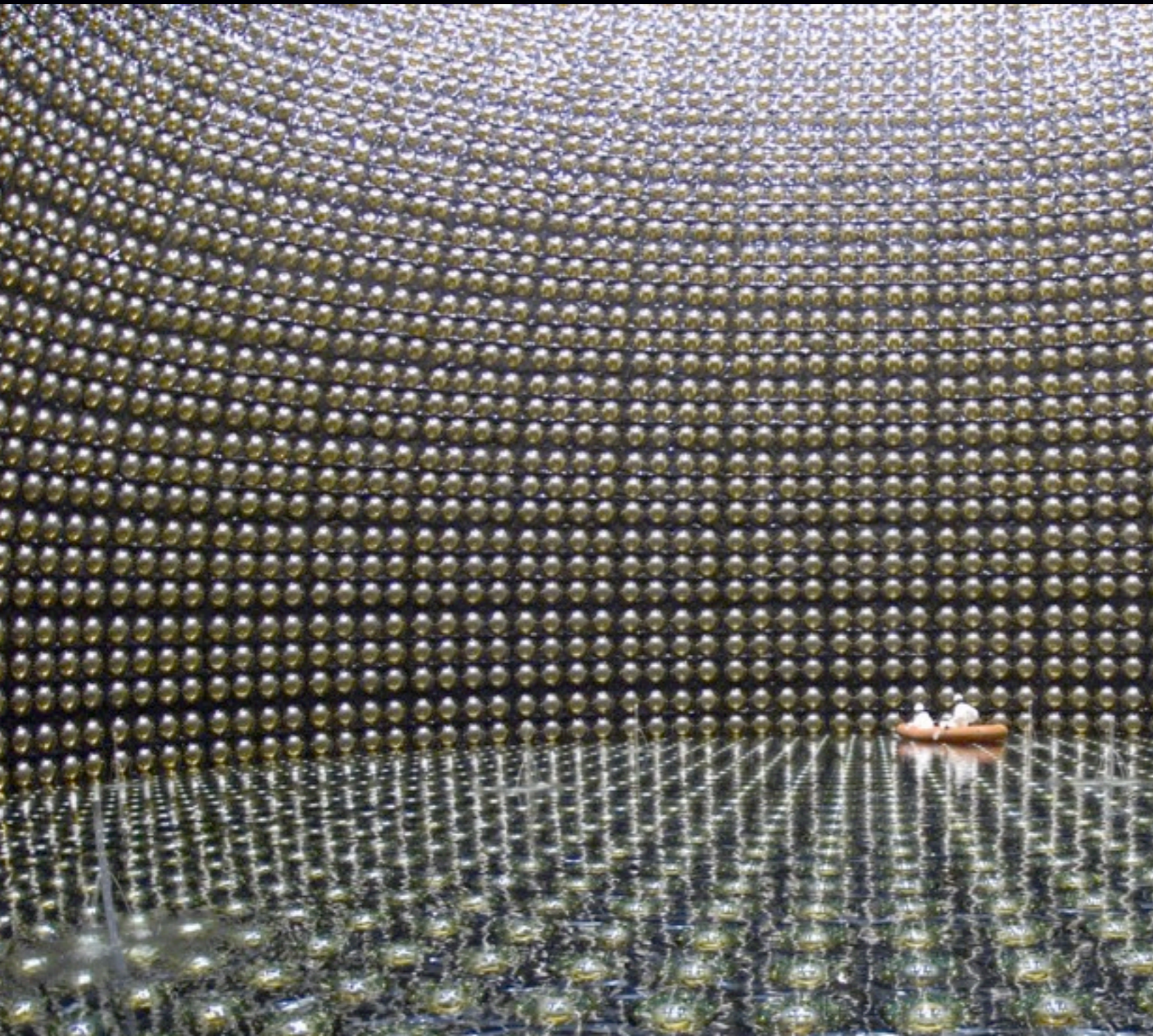


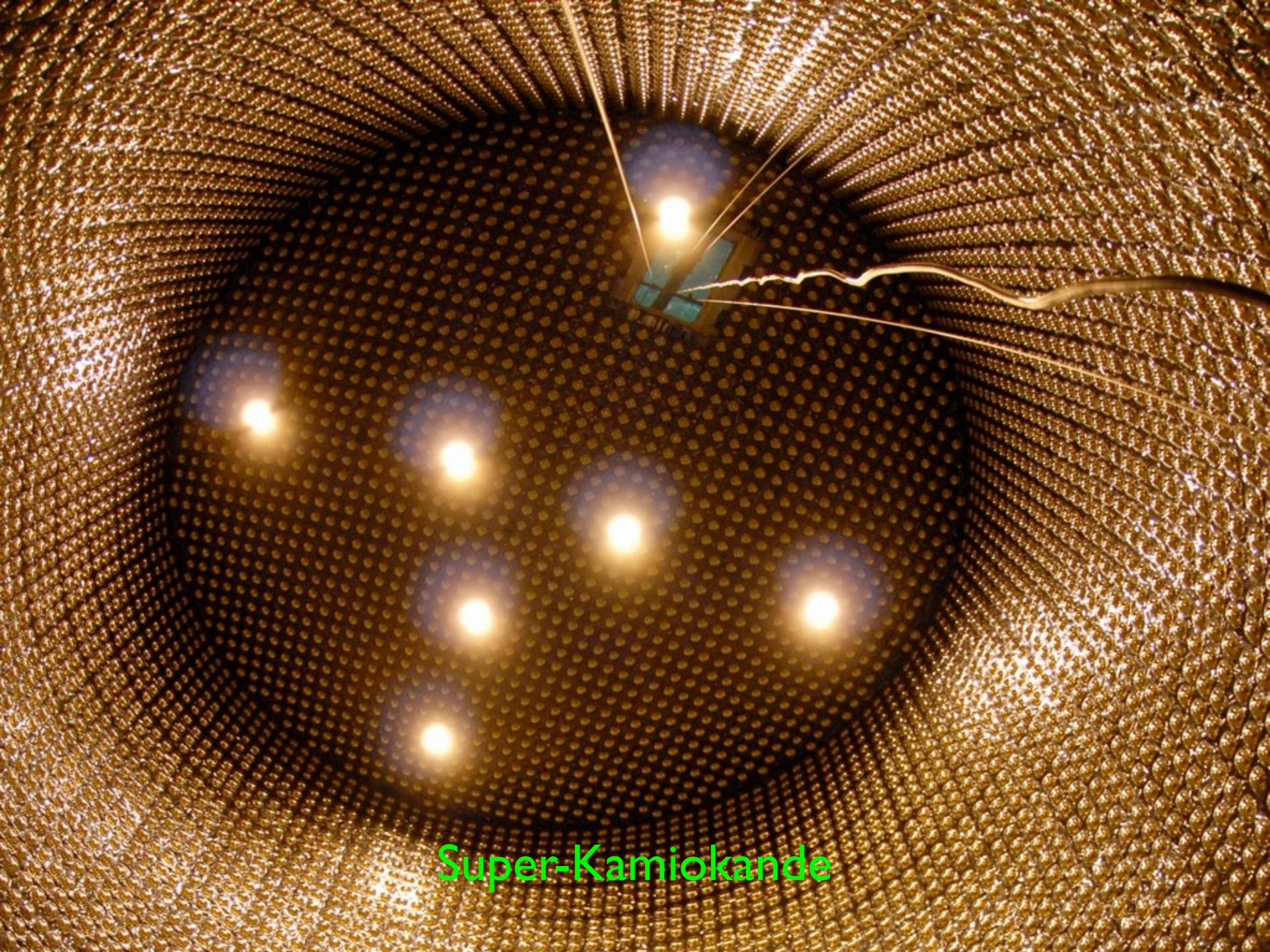
$$E=mc^2$$

the Sun is getting
lighter by
4 million tons
every second

a hundred trillion
neutrinos go through
our body every second

How to see invisible neutrons

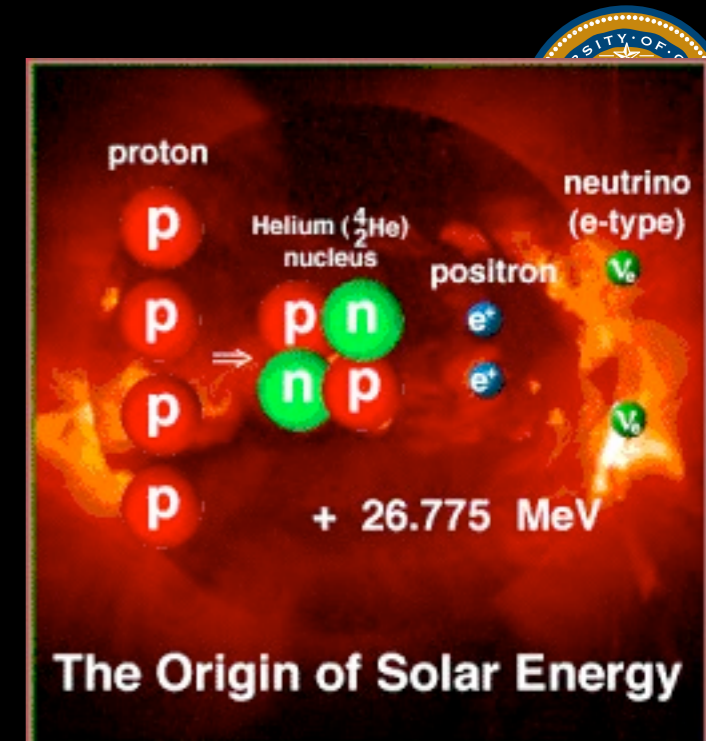




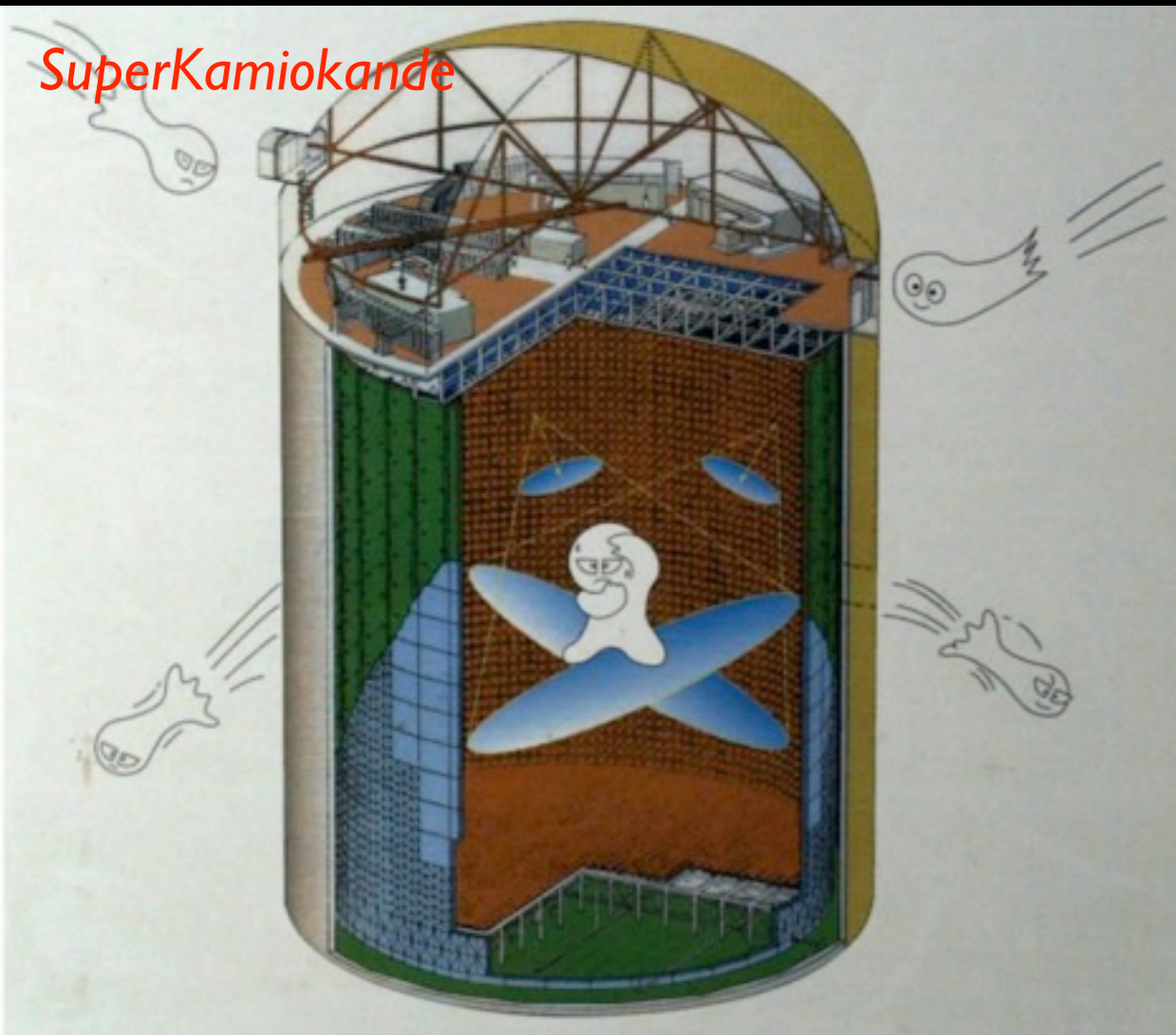
Super-Kamiokande

evidence

*burning atoms in the Sun produces neutrinos
trillions through our body every second*

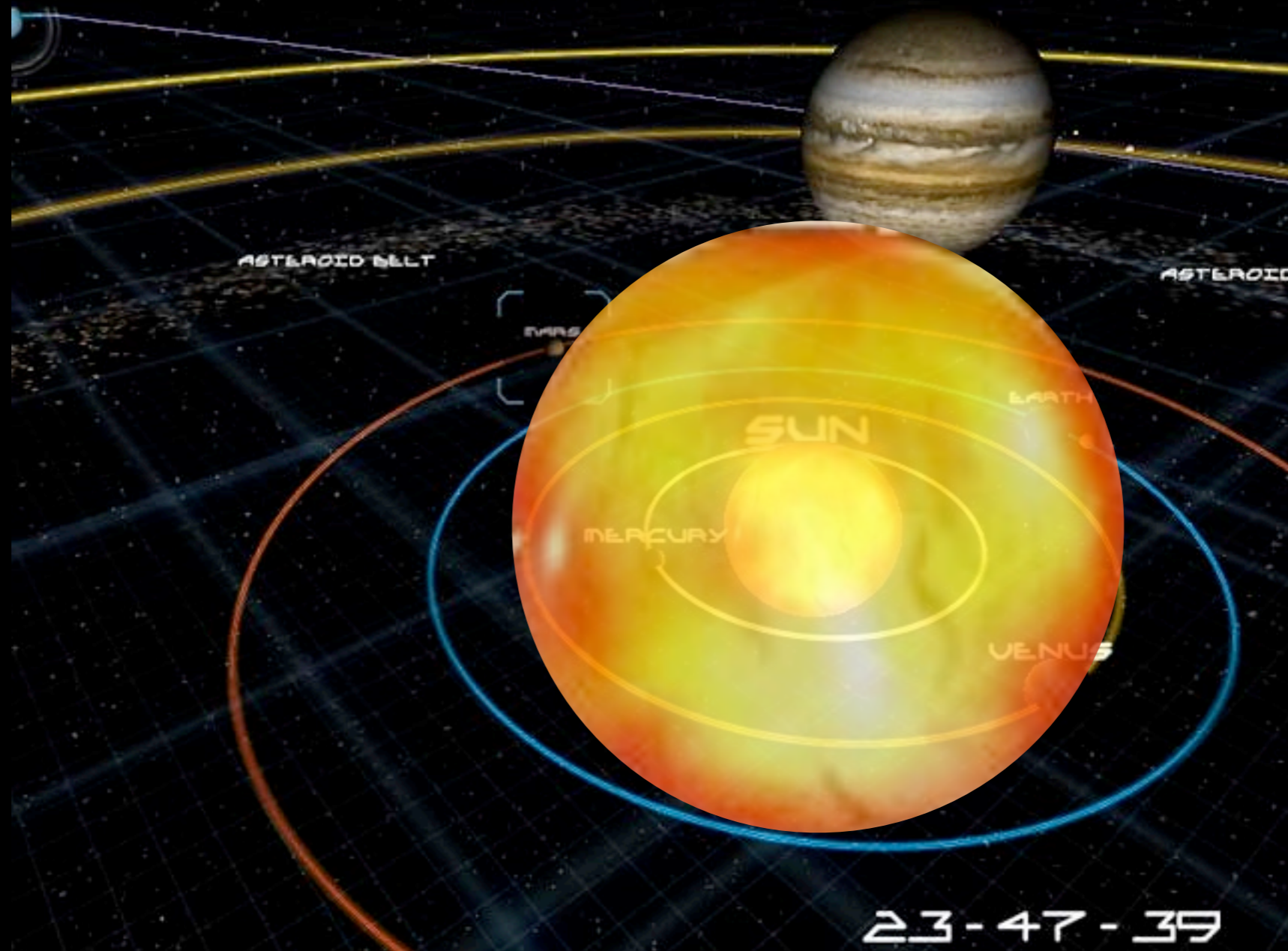


SuperKamiokande



*in pitch darkness
1 km underground*

fate of the Sun



宇宙戰艦

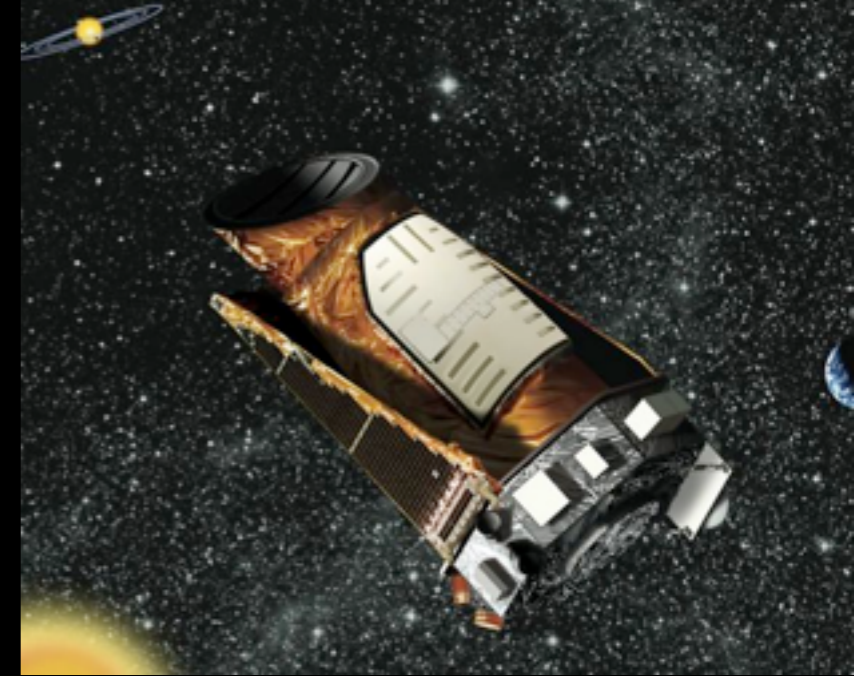
十勇士



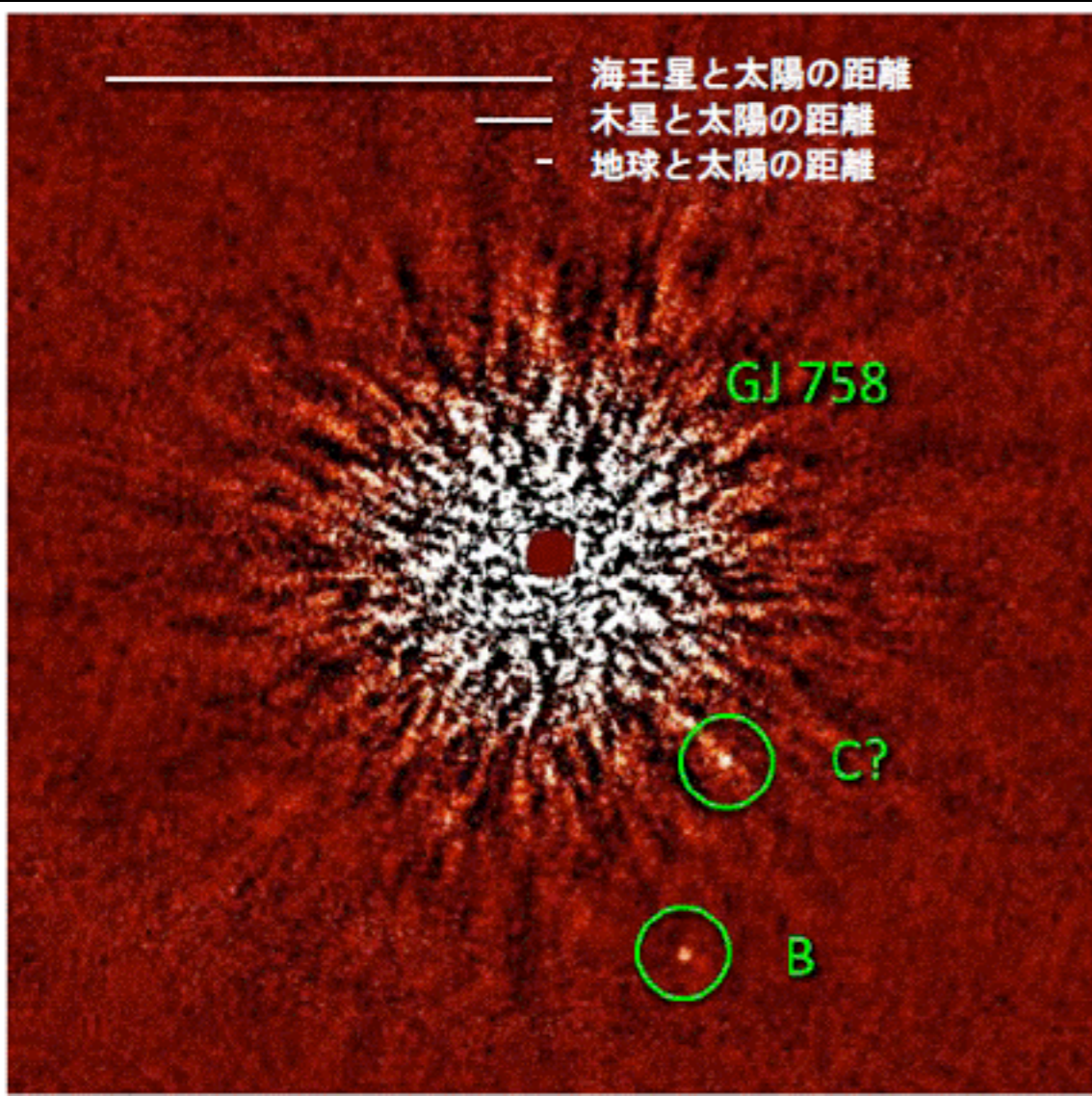
new stars are born



planets



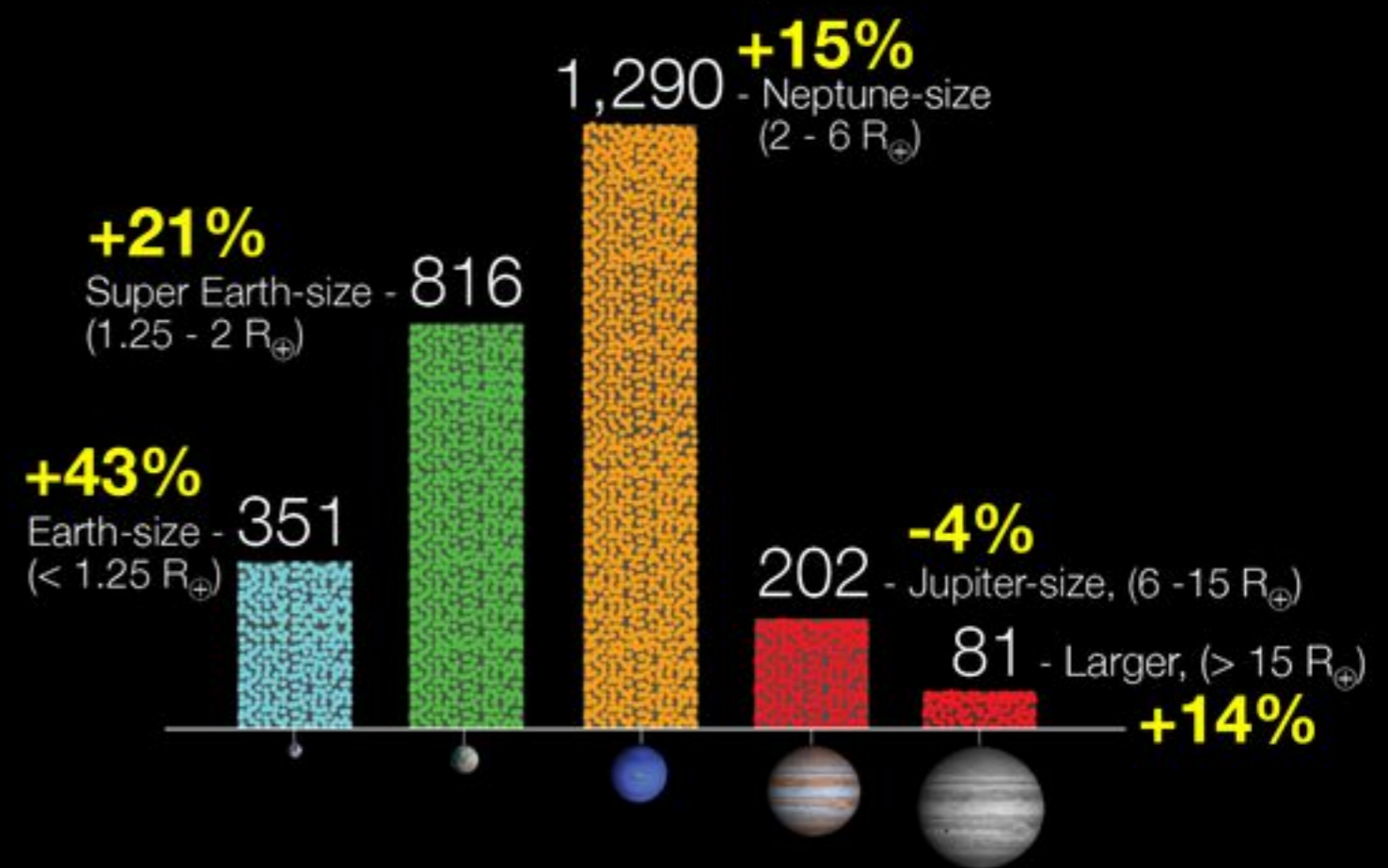
- more than 2000 candidate extrasolar



Kepler

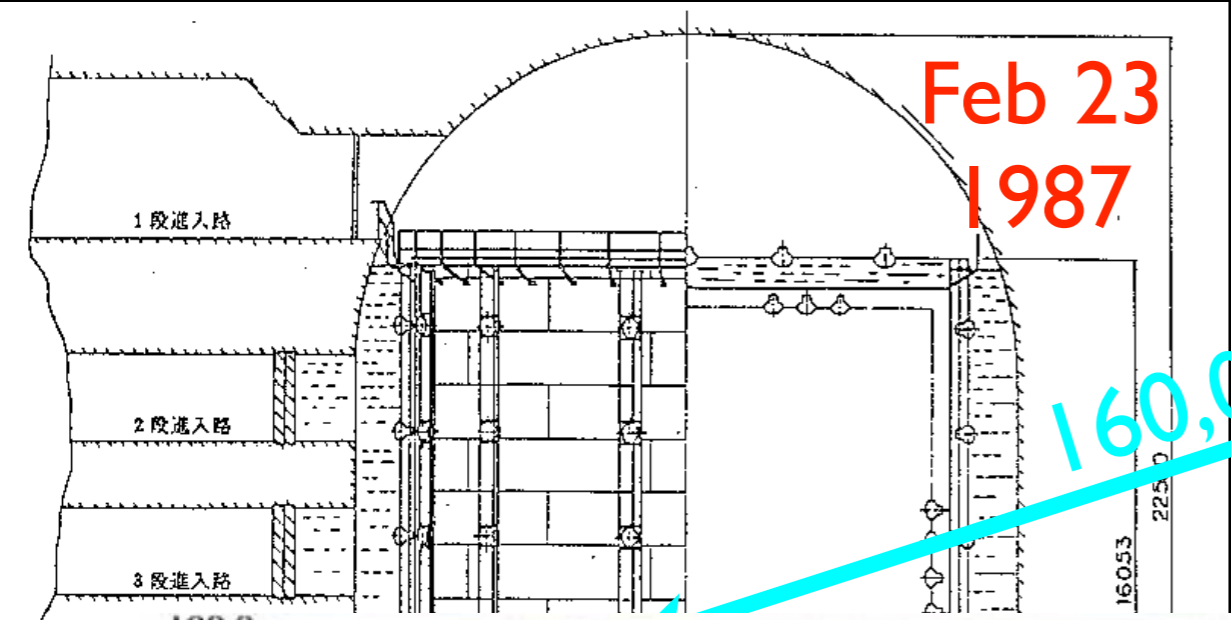
Sizes of Planet Candidates

As of January 7, 2013

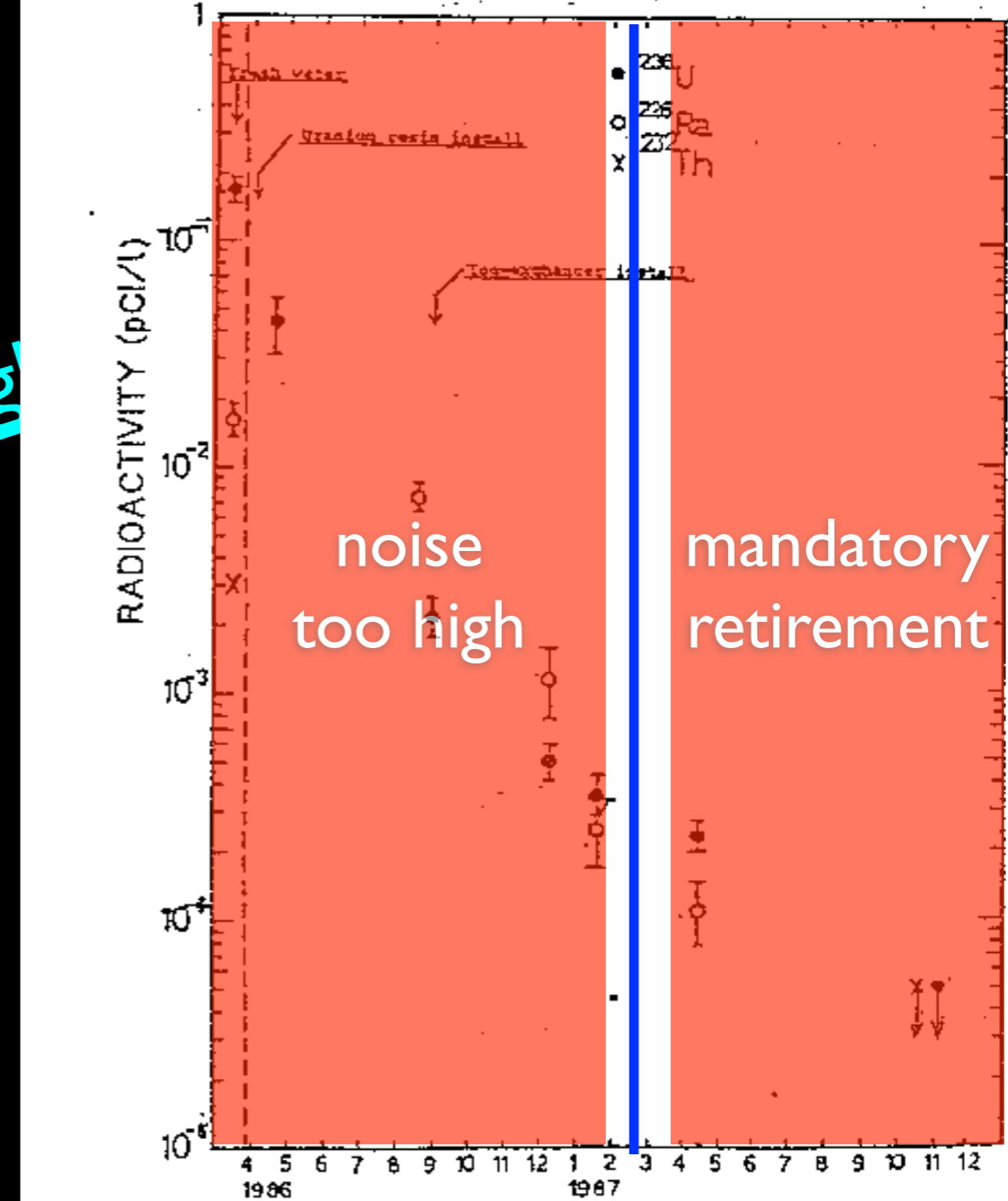
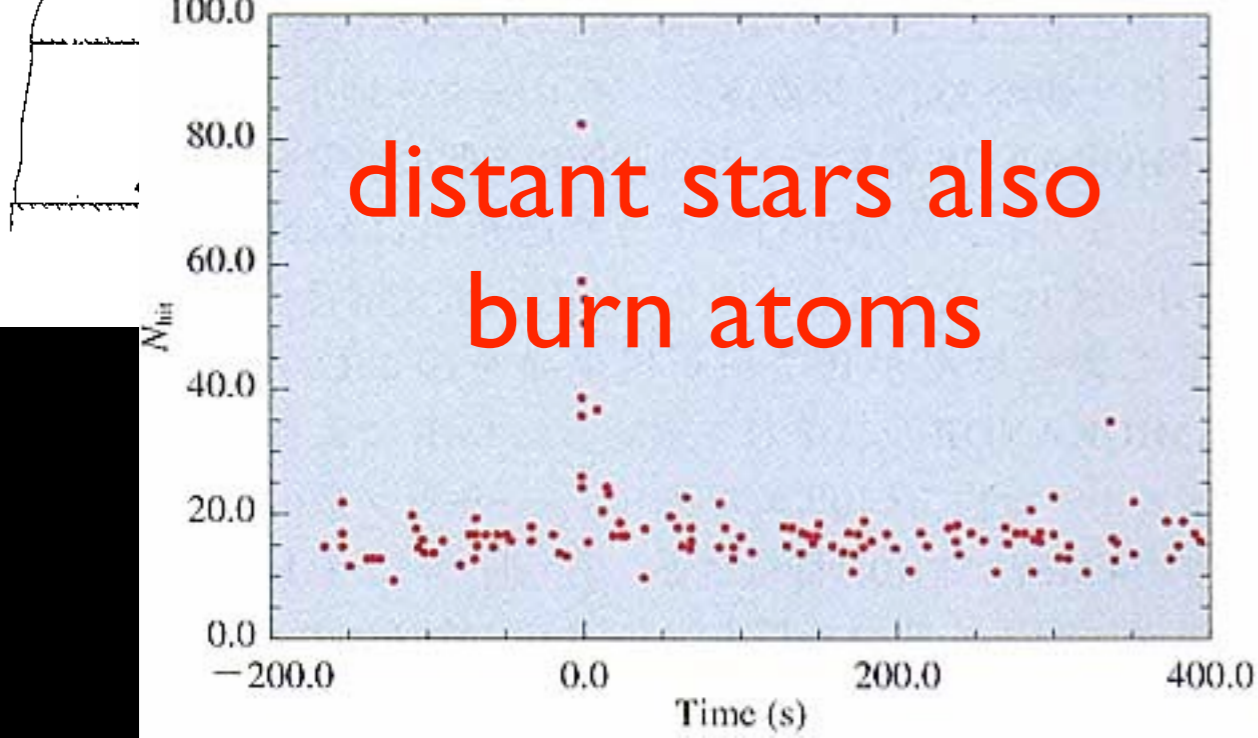




tremendous luck

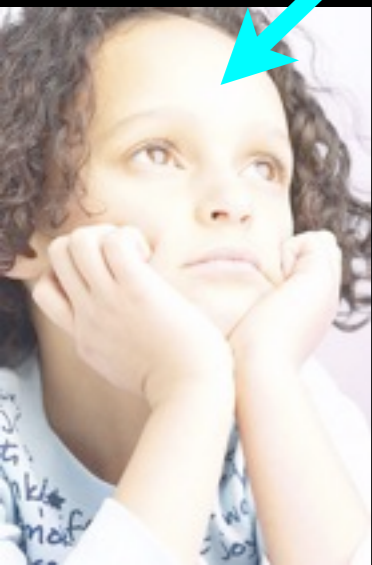


160,000 light



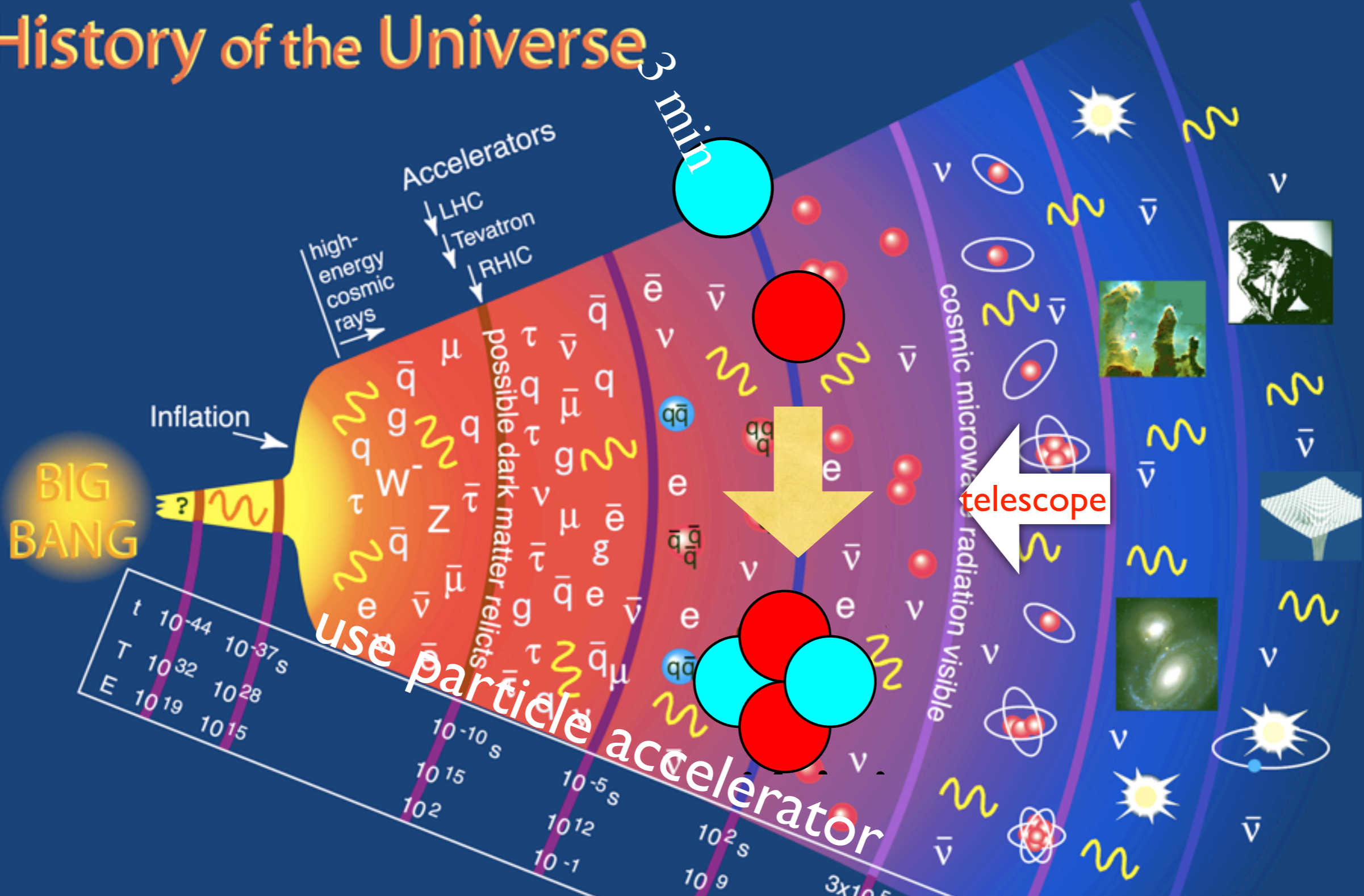
hydrogen
helium

carbon
nitrogen
oxygen
iron



We are star dust

History of the Universe



| | | |
|---|------------|--------------|
| t | 10^{-44} | 10^{-37} s |
| T | 10^{32} | 10^{28} |
| E | 10^{19} | 10^{15} |

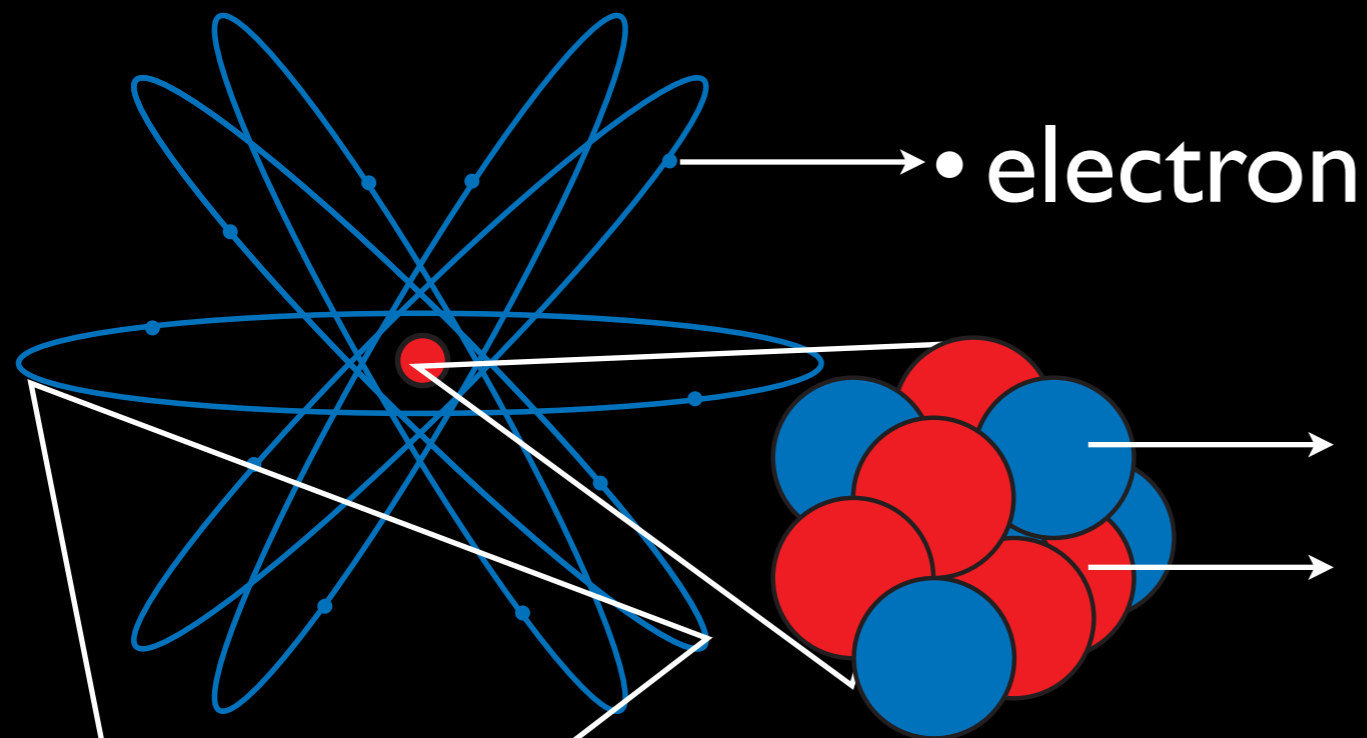
| | |
|--------------|-----------------|
| 10^{-10} s | 10^{-5} s |
| 10^{15} | 10^{12} |
| 10^2 | 10^{-1} |
| 10^2 s | 3×10^5 |

Key:

| | | | |
|----------------|--|------------|--|
| W, Z bosons | | photon | |
| q quark | | meson | |
| g gluon | | baryon | |
| e electron | | ion | |
| μ muon | | tau | |
| ν neutrino | | atom | |
| | | galaxy | |
| | | star | |
| | | black hole | |

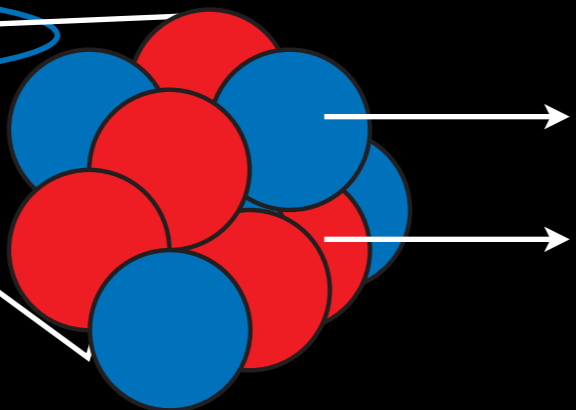
atoms built in Big Bang
 H:He ~ 3:1 in mass
 agrees well with observation!

atom



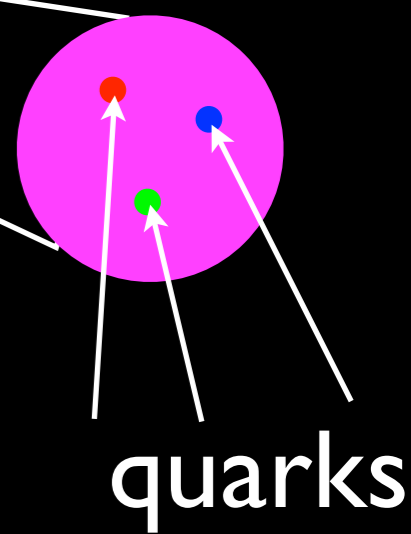
electron

Higgs boson



nucleus

neutron
proton



quarks



number of protons determines the chemical element

LHC

redo the Big Bang!





many accelerators
at hospitals

国内の陽子100 MeV超級イオン加速器

群馬大学重粒子線医学
研究センター
シンクロトロン(重イオン医療用)
(炭素400 MeV/u)

原研高崎研
K = 130 MeV サイクロトロン
(陽子90 MeV)

若狭湾エネルギー研究センター
180 MeV シンクロトロン(医療用)

大阪大学
K = 120 MeV サイクロトロン
(陽子90 MeV)
400 MeV リングサイクロトロン

兵庫県立粒子線医療センター
230 MeV シンクロトロン(医療用)

九州大学
150 MeV FFAG

九州国際重粒子線
がん治療センター
シンクロトロン (H25.4~)

メディオリス医学研究財団
250 MeV シンクロトロン
(医療用, H23.4~)

高エネルギー加速器研究機構
40 MeV リニアック
0.5 GeV シンクロトロン
12 GeV シンクロトロン

東北大学
K = 130 MeV サイクロトロン
(陽子90 MeV)

筑波大学
250 MeV シンクロトロン(医療用)

J-P ARK
400 MeV リニアック
3 GeV シンクロトロン
50 GeV シンクロトロン

国立がん研究センター
235 MeV シンクロトロン(医療用)

理化学研究所
K=540 MeV リングサイクロトロン
(陽子210 MeV)
RIBF リングサイクロトロン
(重イオン用:300 MeV/u)

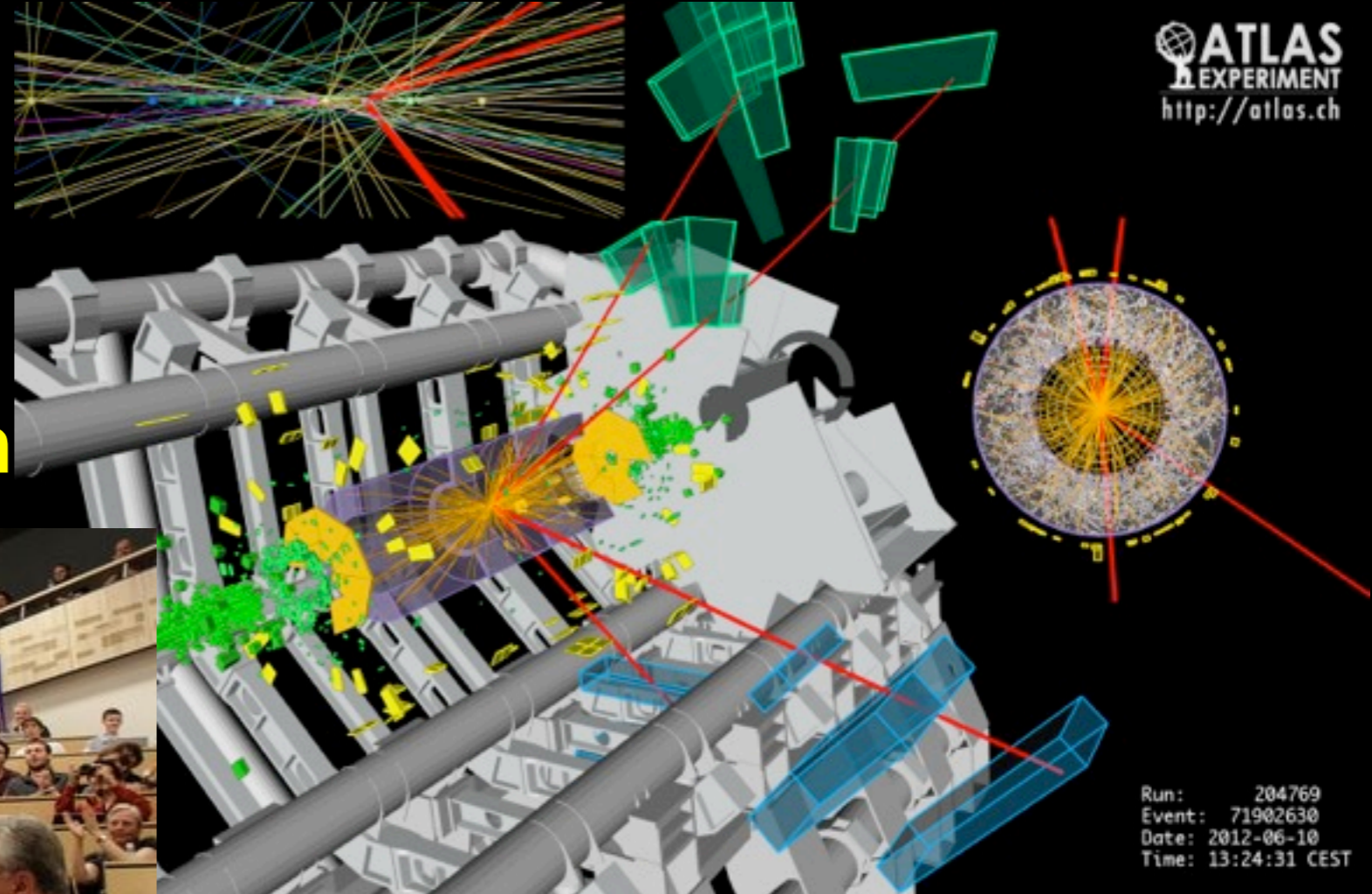
京都大学原子炉実験所
150 MeV FFAG

放射線医学総合研究所
シンクロトロン
シンクロトロン(重イオン医療用)
(800 MeV/u)

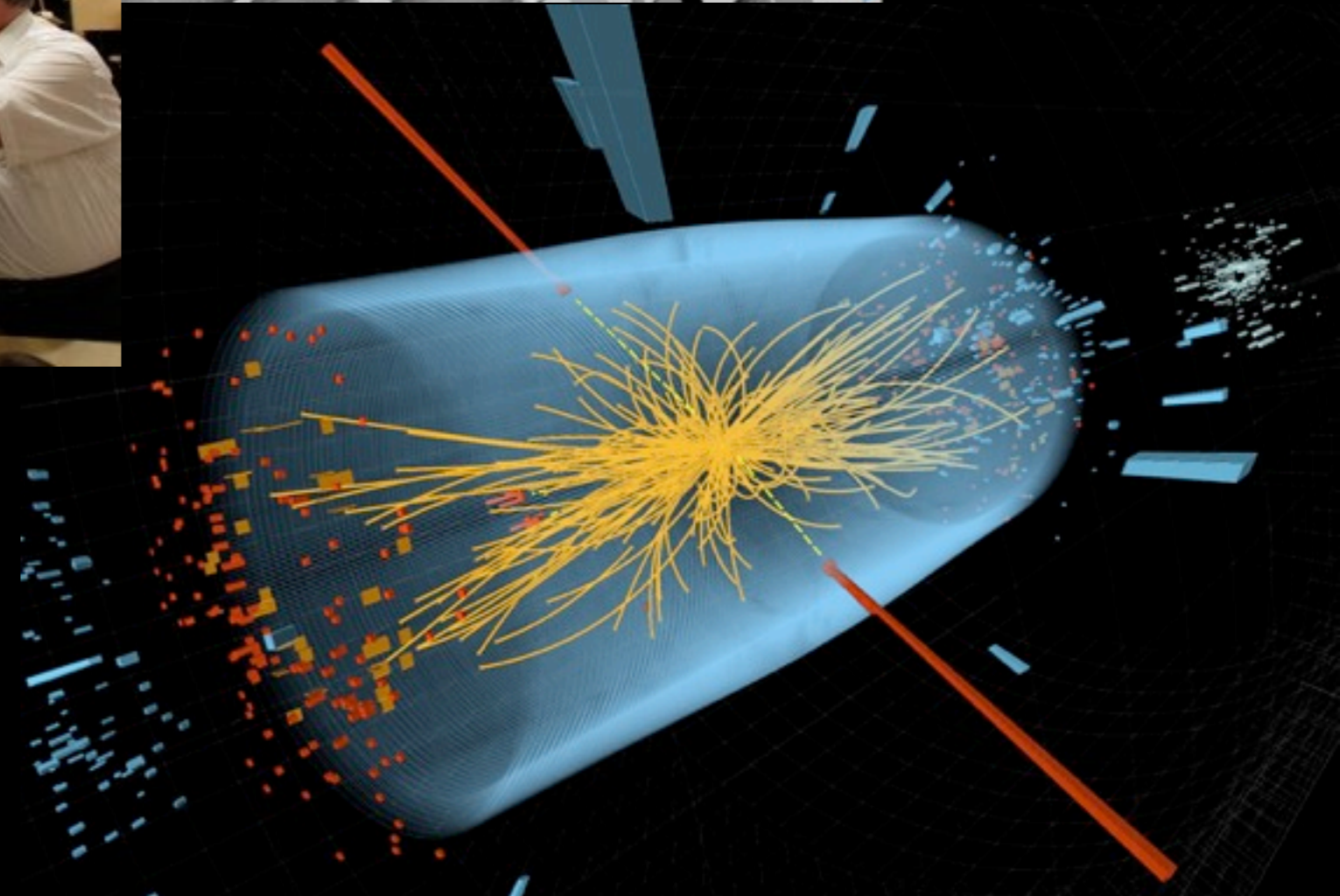
静岡県立静岡がんセンター
235 MeV シンクロトロン(医療用)

2012.7.4

discovery of Higgs boson



Run: 204769
Event: 71902630
Date: 2012-06-10
Time: 13:24:31 CEST

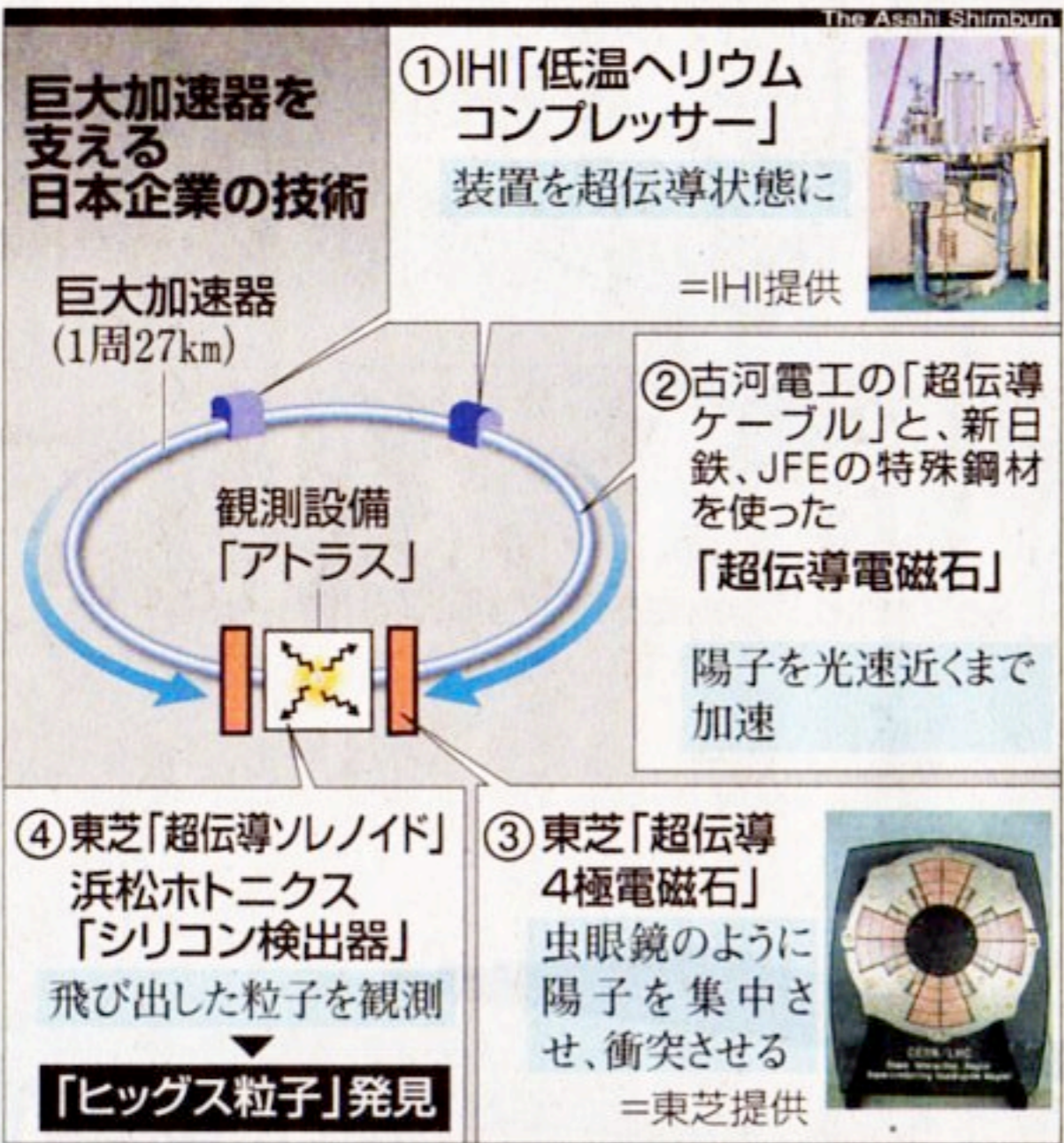


theory : 1964

design : 1984

construction : 2001

ヒッグス粒子研究に日本の技術



万物に質量（重さ）を与えるという「ヒッグス粒子」とみられる新粒子の発見。その舞台となった欧州合同原子核研究機関（CERN）の巨大加速器には、東芝や古河電工など日本企業の先端技術が詰め込まれている。世界的な発見は、日本の技術力なしでは実現しなかった。

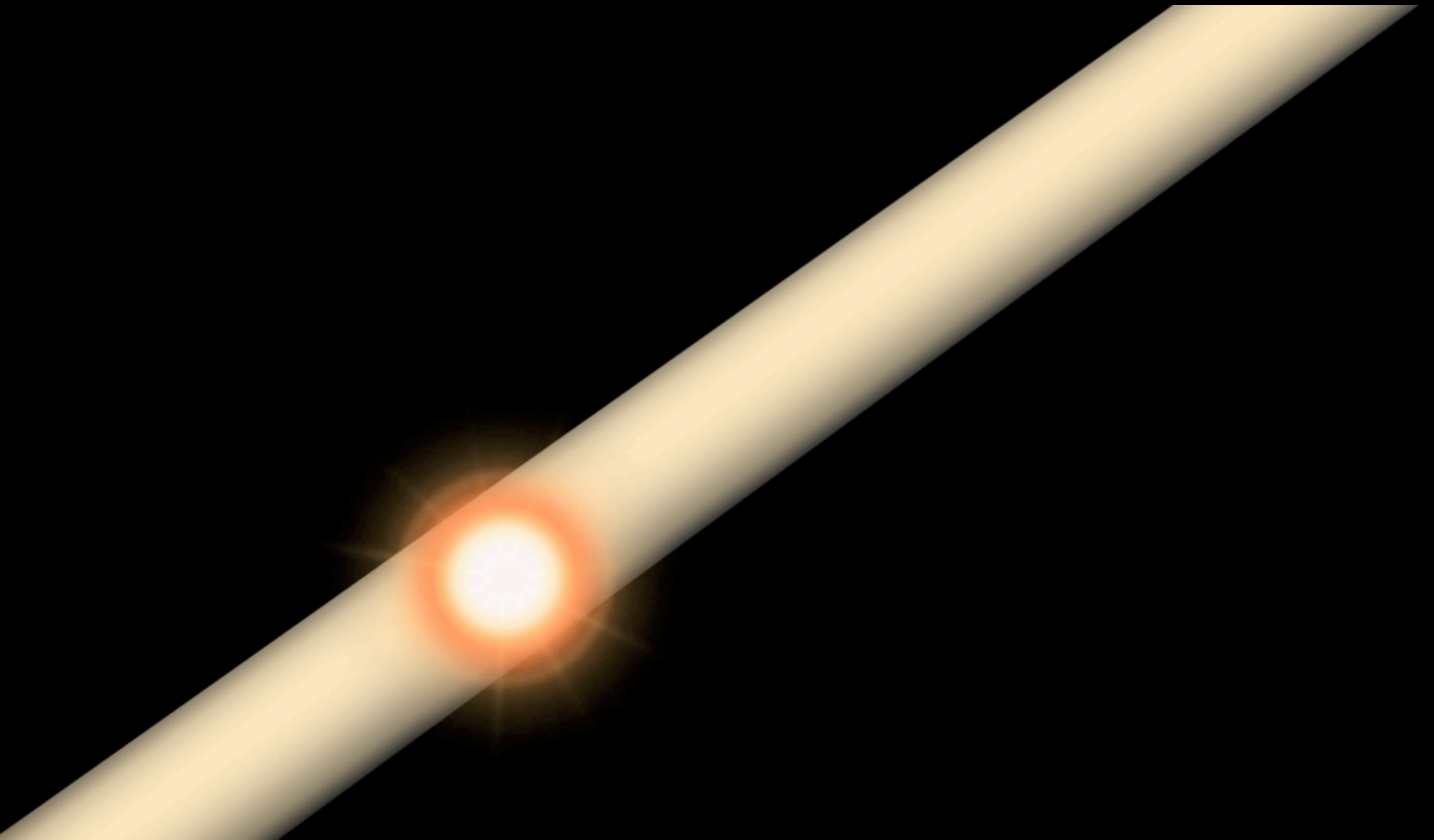
加速器は、陽子を光に近い速さにして衝突させる。すると、ヒッグス粒子が出現するという理屈だ。

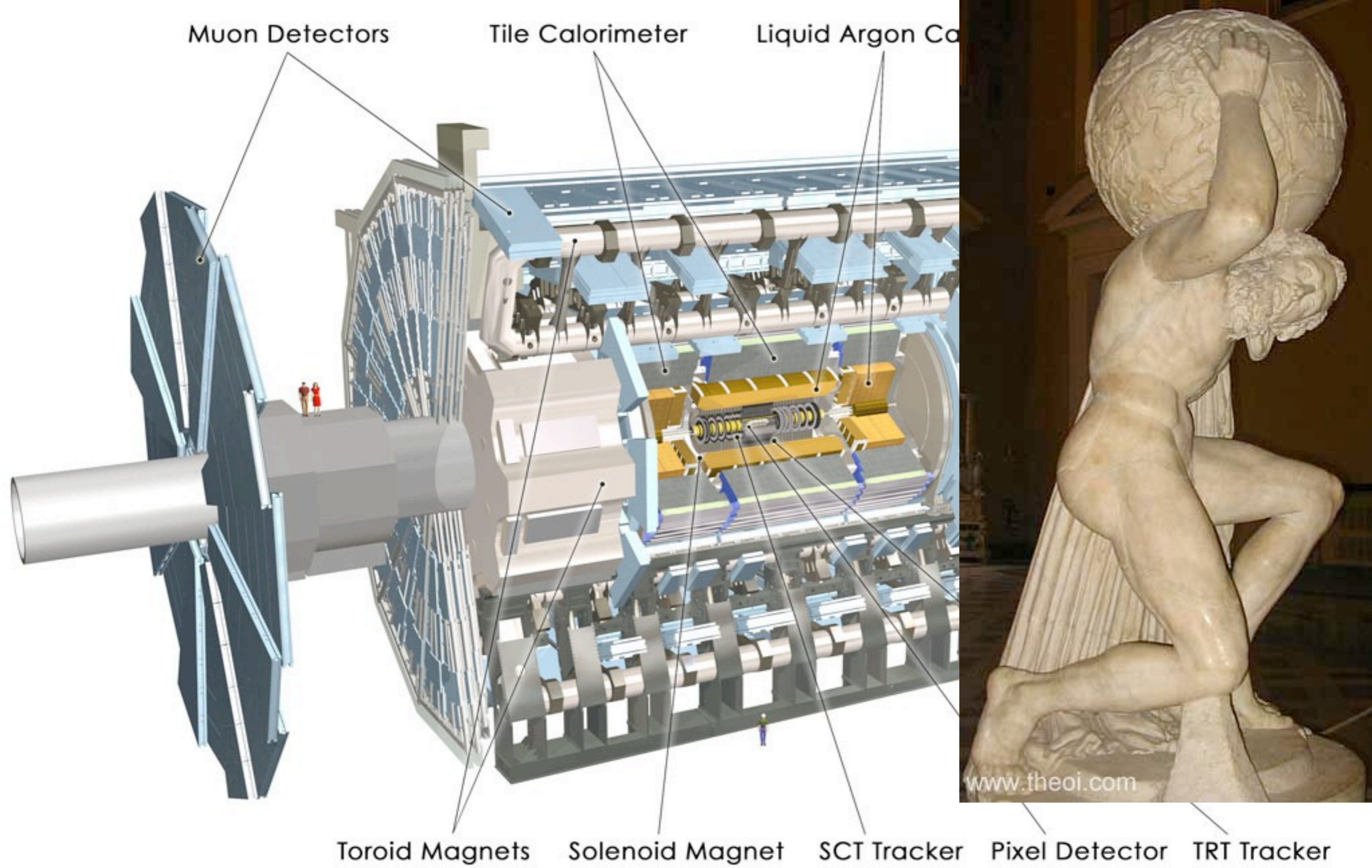
その衝突を実現するのが、東芝の「超伝導4極電磁石」だ。陽子に強い磁力を加え、虫眼鏡で光を集めるように絞り込み、陽子どうしを正確にぶつける。全長27キロという巨大な装置の心臓部といえる。

衝突で飛び出した粒子を観測するのが、観測設備「アトラス」。粒子に磁場をかけ、進む方向がどう変わるかで粒子の質量やスピンドを割り出す。この磁場をつくるのも東芝の装置

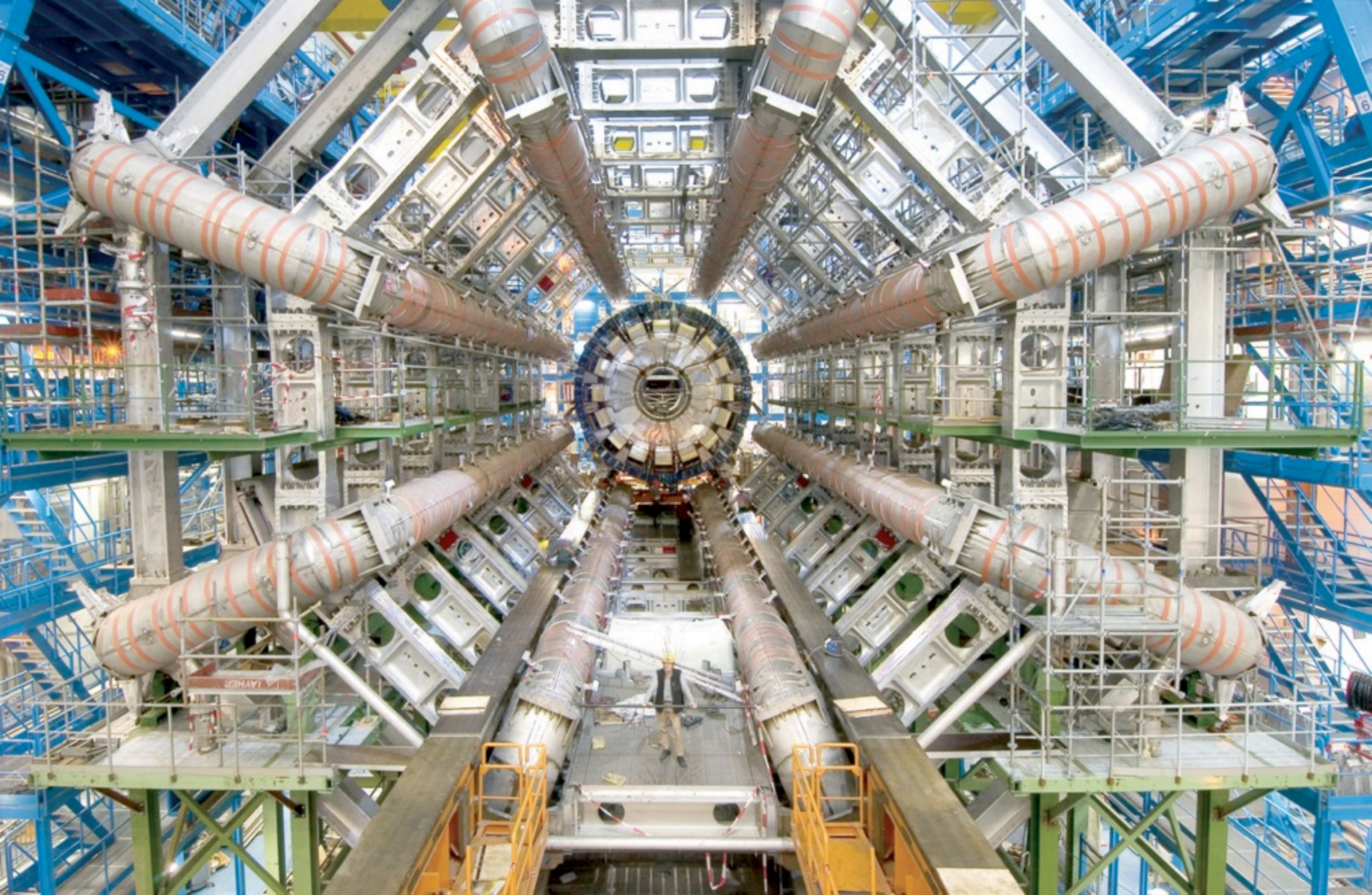
CERNの巨大加速器支える

conceived back in 1984





ATLAS detector



ATLAS detector



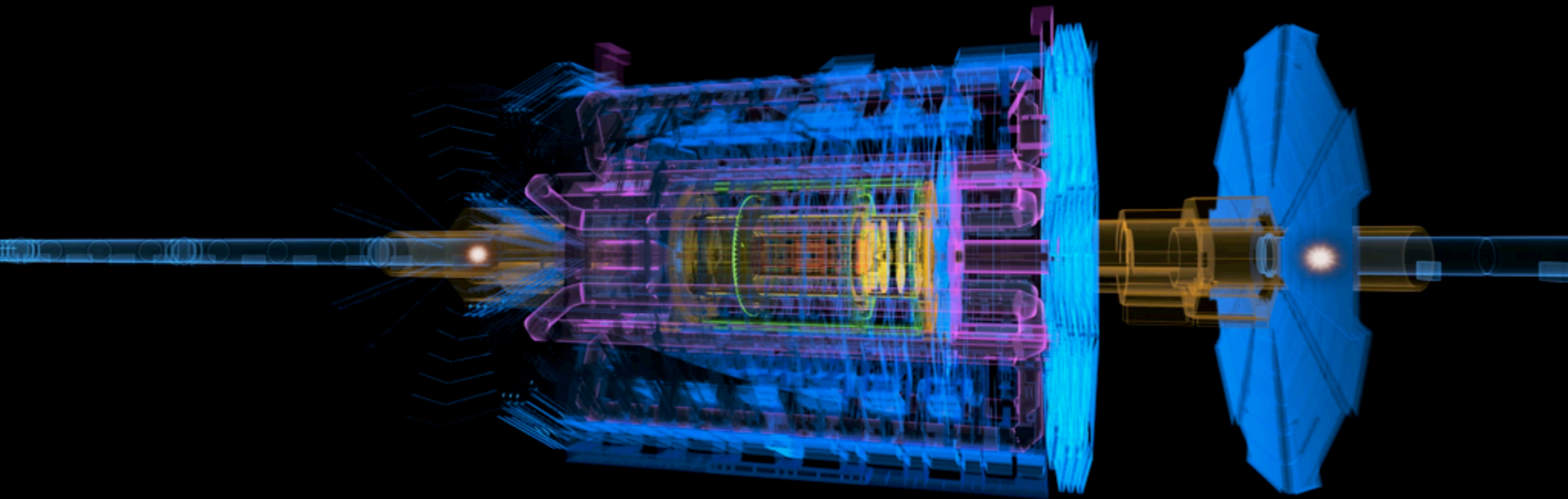
collision of protons

$Z \rightarrow \mu\mu$ event from 2012 data with 25 reconstructed vertices

$Z \rightarrow \mu\mu$

ATLAS experiment

look for tens of cases out of a quadrillion collisions

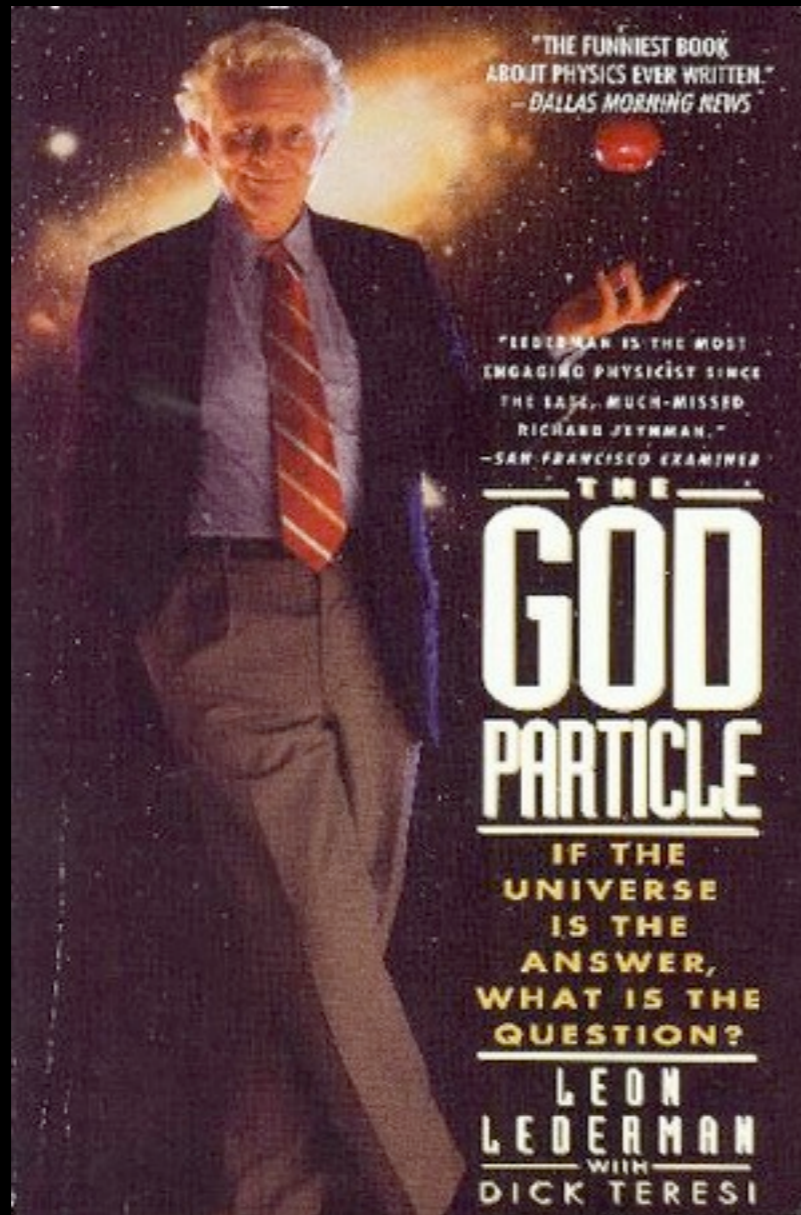


Peter Higgs blessing leader of the ATLAS group



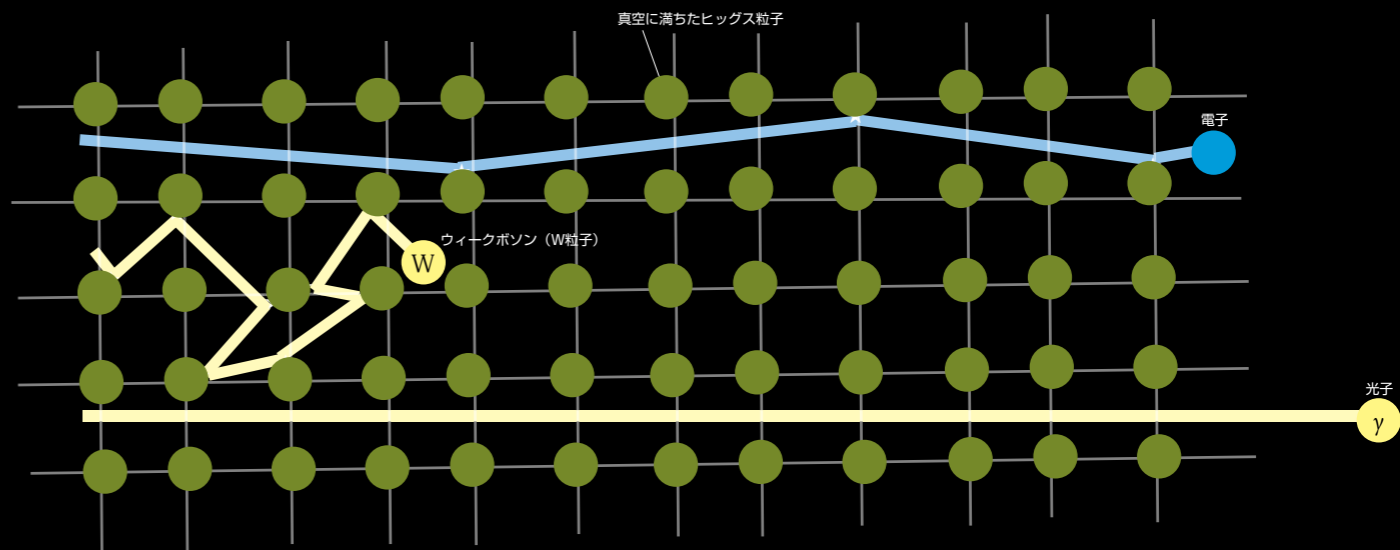
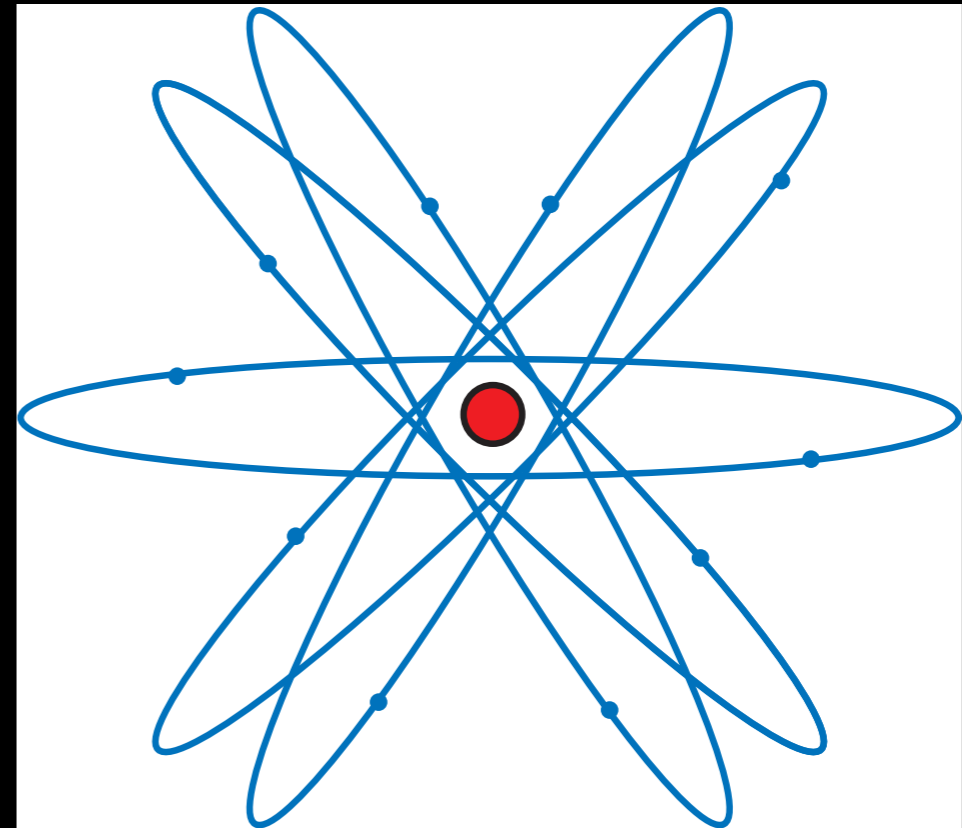
Fabiola Gianotti

God particle?

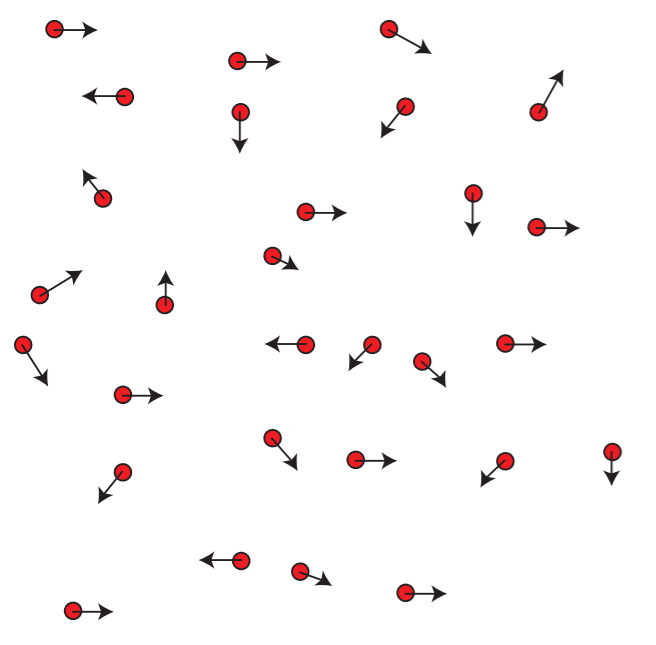


Goddamn particle!

Universe is filled with Higgs

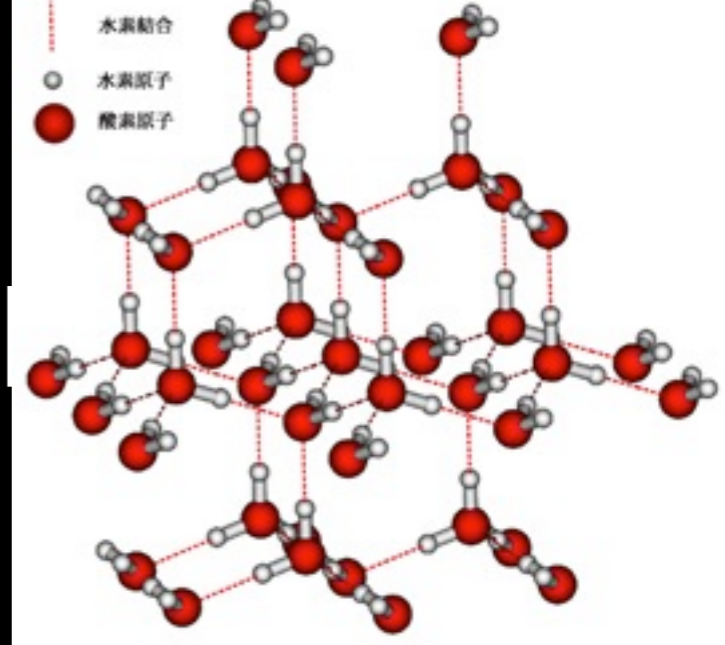


- Higgs bosons fill up space
- slows down every elementary particles from speed of light
- otherwise no atoms, no us!
- without it we evaporate in a nanosecond
- created *order* in the Universe
- our existence relies on it
- *What is it exactly??*
we got only started with this question



Universe got cooler

4 quadrillion degrees



disorder

⇒

order

Why don't we notice?

- just like the air
- ancient people didn't know that we live in the air
- flow = wind makes us notice something is there
- but can't make the Higgs bosons flow because they are frozen rigidly
- the only way: strike it hard to take one out

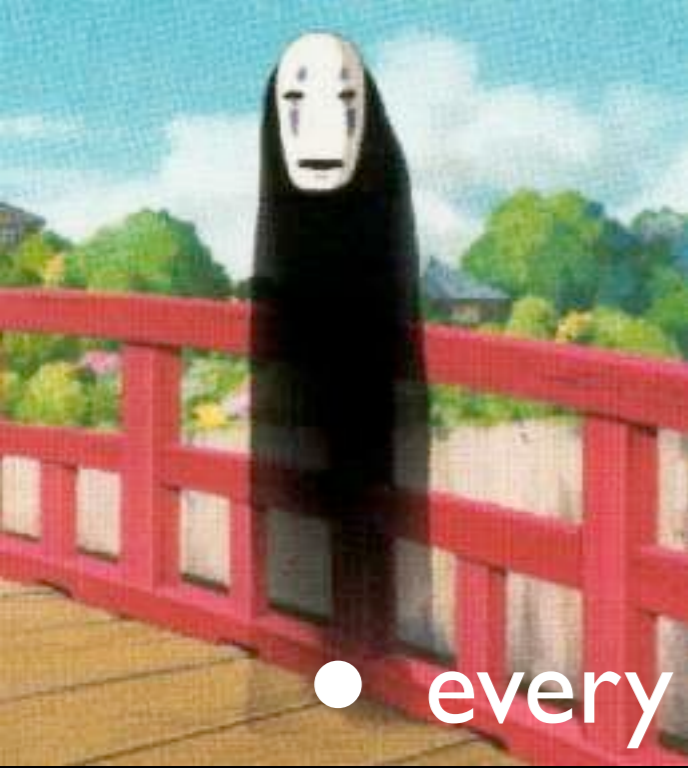




atoms

electrons

nuclei

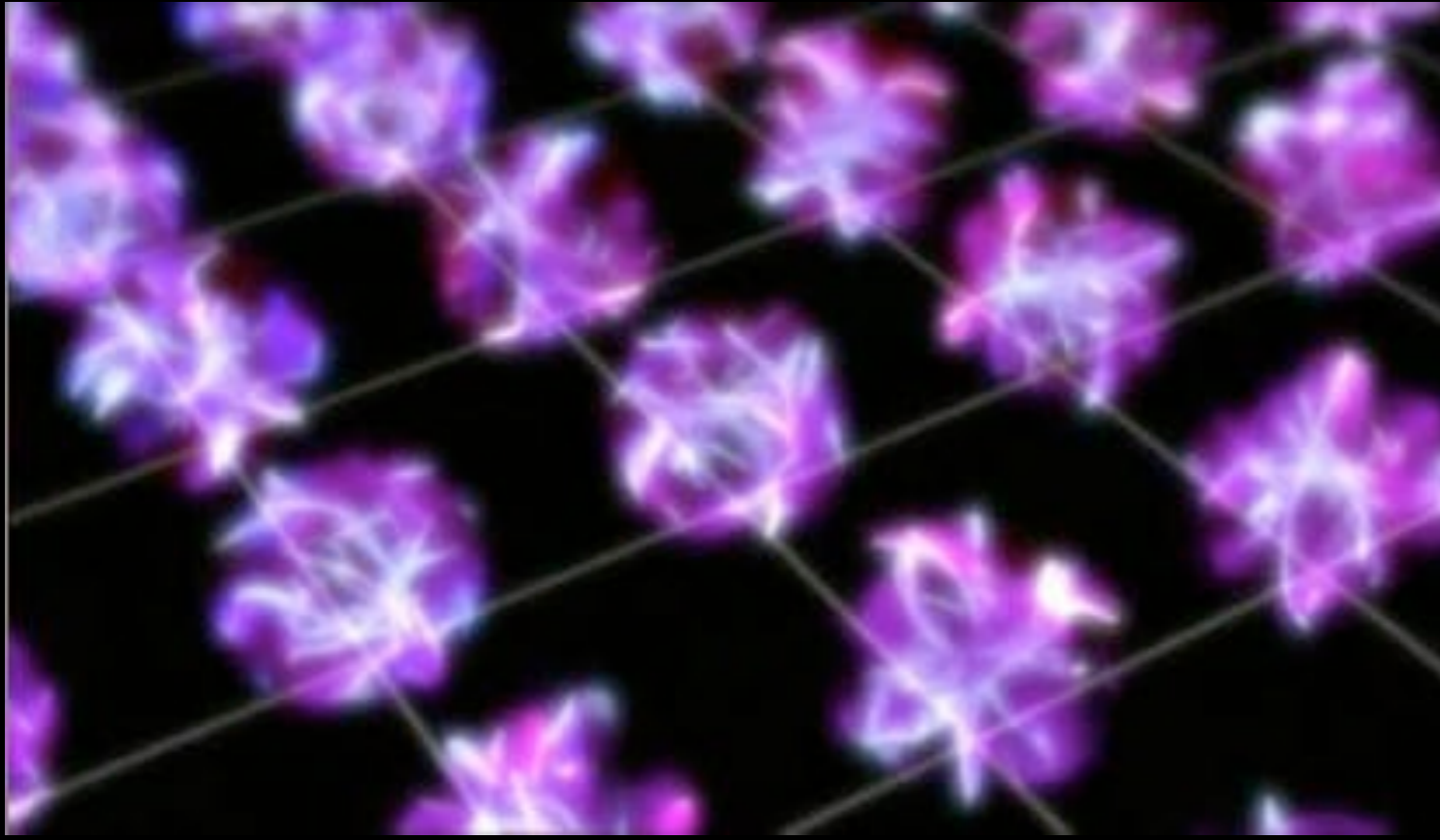


Spin

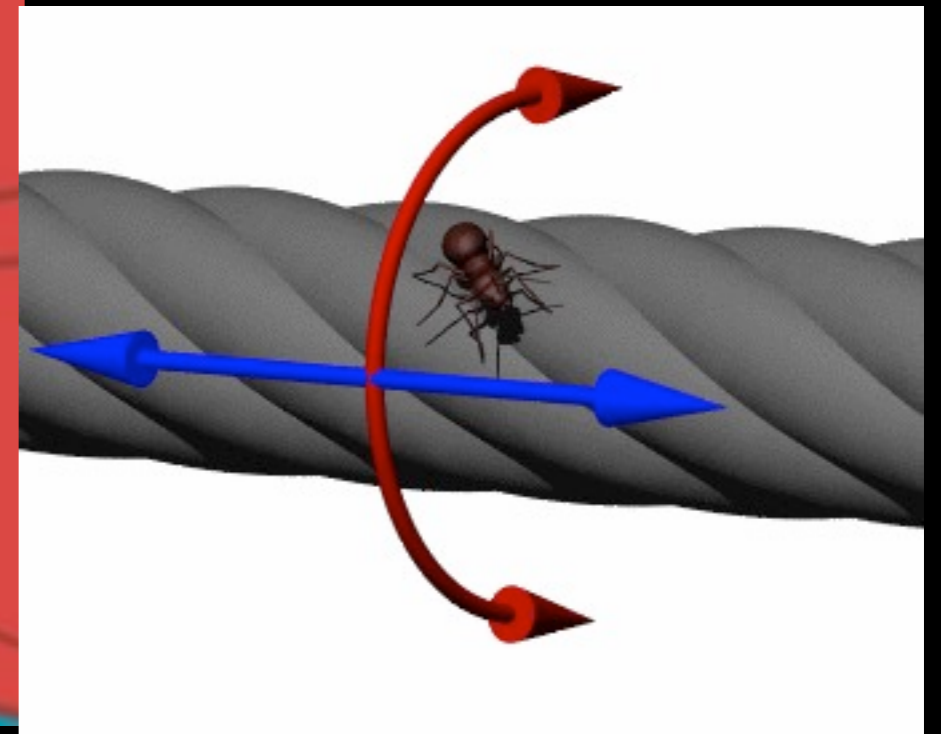
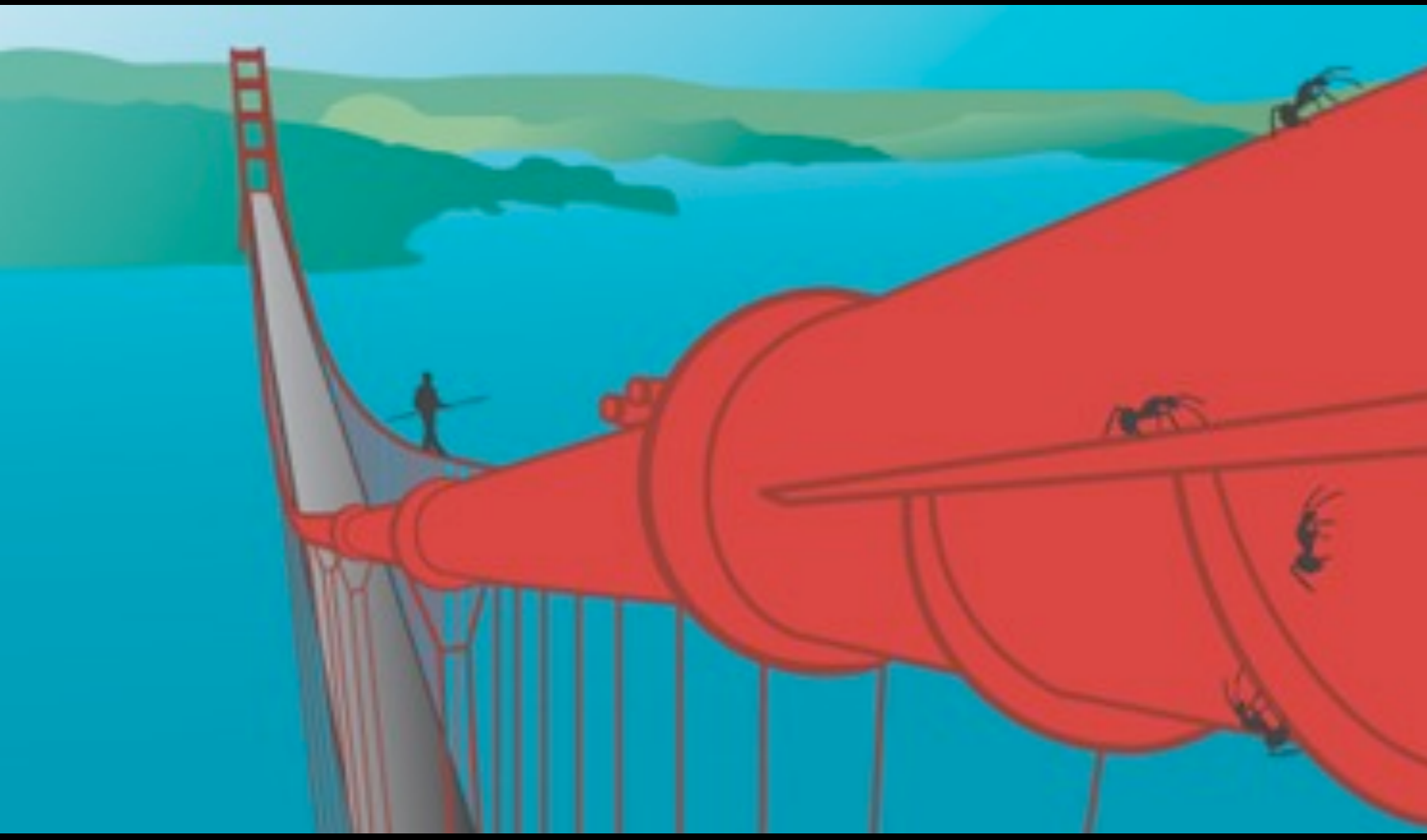


- every elementary particles spin forever
- electrons, photons, quarks, ...
- only Higgs boson doesn't spin
- faceless!
- I had proposed “Higgsless theories”
- spooky particle
- does it have siblings? relatives?
- maybe composite?
- why did it freeze in?





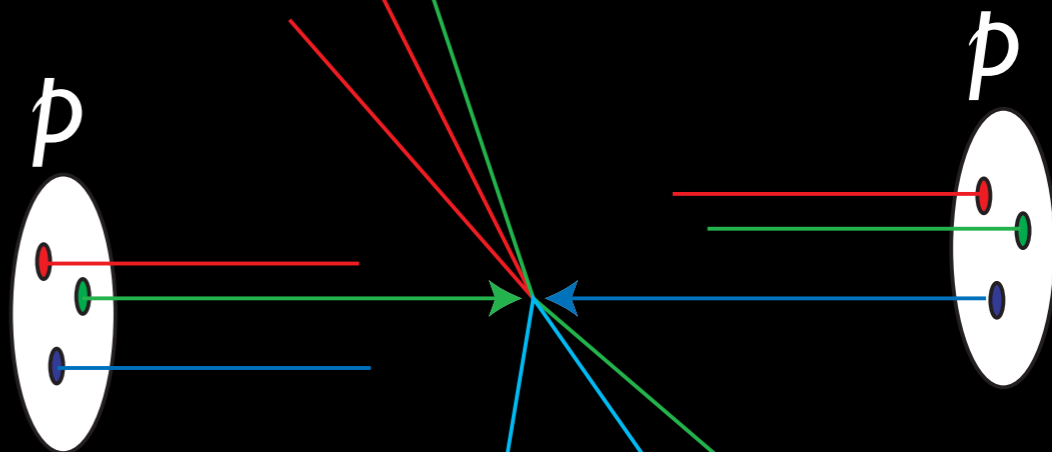
maybe Higgs boson
spins in extra
dimensions of space?



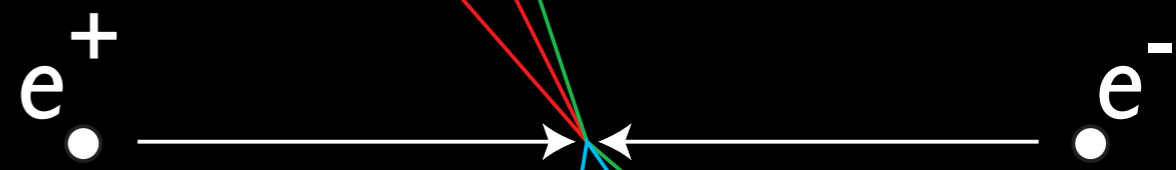


- elementary particles
- well-defined energy, angular momentum
- uses its full energy
- can produce particles democratically
- can capture nearly full information

LHC



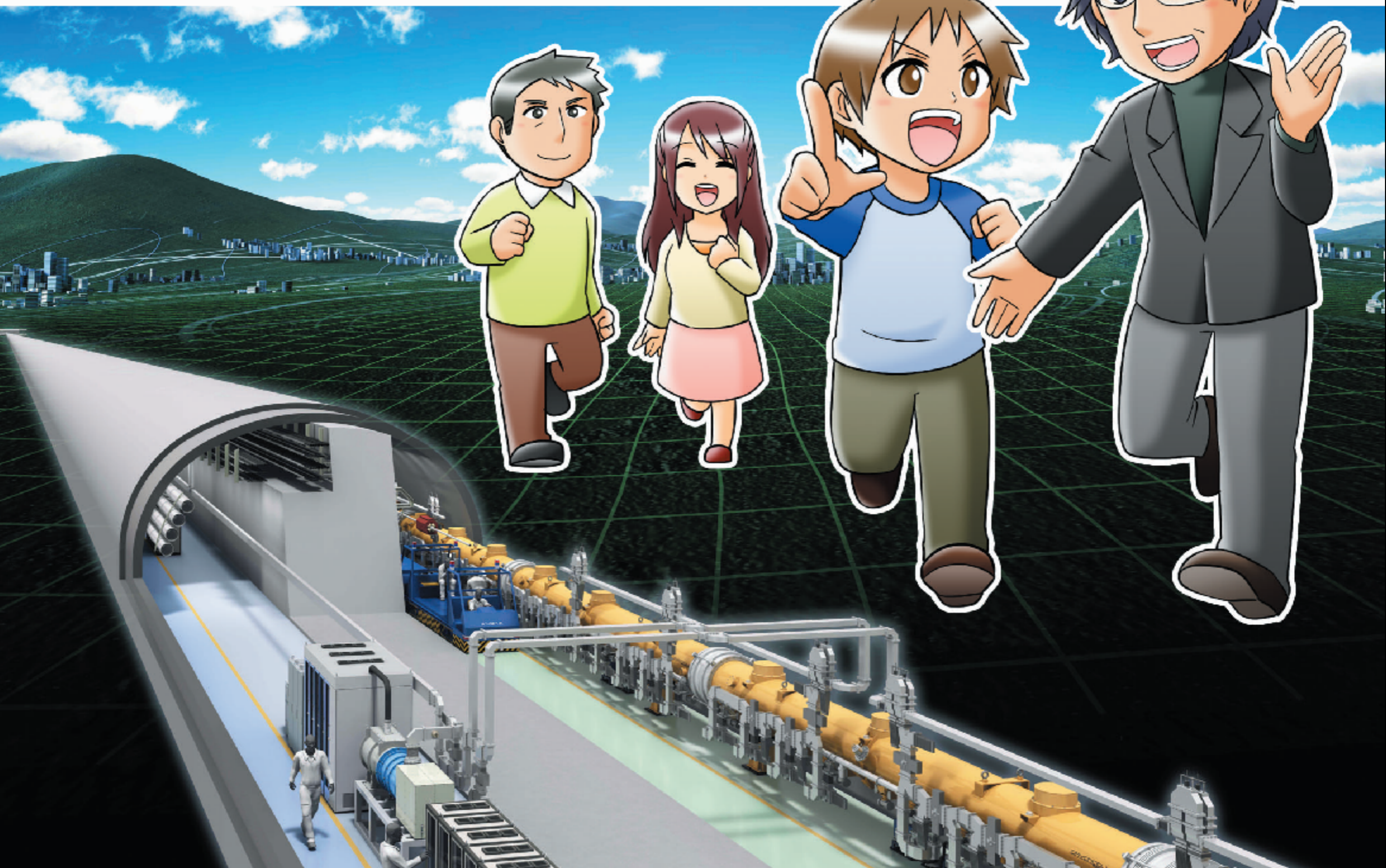
ILC



企画 大学共同利用機関法人 高エネルギー加速器研究機構

監修 村山 斉 (カリフォルニア大バークレイ教授、東大カブリ数物連携宇宙研究機構 機構長、
リニアコライダー・コラボレーション副ディレクター)

制作 うるのクリエイティブ事務所





そのヨーロッパの
加速器じゃダメなのか？



それは……



……陽子がこのチェリーパイ
だとすると……

……中のサクランボが
素粒子……



我々は、この素粒子=サクランボ
同士がぶつかったときに何が起こ
るのかを知りたい……

そこで……



ぶつけるっ!!

やっ

どっせい!!



わああああ!!

……でもチェリーパイをぶつけると、パイ皮とかジャムとか余計なものまで飛び散ってしまうんですよねえ。

この状態の中からサクランボ同士のぶつかり方だけをチェックするのがLHCの方法なんだけど……

むちゃくちゃ大変だな……

フ～か散らかさなつ!!

そう！ それでILCなんです！
ILCは陽子じゃなくて電子と陽電子という一番小さい素粒子を使う加速器だから、余計なモノを散らかさないでサクランボとサクランボをぶつけられるわけです！

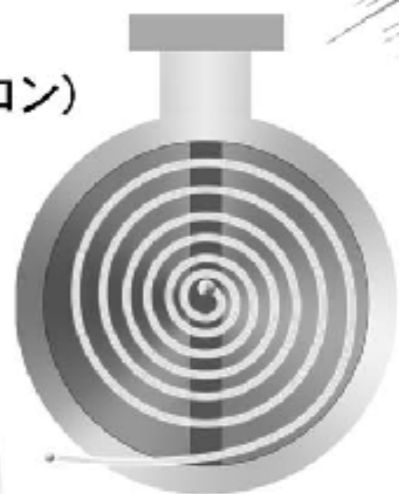
……とにかく散らかさないで。

でも、なんでILCは真っ直ぐなんだ？
セルンの加速器とかは丸いのに……

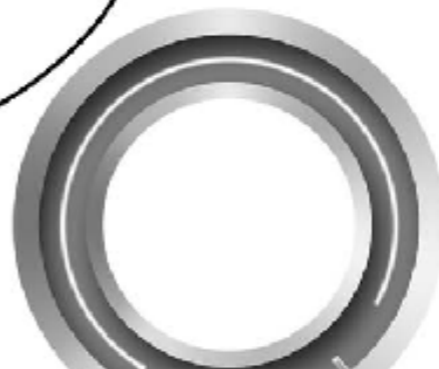
おっ、いい質問ですねっ！

円形加速器は、円周上をグルグルと周回させることで長い加速距離を得られるのですが、そのためには粒子を曲げて飛ばさなければなりません。

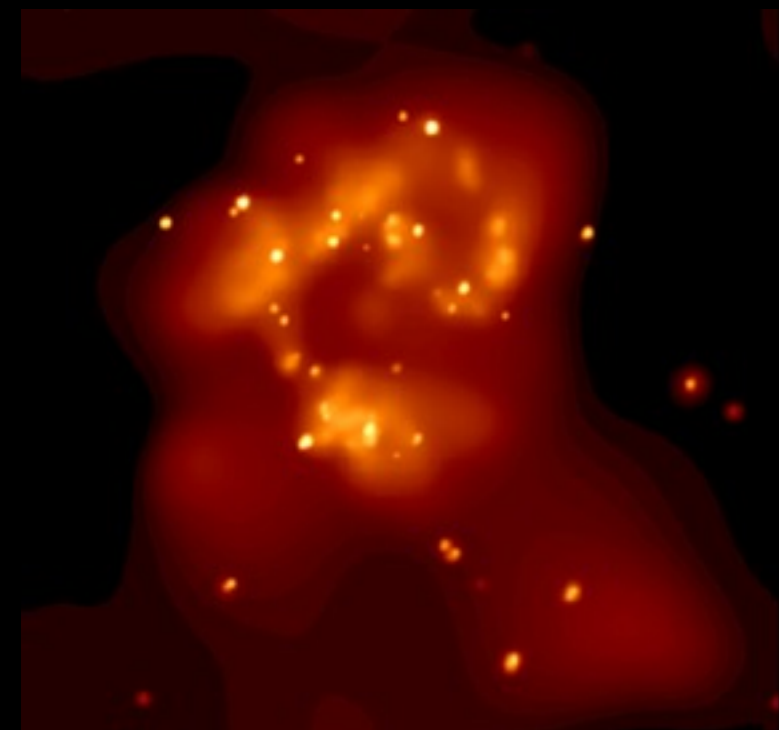
■円形加速器
(サイクロトロン)



■円形加速器



Multiple Wavebands in Astronomy



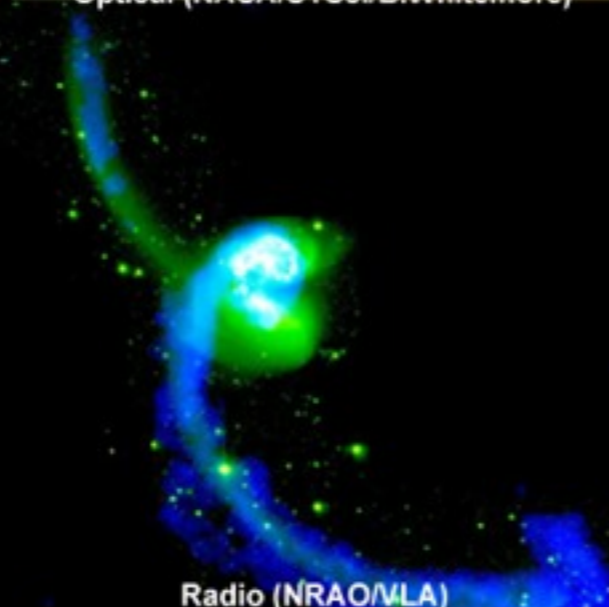
X-Ray (NASA/CXC/SAO/G.Fabbiano et al.)



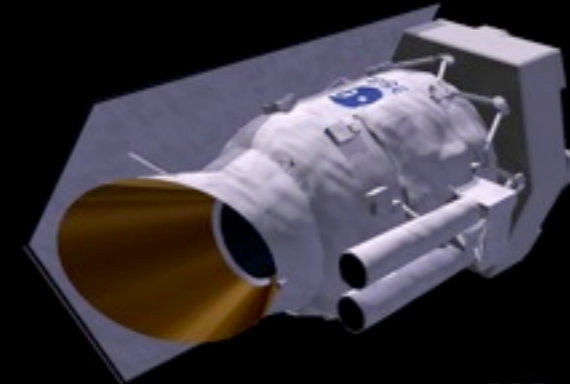
Optical (NASA/STScI/B.Whitemore)



Infrared (ESA/ISO/L.Vigroux et al.)



Radio (NRAO/MLA)



esa
ISD VisuLab



Telescopes vs Accelerators

| aim | need | telescopes | accelerators |
|--------------------|-------------------|--|-------------------------------|
| probe deeper | better resolution | better mirrors, CCD | higher energy |
| better image | better exposure | larger telescopes, more time | more powerful beams |
| full understanding | multiple probes | visible, radio, infrared, UV, X-ray, gamma | protons, electrons, neutrinos |



LHC vs ILC

(oversimplified)



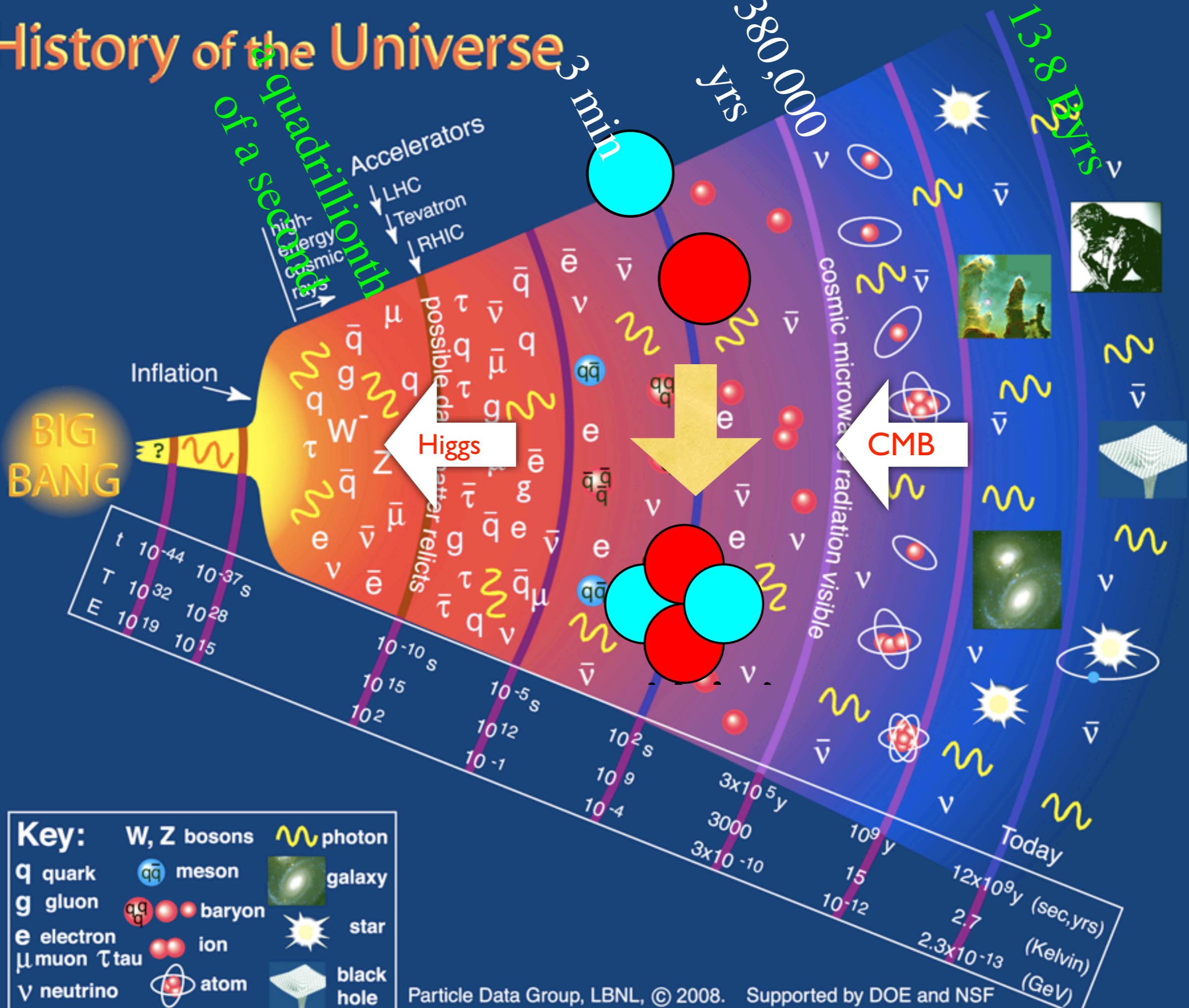
| | | |
|---------------|---------------------------|-----------------------|
| total energy | 14TeV | 0.5-1 TeV |
| usable energy | a fraction | full |
| beam | proton (composite) | electron (point-like) |
| signal rate | high | low |
| noise rate | very high | low |
| analysis | easy to spot particles | nearly all particles |
| events | lose info along the beams | capture the whole |
| status | being upgraded | finished design |

Lyn Evans
the man who
built the LHC



Mar 27, 2013

History of the Universe

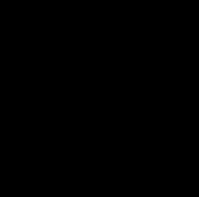


since Oct 2007



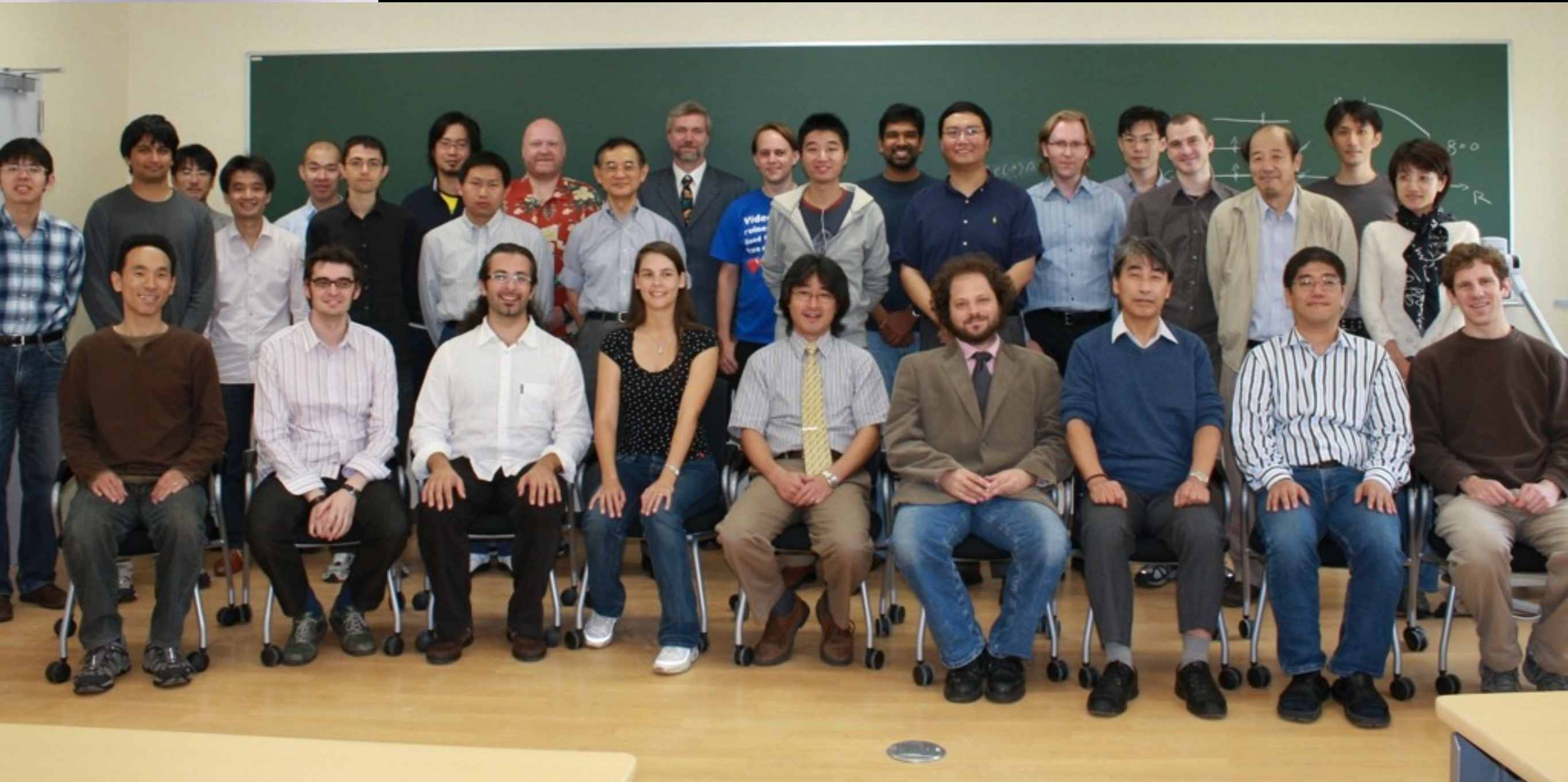


Oct 2007



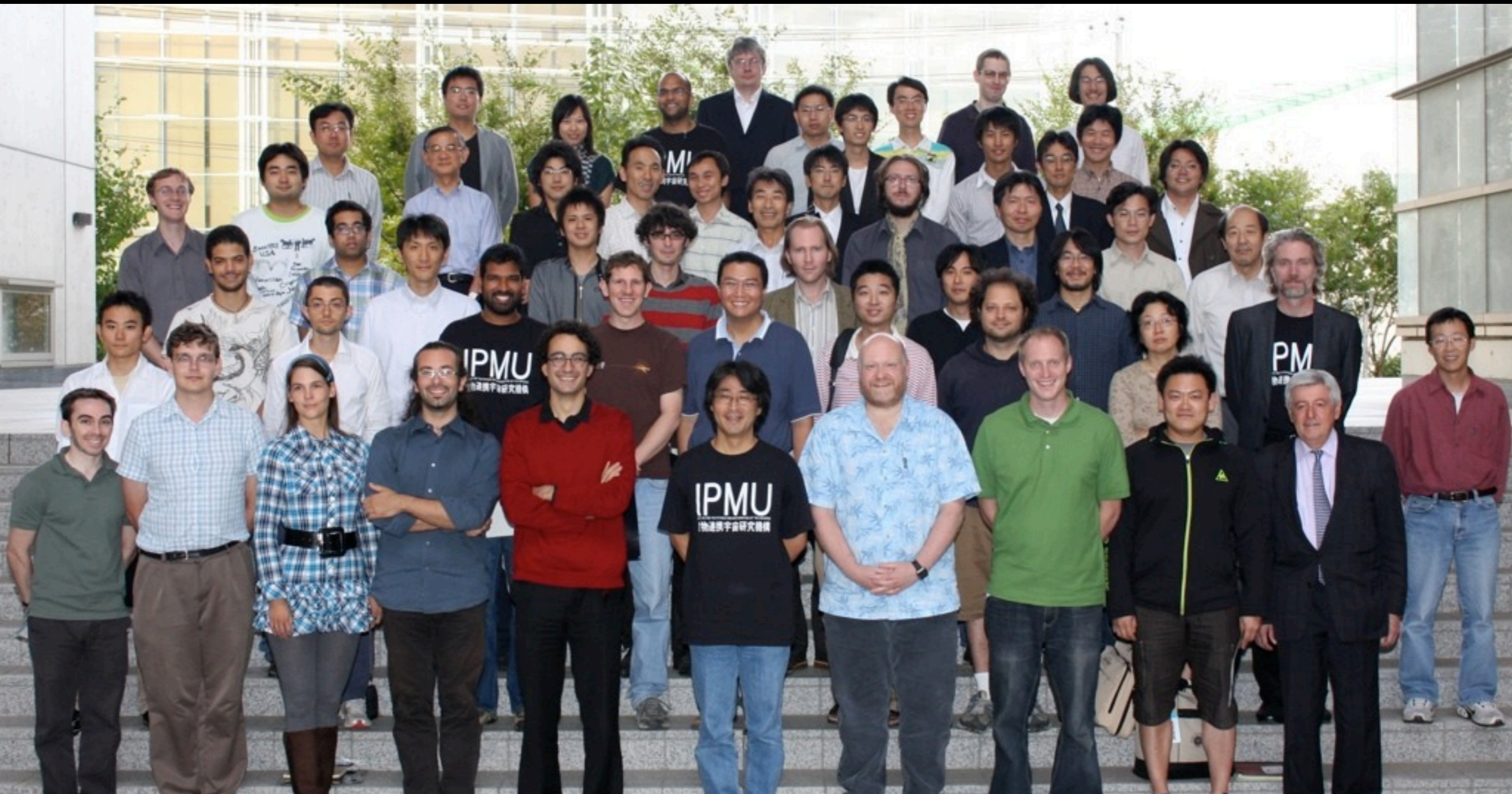


Oct 2008





Oct 2009





Oct 2010





Oct 2011





Oct 2012



日本の頭脳

Asahi TV

How did the Universe begin?

What is its fate?

What is it made of?

What are its fundamental laws?

Why do we exist?

