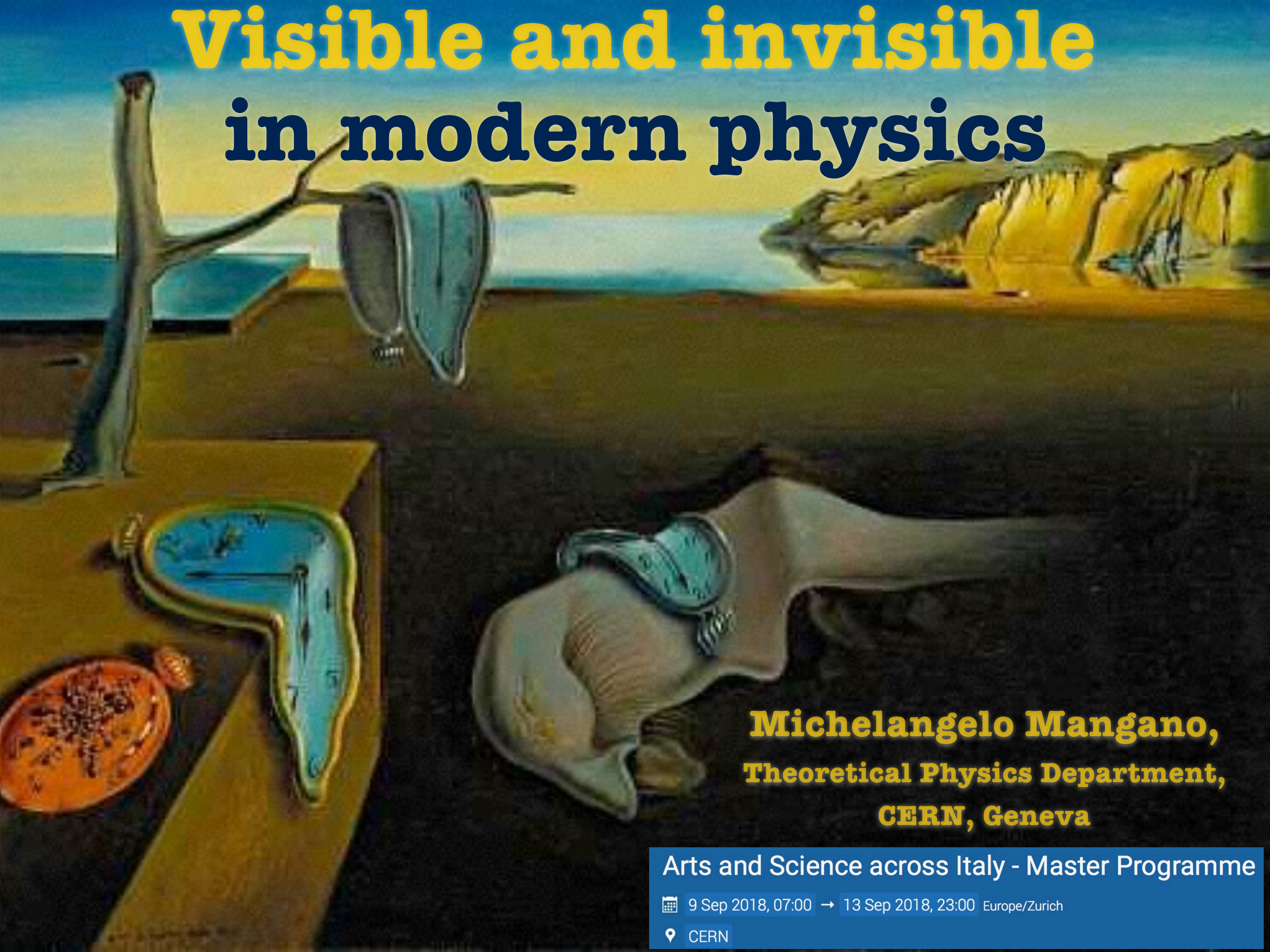
Visible and invisible in modern physics



Michelangelo Mangano,

Theoretical Physics Department,

CERN, Geneva

Arts and Science across Italy - Master Programme

9 Sep 2018, 07:00 → 13 Sep 2018, 23:00 Europe/Zurich

CERN

no artist better than Salvador Dali represents the inspiring power of science, and was more fascinated by the relation of visible and invisible ....

“In the Surrealist period I wanted to create the iconography of the interior world and the world of the marvelous, of my father Freud.

Today the exterior world and that of physics, has transcended the one of psychology.

My father today is Dr. Heisenberg.”

S.Dali, ‘Anti-matter manifesto‘ (1958)

Previous page:
S.Dali, The persistence of memory (1931)

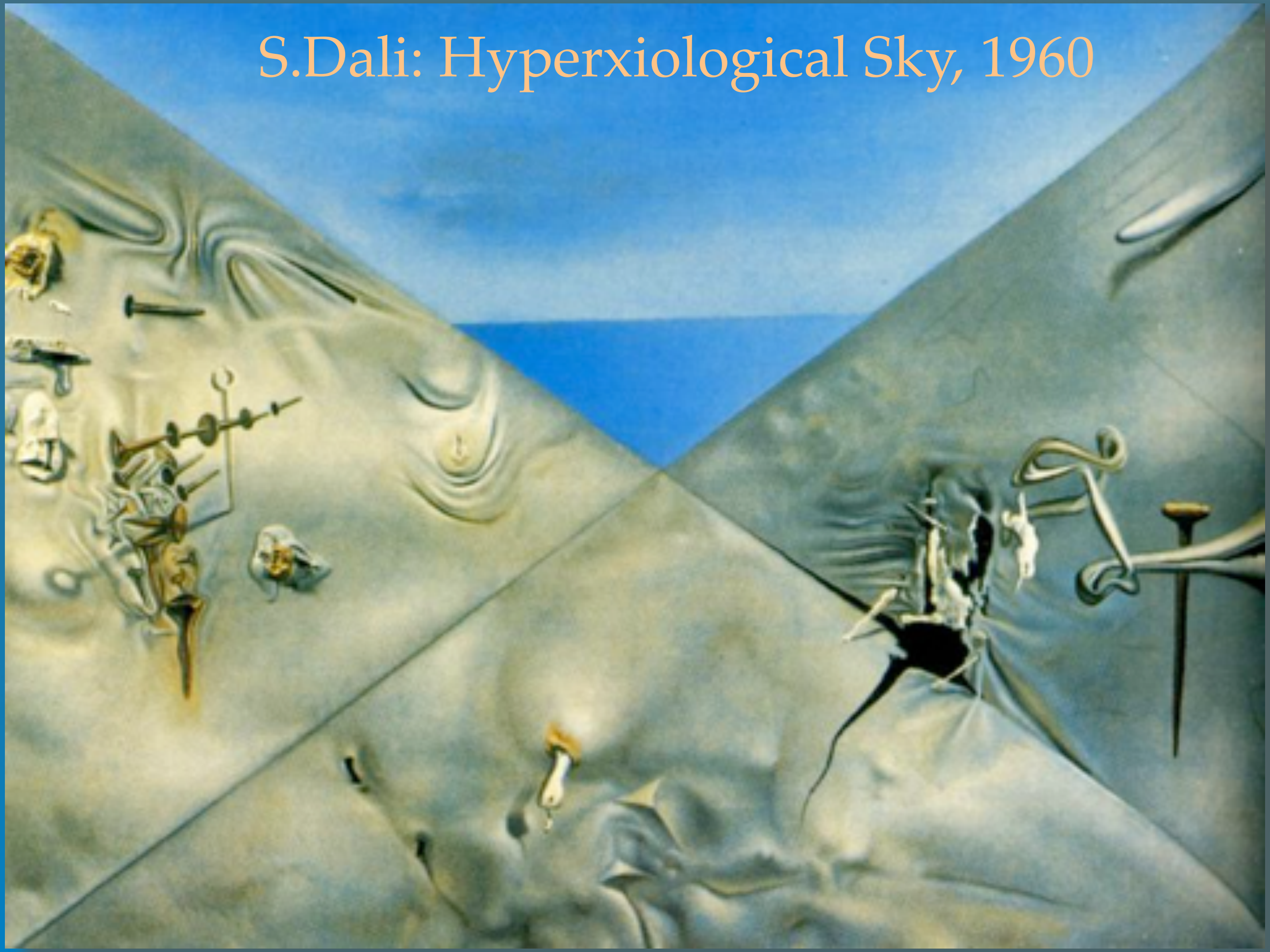
Hubble Ultra Deep Field

Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, S. Beckwith (STScI) and the HUDF Team

STScI-PRC04-07a


S.Dali: Ciel, 1931


S.Dali: Hyperxiological Sky, 1960

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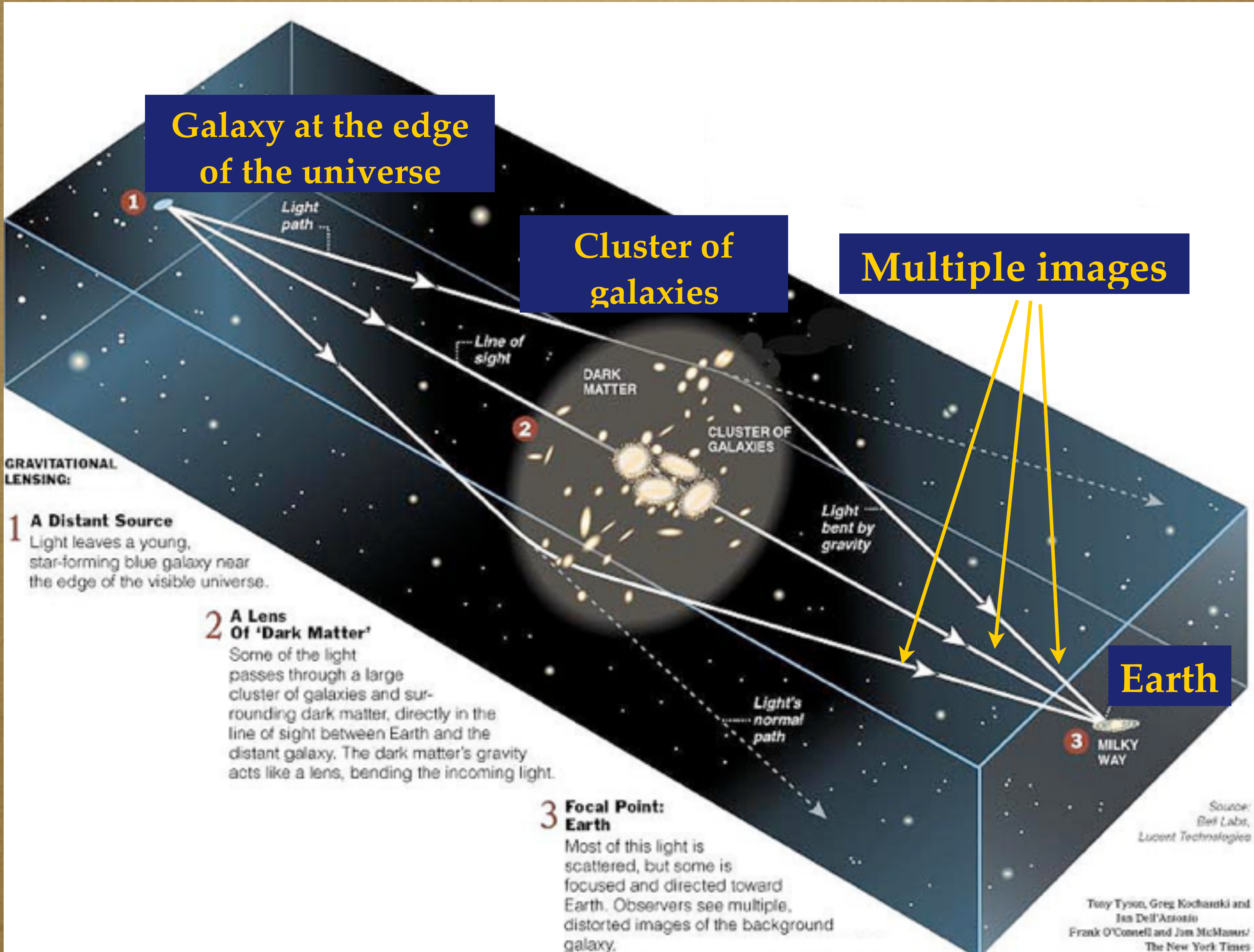
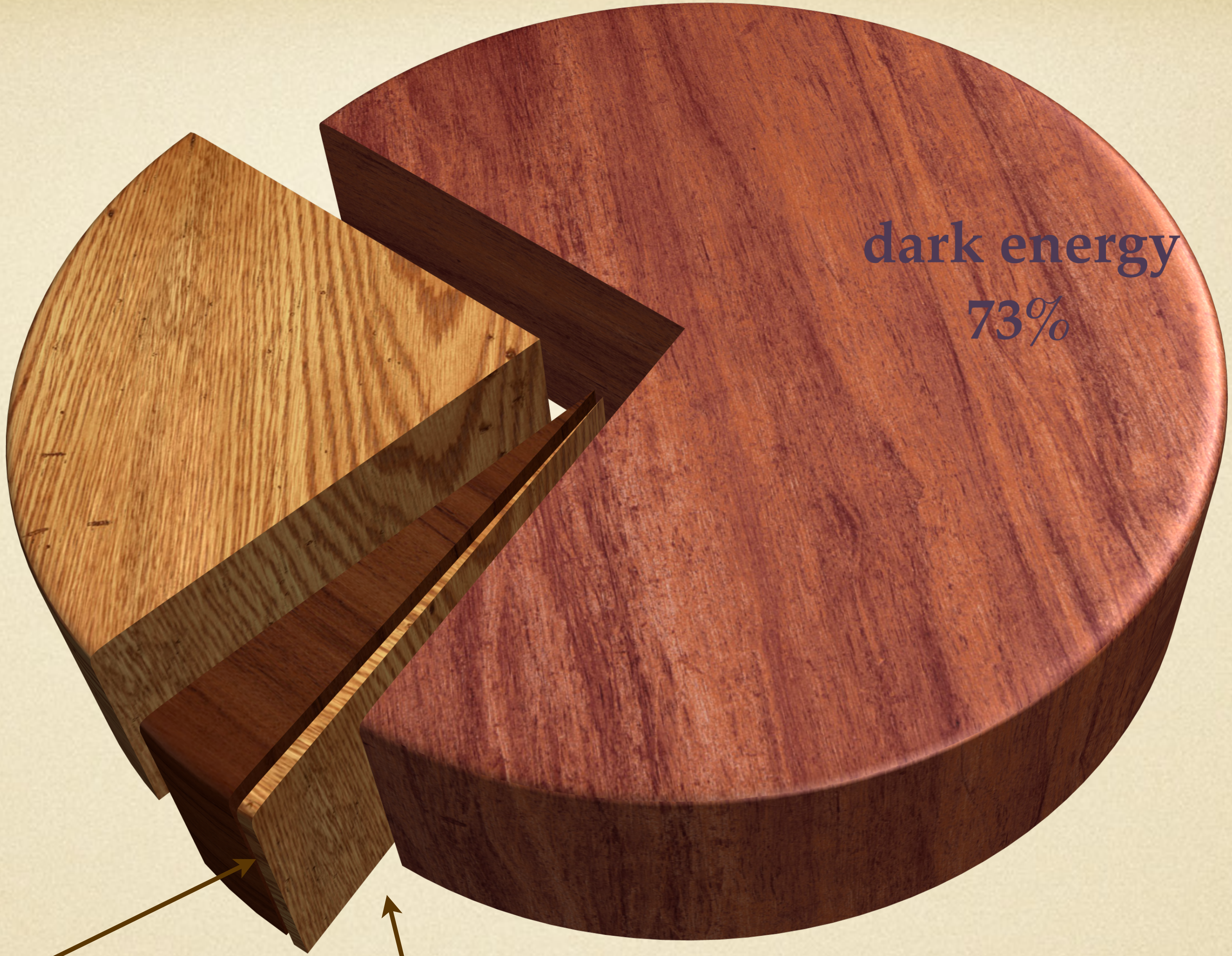
Gravitational lensing



Credits: *European Space Agency, NASA, J.-P. Kneib (Observatoire Midi-Pyrénées) and R. Ellis (Caltech)*

The shape and intensity of lensed images requires the presence of much more mass than what's **visible** in those galaxies !

→ Invisible dark matter


dark energy
73%
dark matter
23%
non-luminous ordinary matter (e.g. planets, dead stars, dust, etc), ~4%
luminous matter (stars, gas) ~0.5%

For something to be declared invisible, we must know it's there, and if we know it's there, it's not *truly* invisible any longer .....

S.Dali, Surrealist Composition with Invisible Figures, 1936

Proving the existence of the invisible, namely providing evidence that there is something where there appears to be nothing, turning the invisible into visible, is one of the main drivers of scientific progress.

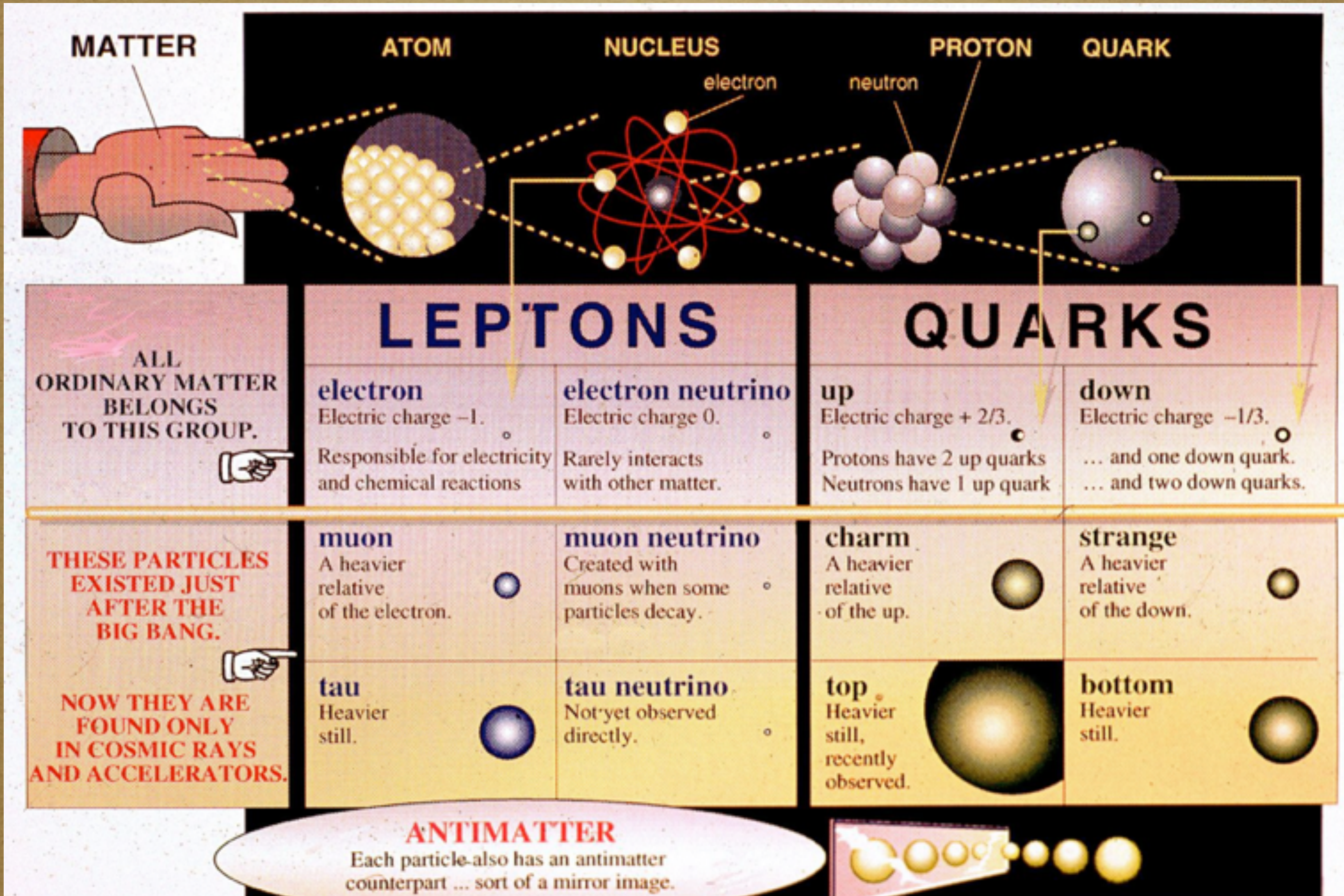
It is a very basic process, that moves us from the realm of magic and superstition to the domain of science.

Invisible Harp, 1934

Establishing the **nature** of the invisible is the really crucial step .....

Goal of modern physics: to unveil the invisible, give it substance, and explore its consequences on the universe

The Standard Model of particle physics



BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.39	–1
W^+ W bosons	80.39	+1
Z^0 Z boson	91.188	0

Strong (color) spin =1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction (Electroweak)	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60

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EW symmetry breaking spin=0

H higgs	**125**	**0**

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what? how?

- Is nature built out of fundamental building blocks?
- If so, what are they?
- How do they interact?
- How do they determine the properties of the Universe?

The description of the natural phenomena that emerges from the Standard Model agrees **quantitatively** with great precision with all phenomena that we **see** around ourselves, and that we **measure** in the laboratory

The Standard Model provides the underlying explanation of all nuclear, chemical and electrical phenomena, the atomic structure of elements, the electrical/mechanical/thermal behaviour of metals, semiconductors, etc. etc. etc.

A few anecdotes on the role of the invisible in the discovery and understanding of fundamental particles and interactions

Late 1920's, a mystery of the invisible

$^{6}\mathrm{He} \rightarrow {}^{6}\mathrm{Li} + e^{-}$

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If this were all that happens, energy conservation would demand that the energy of the emitted electron be the same for each decay

$$\text{Energy}[e^{-}] = \text{Mass}[{}^{6}\text{He}]c^{2} - \text{Mass}[{}^{6}\text{Li}]c^{2}$$

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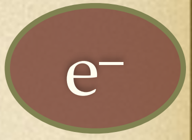

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Enter neutrinos ...

After months of speculations, including the possibility that the principle of energy conservation be violated in microscopic quantum phenomena, Wolfgang Pauli proposes the existence of the **invisible neutrino**

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S.Dali, The invisible man, 1929

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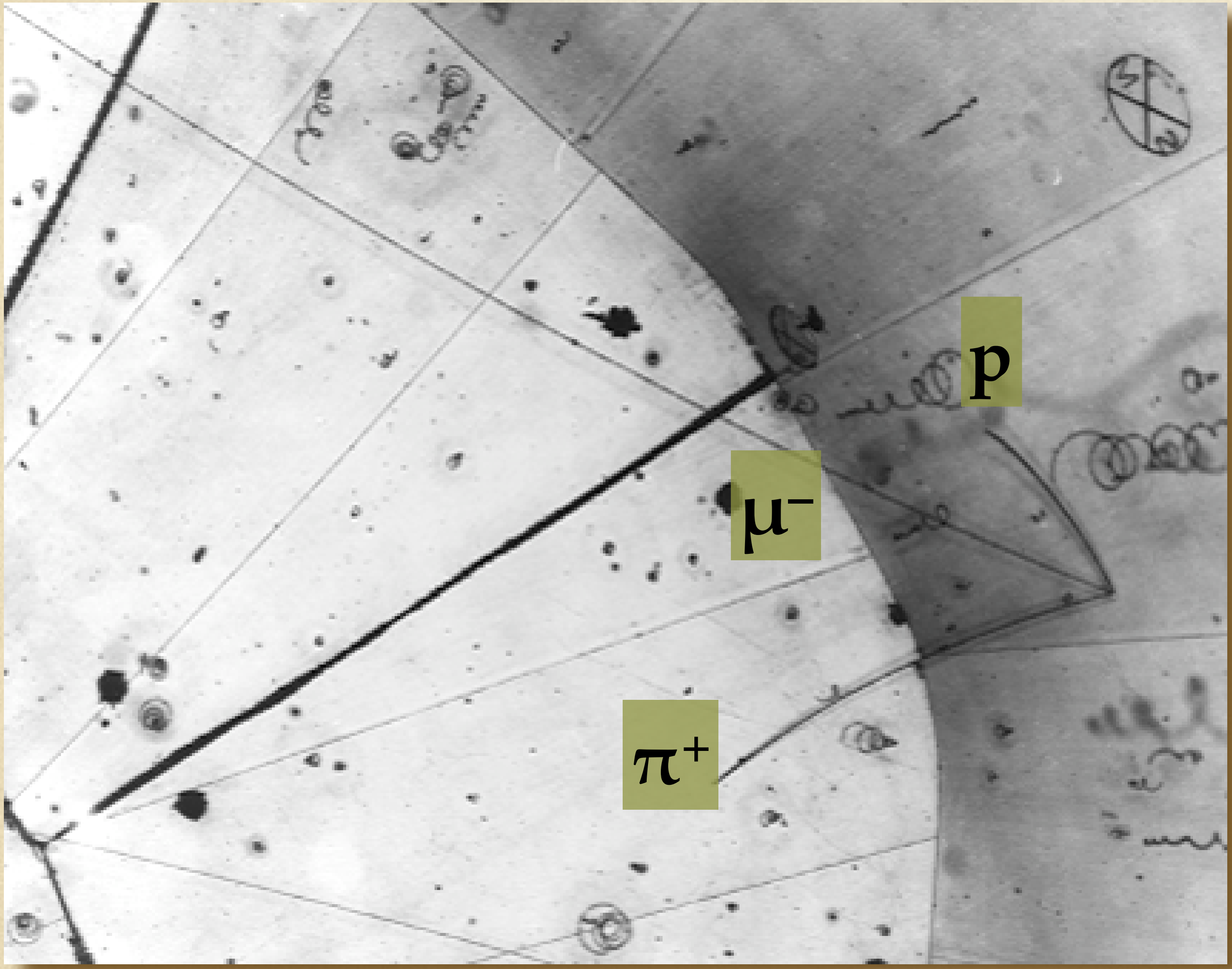
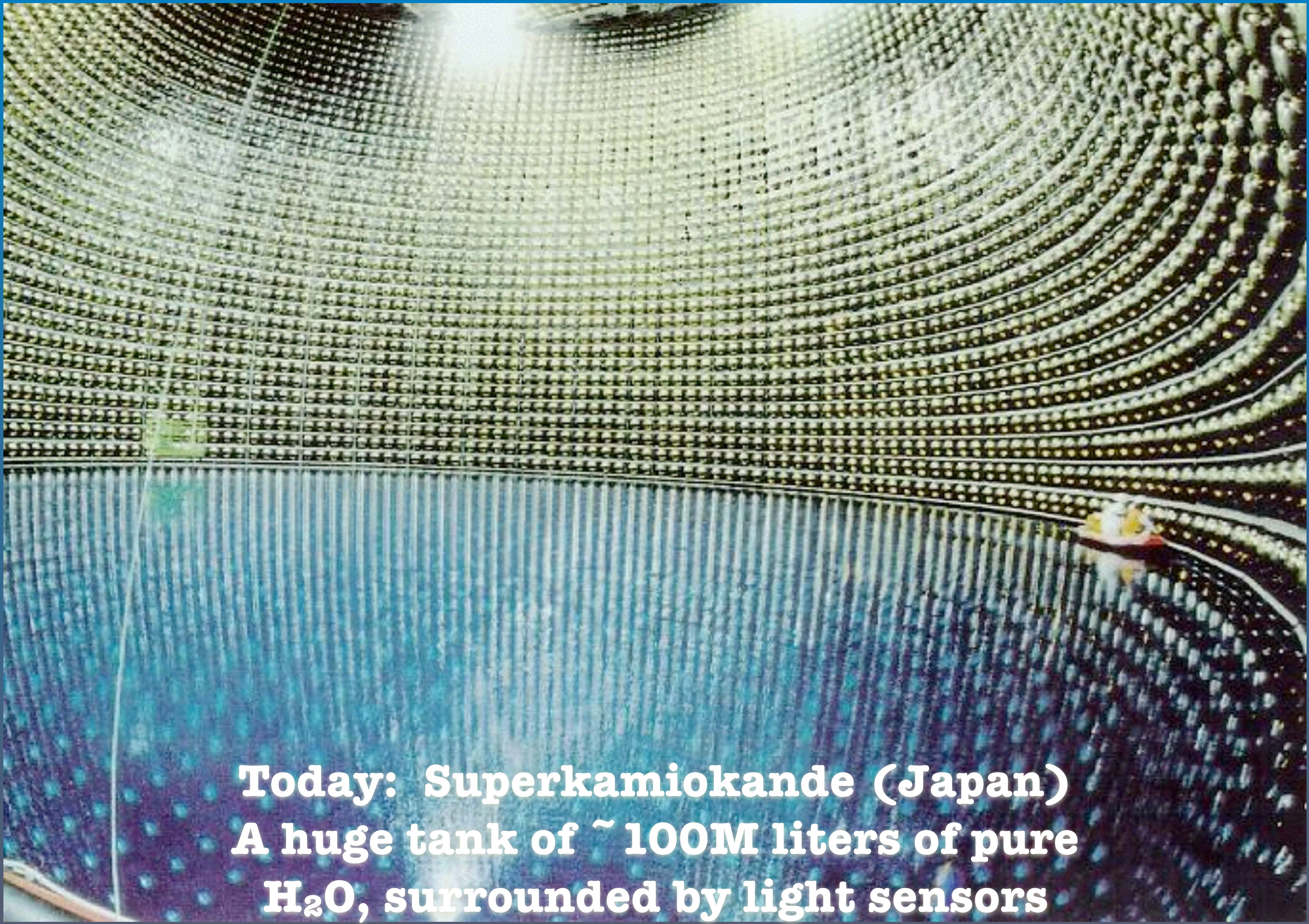
It took more than 20 years for a neutrino to be directly observed!

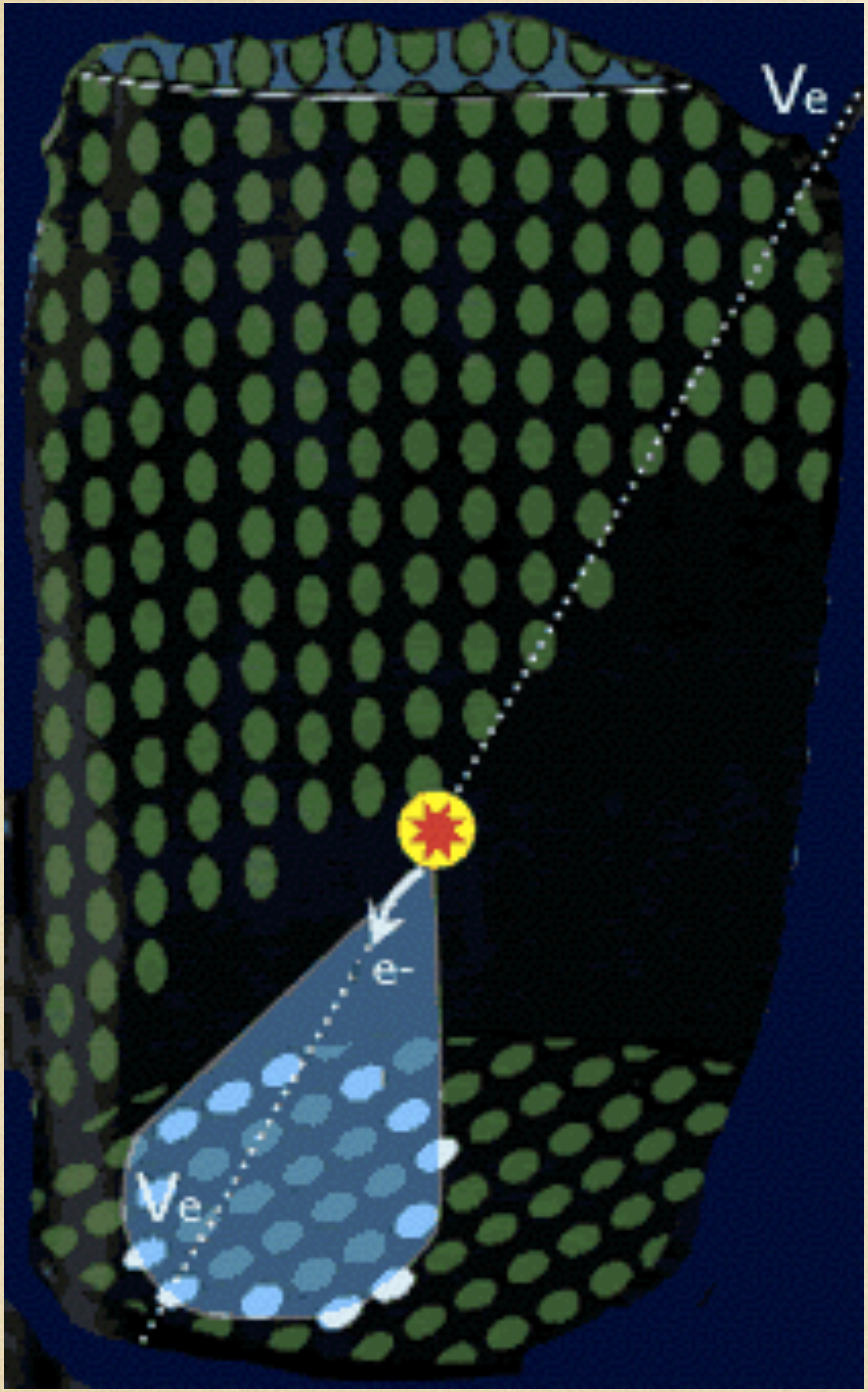


ν from a beam of π mesons

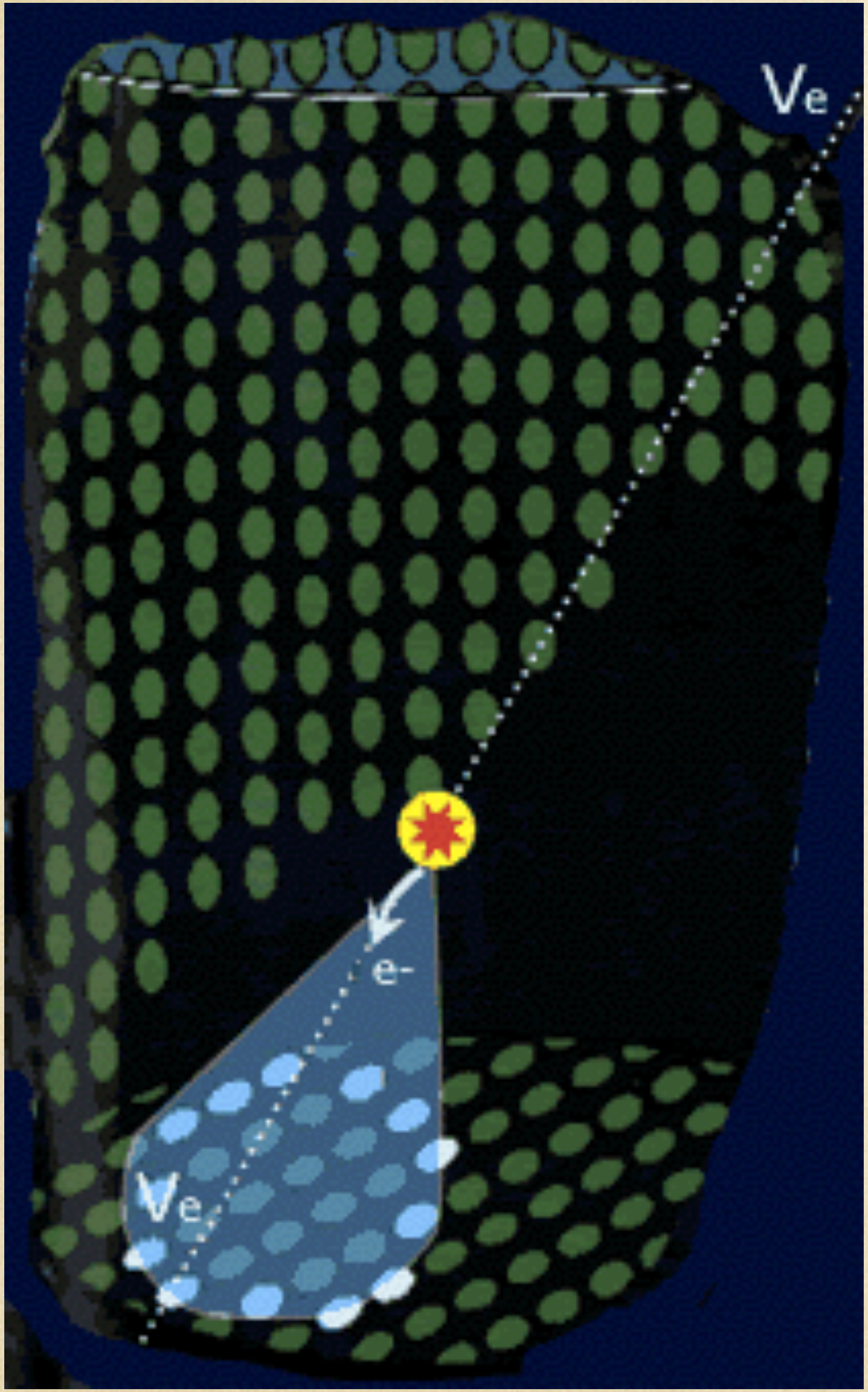
The world's first neutrino observation in a hydrogen bubble chamber. It was found Nov. 13, 1970, in this photograph from the Zero Gradient Synchrotron's 12-foot bubble chamber. The invisible neutrino strikes a proton where three particle tracks originate (lower right). The neutrino turns into a mu-meson, the long center track (extending up and left). The short track is the proton. The third track (extending down and left) is a pi-meson created by the collision. *Argonne National Laboratory*



Today: Superkamiokande (Japan)
A huge tank of ~100M liters of pure H_2O, surrounded by light sensors



Neutrino from the collision of a cosmic ray with the earth atmosphere, or from the sun



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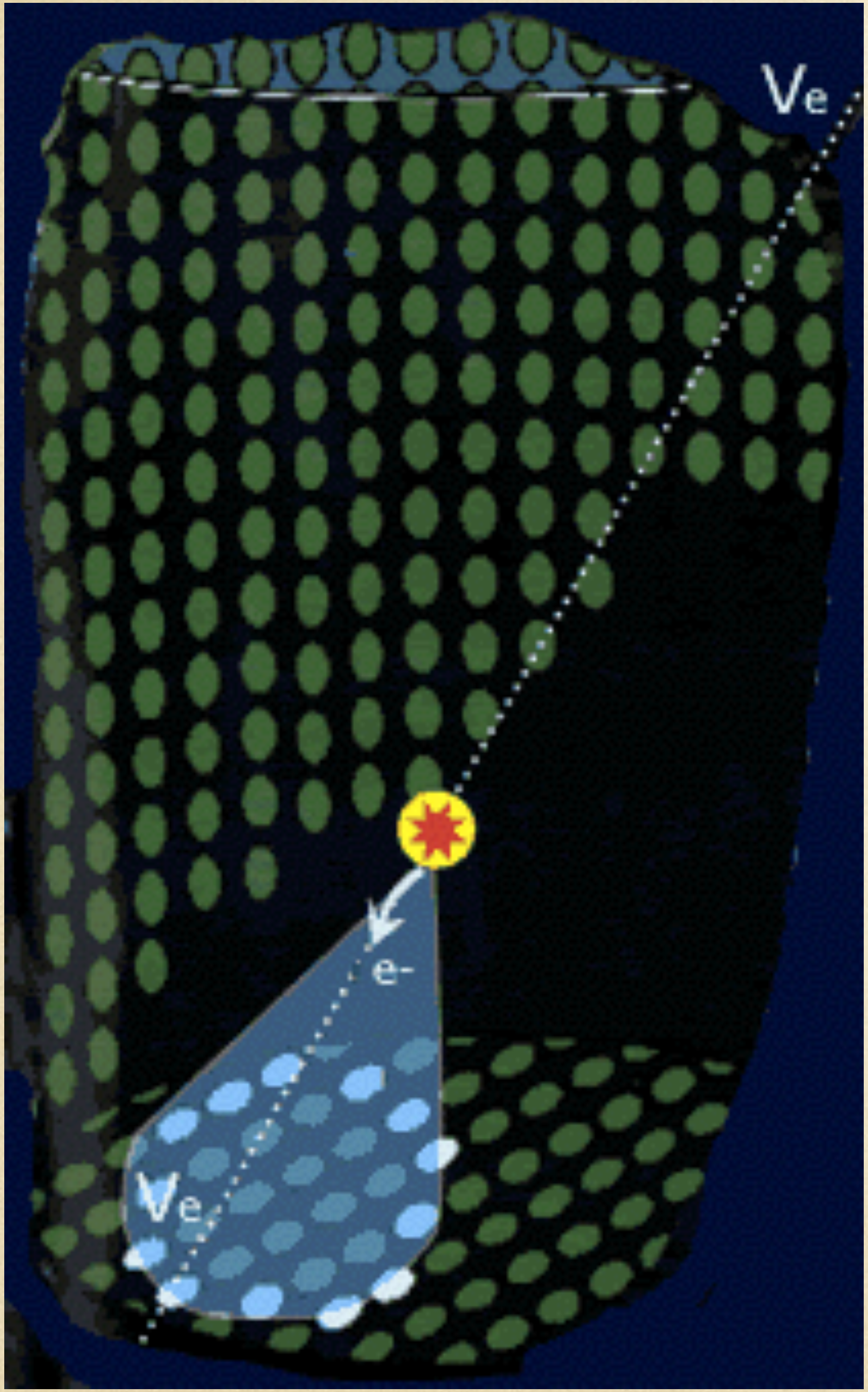
It interacts with an atom in the water, and becomes an electron



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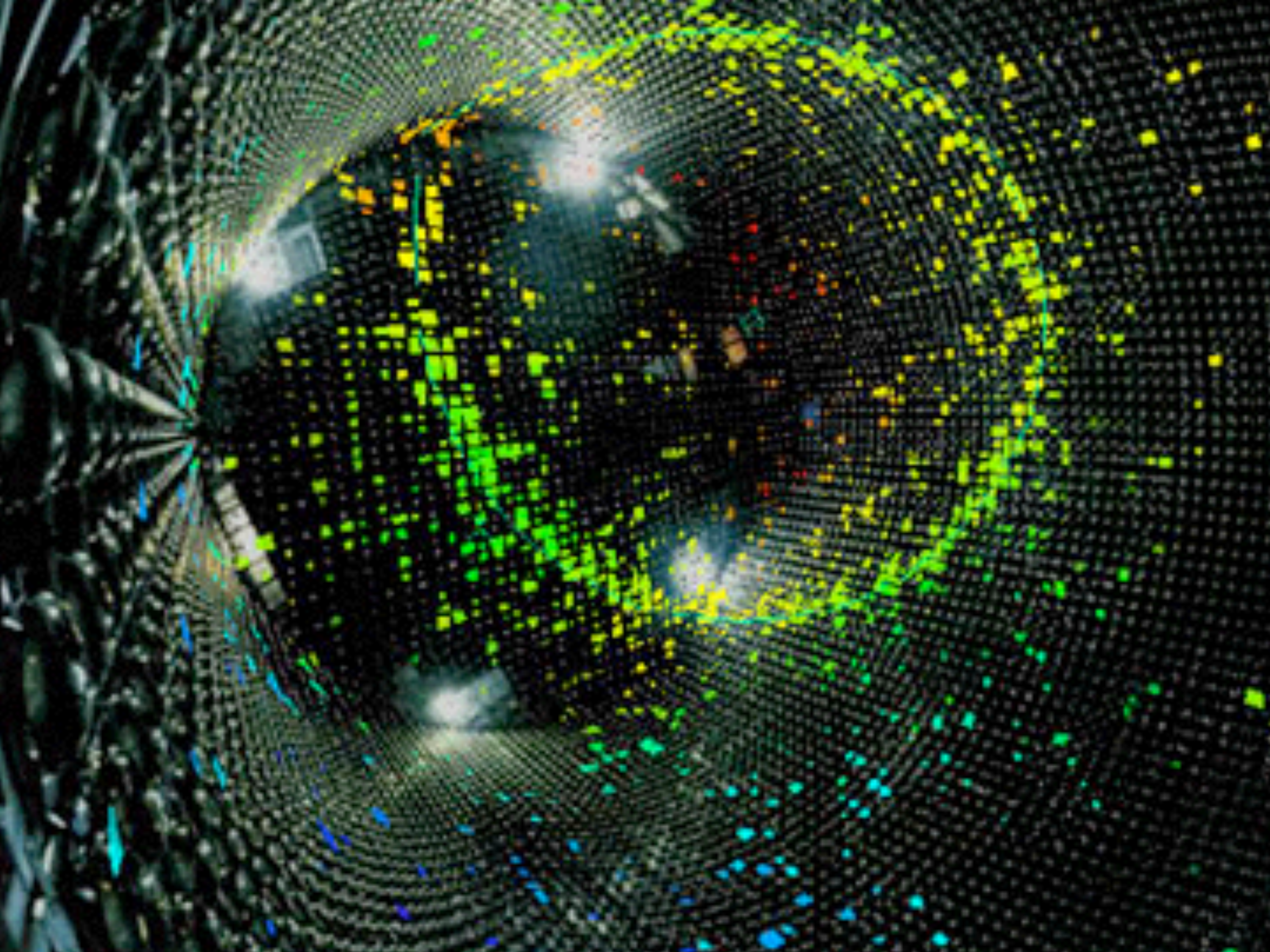
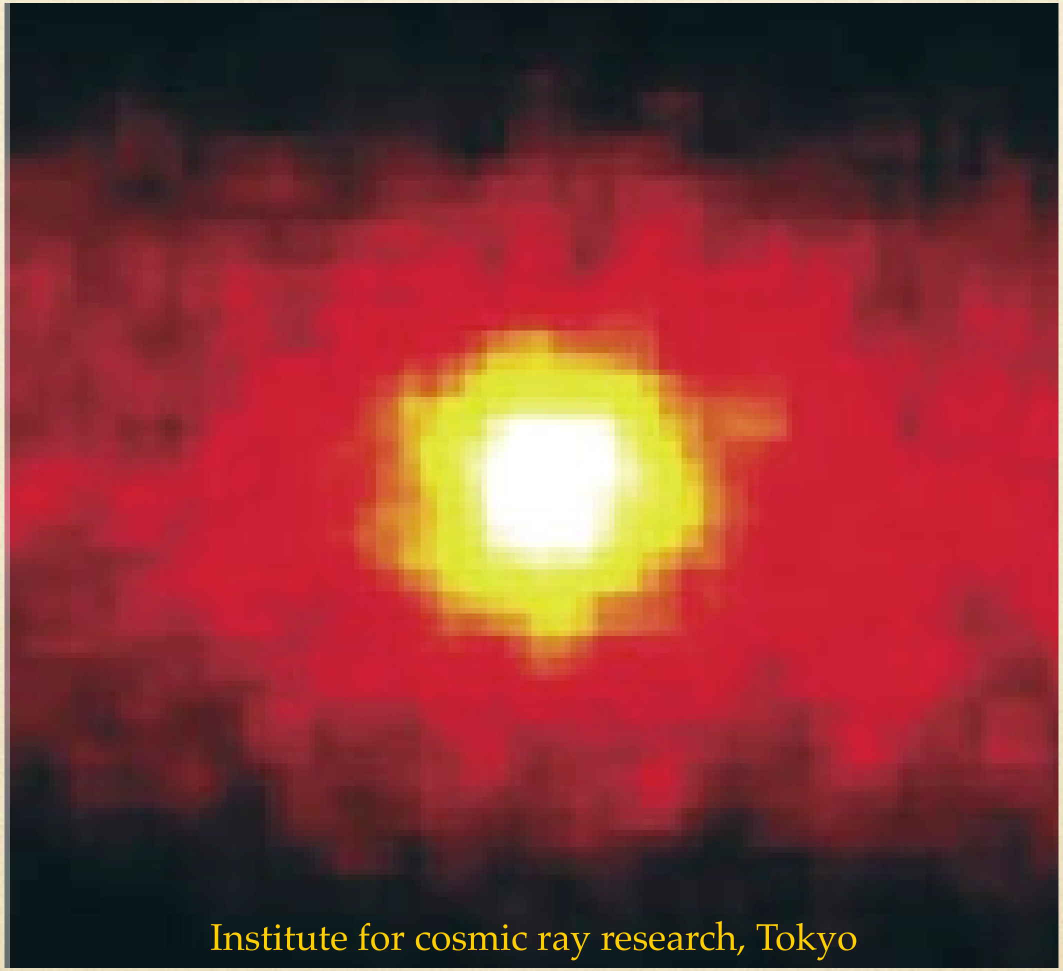
The electron travels superluminal in water, and creates a light-bang – the luminous equivalent of an airplane supersonic bang – to be detected by the sensors on the surface of the tank



Reconstructing the neutrino direction, and mapping on the sky the position of their origin, allows to use neutrino detectors as "telescopes": neutrino eyes!



A picture of the invisible part of the Sun, namely its innermost core, where nuclear reactions take place!

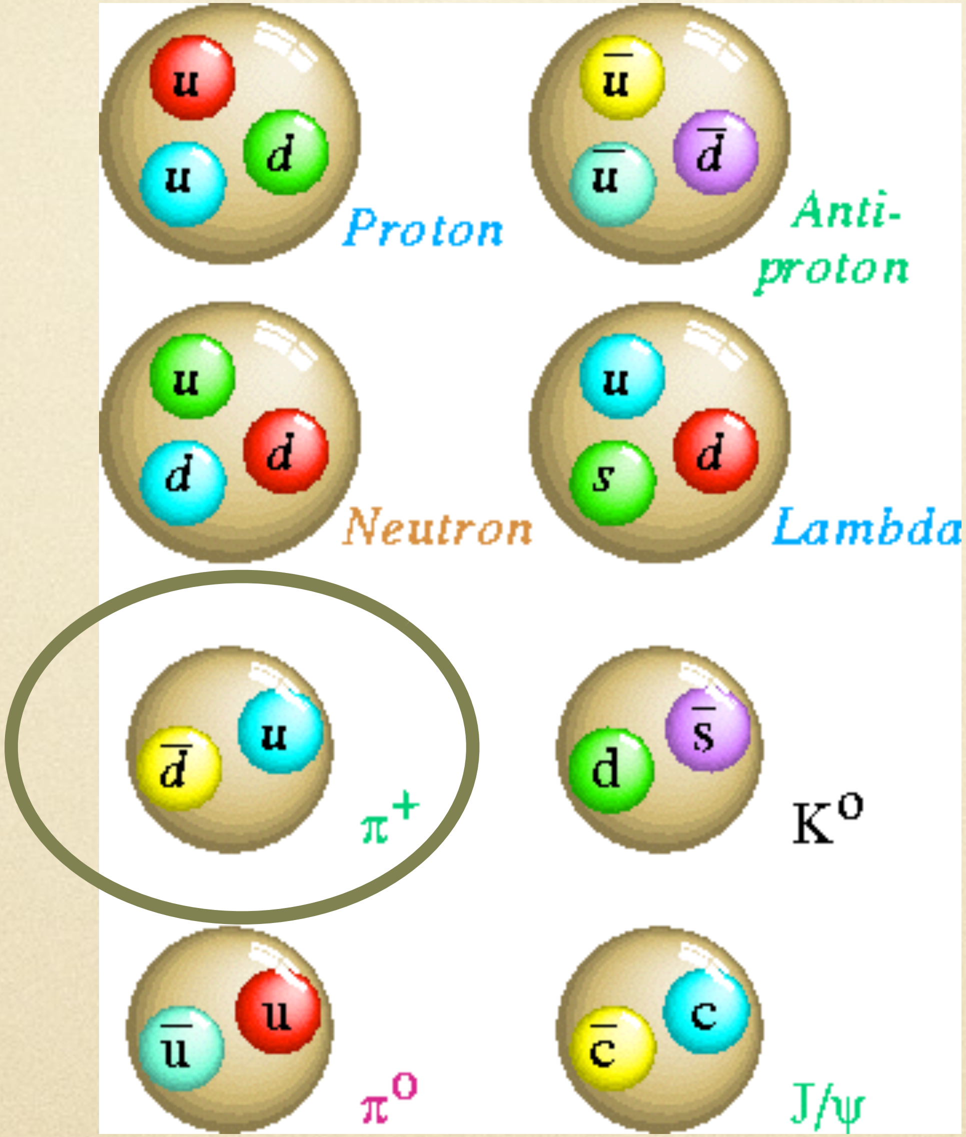
90 years after they entered in our understanding of nature, neutrinos are still among the most intriguing elements of the Standard Model (SM)

- what are the precise values of their masses?
- why is their mass so much smaller than all other SM particles?
- are neutrinos their own antiparticles?
- how many types of neutrinos are there?
- are they subject to interactions other than SM ones?
- ….

The continued exploration of neutrino properties forms one of the pillars of the future programme of experimental particle physics worldwide

“It is with π-mesons and the most gelatinous and indeterminate neutrinos that I want to paint the beauty of the angles and of reality.”

S.Dali, ‘Anti-matter manifesto‘ (1958)


u
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Lambda
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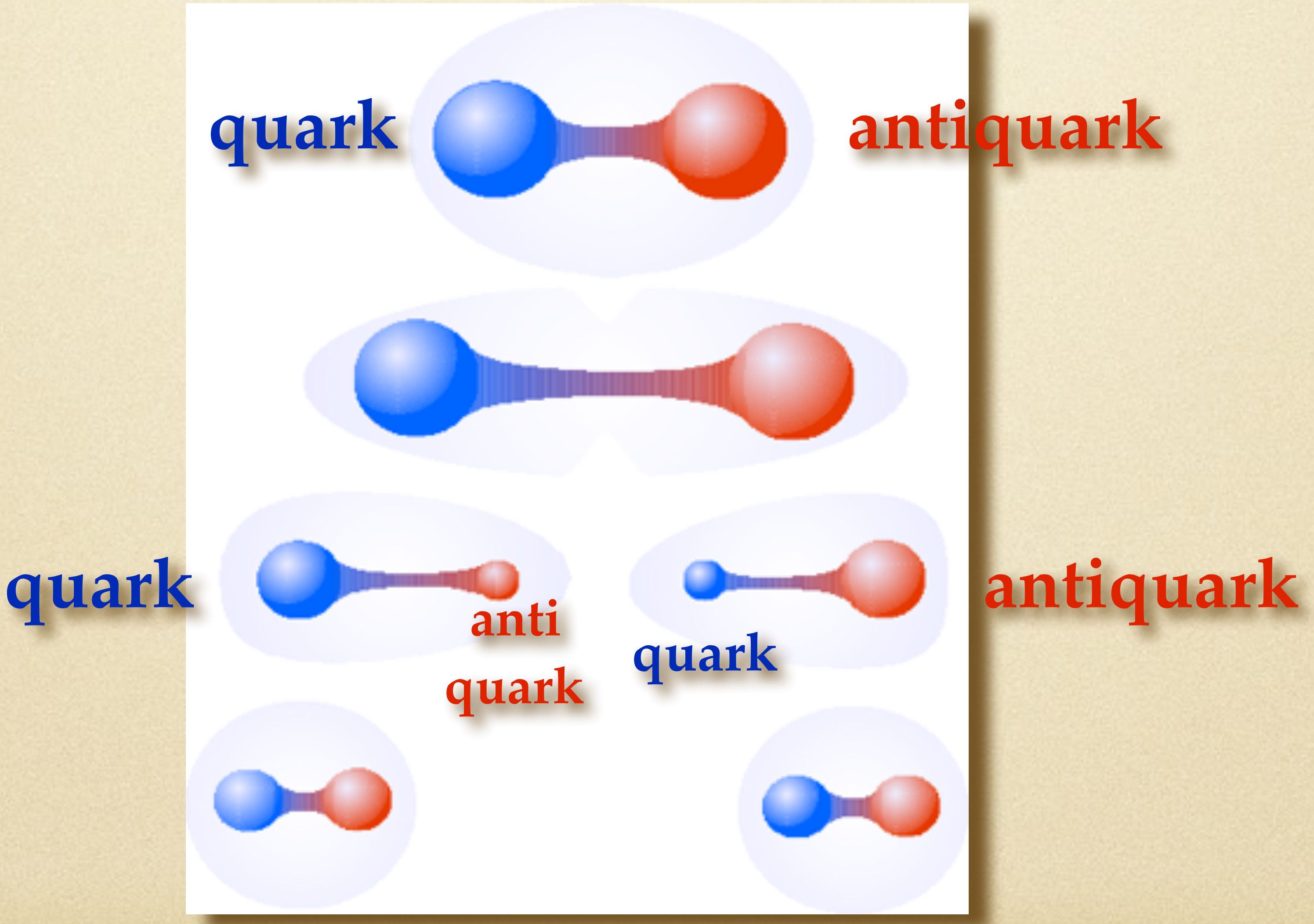
u
π+
d
s
K0
u
u
π0
c
c
J/ψ

The ultimate invisible: quarks inside matter ......

If we try to pull the quarks out of a proton or a pion, the energy we need to win the strong force will eventually convert into a new quark-antiquark pair (using $E=mc^2$), and we'll be left with two **pions ....**

we know quarks are there, but can't get them out!



Saint surrounded by three π mesons, 1956

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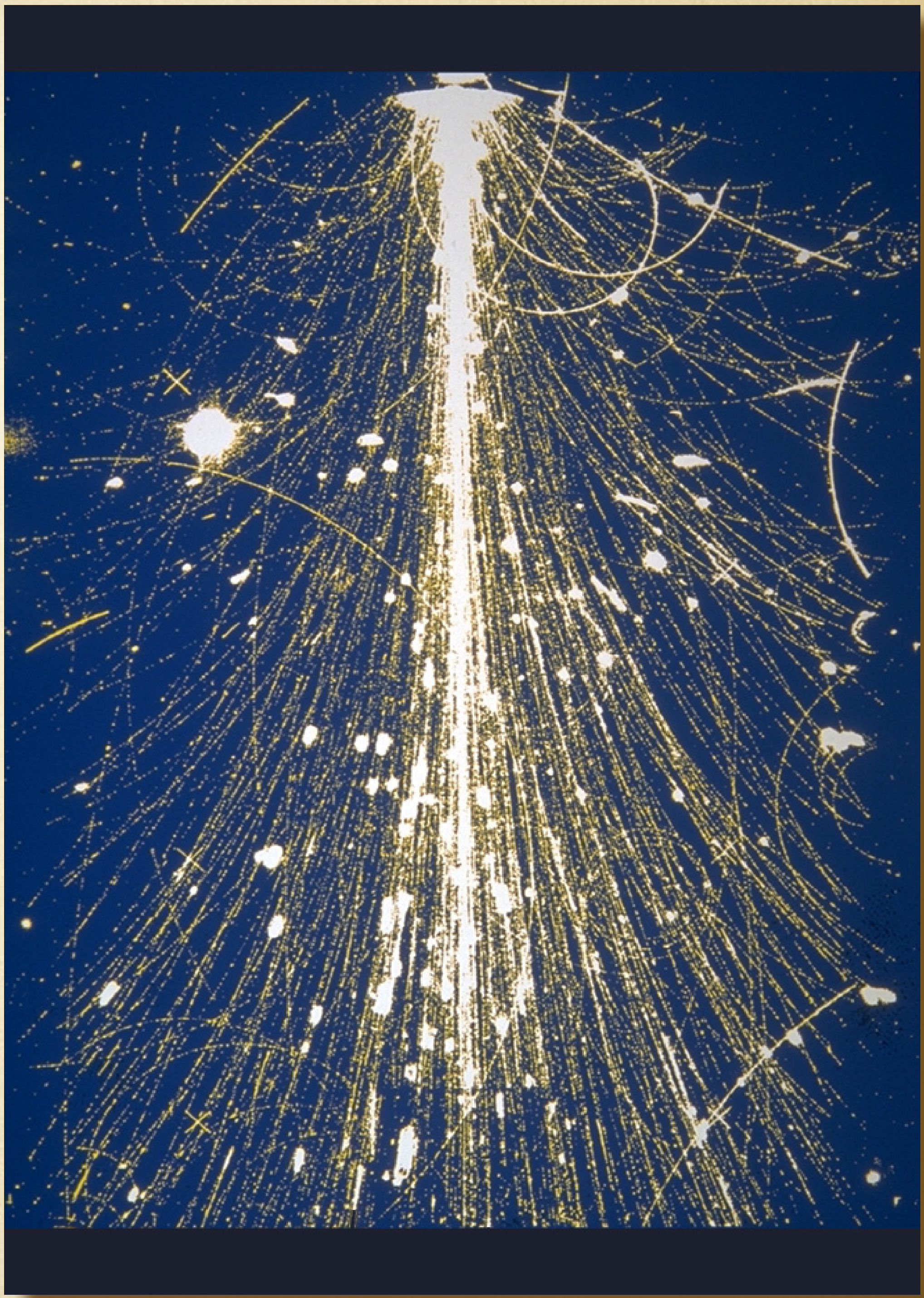

... just π mesons, in a real experiment ...

Some of the main open questions

What is the vacuum really made of?

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S.Dali,
The echo of void
1935

The vacuum, and the Higgs field

We call vacuum the state of any volume of the Universe if we were to take away from it all matter and interactions from nearby matter.

The Standard Model predicts that the vacuum is occupied by a constant density field of the Higgs boson, which we cannot "take away".

This permeates the Universe like an ether, everywhere and permanently, since about 10^{-10} seconds after the Big Bang

Interacting with this field, particles acquire their mass

Producing Higgs bosons

Like any other medium, the Higgs continuum background can be perturbed. Similarly to what happens if we bang on a table, creating sound waves, if we "bang" on the Higgs background (something achieved by concentrating a lot of energy in a small volume) we can stimulate "Higgs waves". These waves manifest themselves as particles, the so-called Higgs bosons

What is required is that the energy available be larger than the Higgs mass
$\Rightarrow$ particle accelerators !!!

What's the origin of invisible dark matter ?

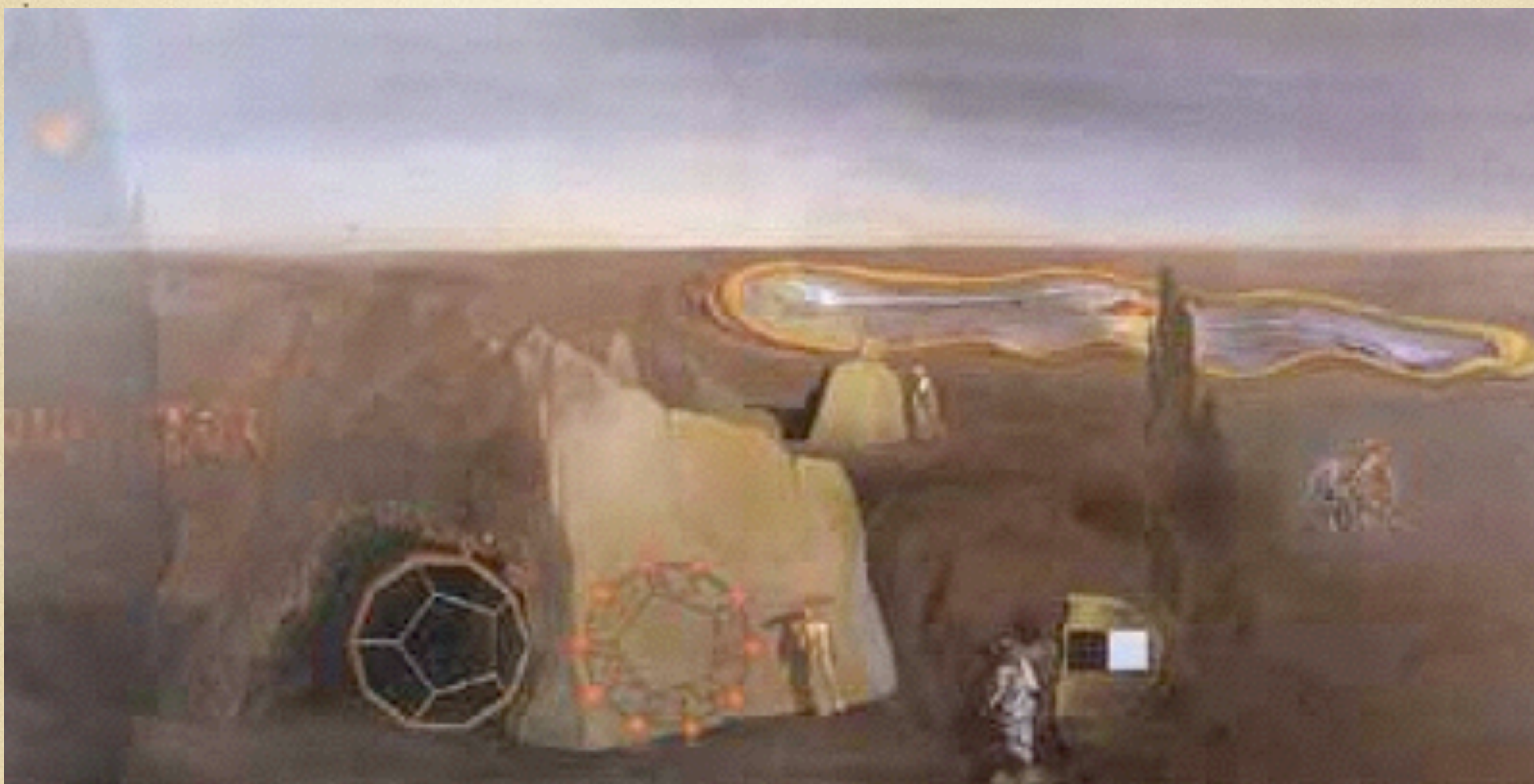
L'homme invisible, 1929

Whatever happened to the antimatter in the Universe?

Antiprotonic assumption, ‘56

Why do we live in 4 dimensions?

are there more, hidden and invisible dimensions of space-time?



In the search of the 4th dimension (1979)

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- a new (set of) particle(s) (*eg the DM particle, or those predicted by Supersymmetry*)?

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- …. all of the above ??

Final remarks

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- Progress continues on the remaining ones, but with the understanding that ...

- .... there will always be a new layer of unknown invisible, the invisible hand of nature that decided that, after all, there should be **something instead of nothing**