Bruno Pontecorvo, Edoardo Amaldi

and the invisible light of the stars

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U. of Rome Tor Vergata

The beginning:
I ragazzi di via Panisperna

They took their name, the boys from Panisperna Street, from the street in central Rome where the Physics Institute at which Fermi and his collaborators worked from 1926 to 1937 was located.
It was there that at the beginning of 1934 they made the historic discovery that new radioactive isotopes were produced when elements were bombarded by neutrons.

Rome 1934. I ragazzi di via Panisperna
From left: Oscar D'Agostino, Emilio Segrè, Edoardo Amaldi,Franco Rasetti,and Enrico Fermi (on the top: Bruno Pontecorvo and Ettore Majorana)

E. Amaldi F. Rasetti E. Segrè

The physicists organized themselves by dividing the responsibilities, sharing the work and enjoying vacations together.

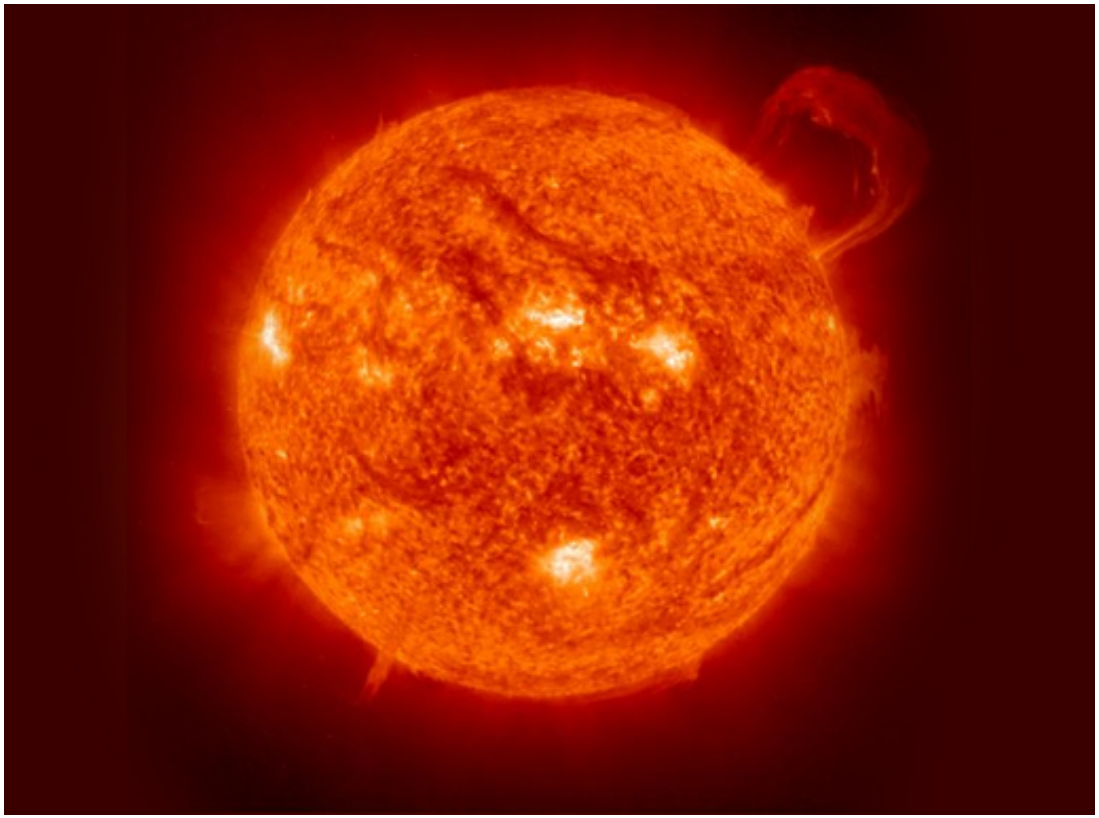
The US science historian Gerald Holton has said that “this was the first real science Group”.

Contents

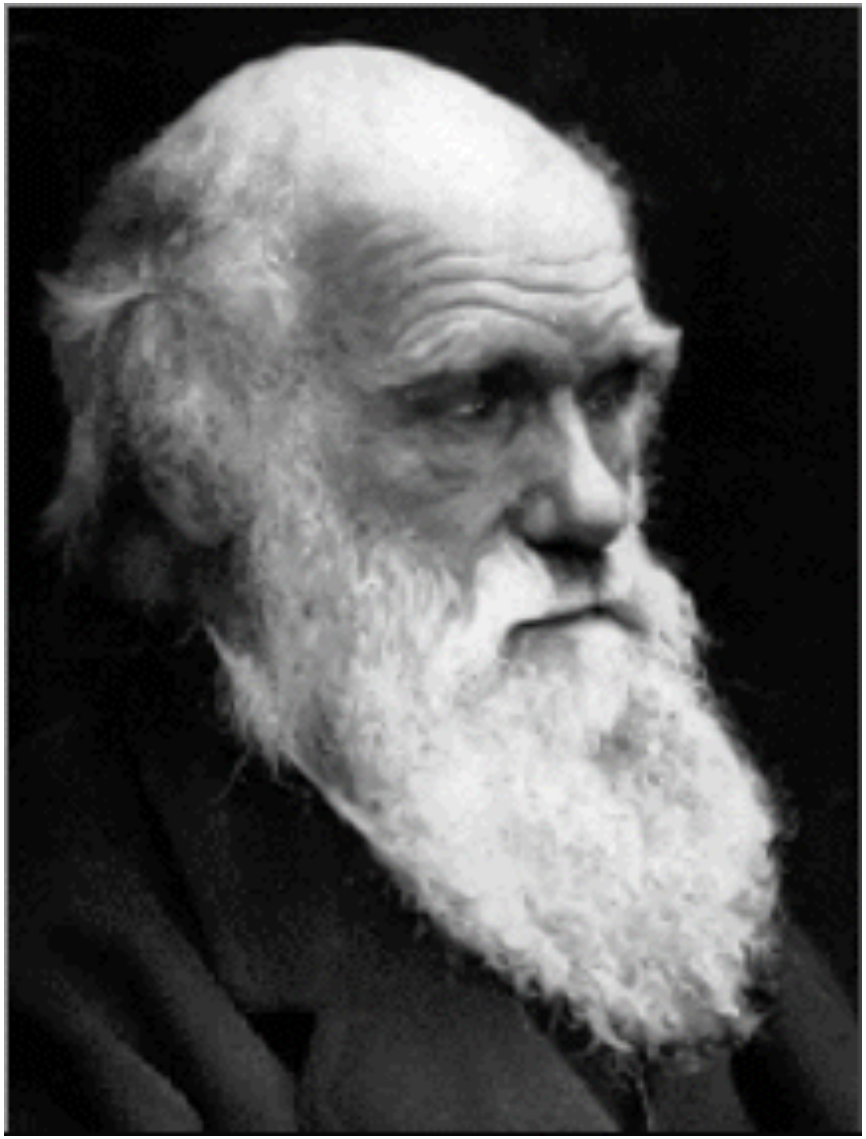
- Pontecorvo, the completion of a story beginning with Darwin and the birth of neutrino astronomy

- Amaldi and the birth of the gravitational wave research in Italy

What makes the sun shine?



How old is the sun?
How old is life on Earth?



Charles Darwin 1859

Age required
for the evolution
of life on Earth

- 1 billion years

Lord Kelvin 1862

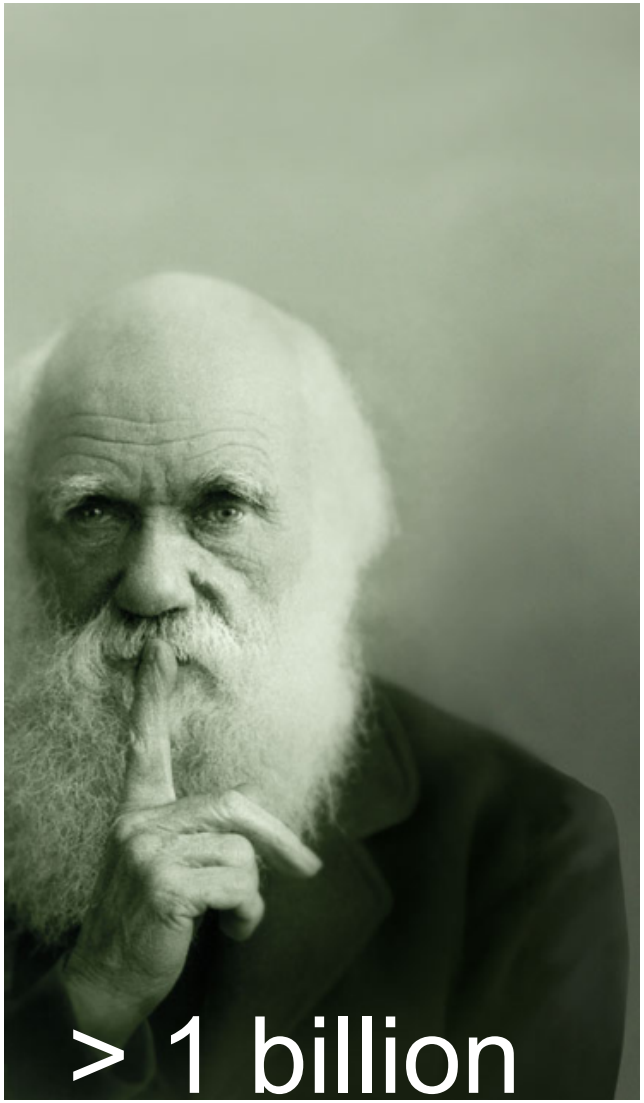
Luminosity x age =

Gravitational energy

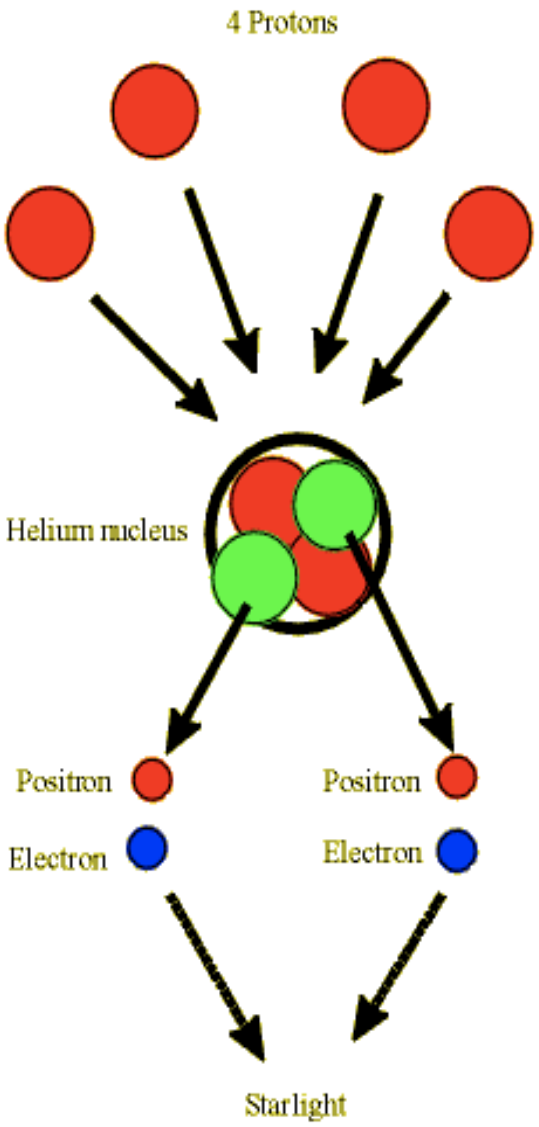
$$T = \frac{GM}{R}\frac{1}{L}$$

Result:

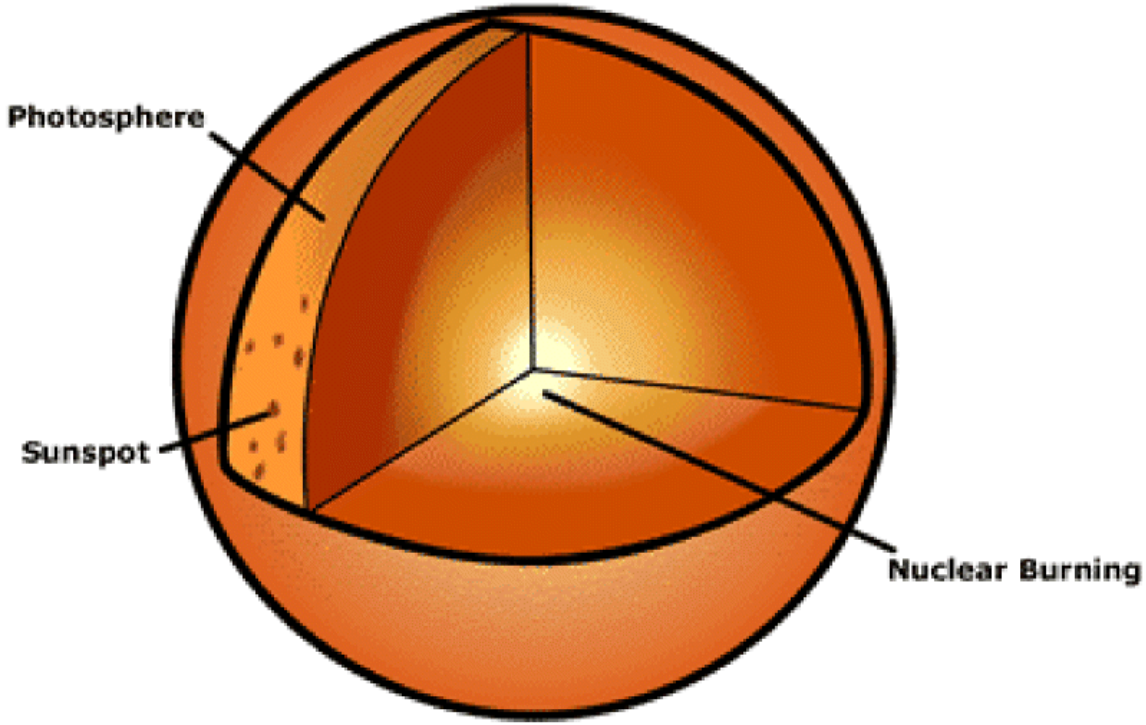
30 Million years



Age of the Sun: 4.6 Billion years

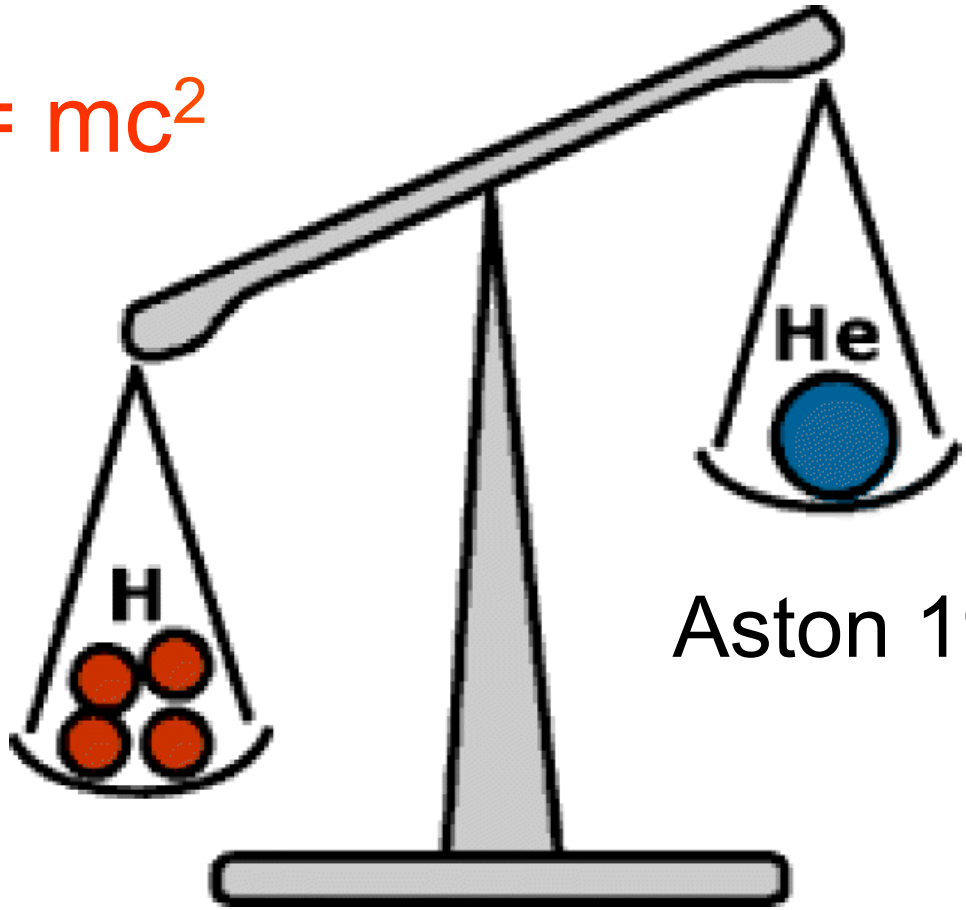


Gravity compresses the hydrogen gas, allowing the center of the Sun to become a thermo-nuclear plant



Einstein 1905

$E = mc^2$



Aston 1920

That is how the sun shines?

Theory: 1939

H. A. Bethe

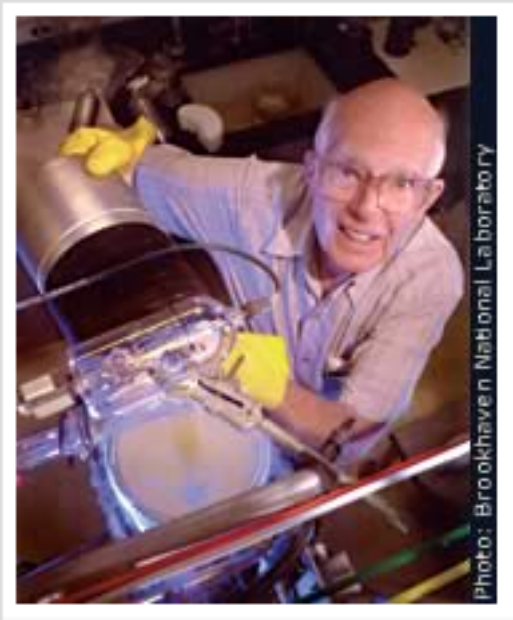
$p+p+p+p = He + \nu + \gamma + ...$

The sun is shining with light and neutrinos !

To understand the Sun we must observe neutrinos

To observe neutrinos we need special instruments (and special laboratories)

Bruno Pontecorvo

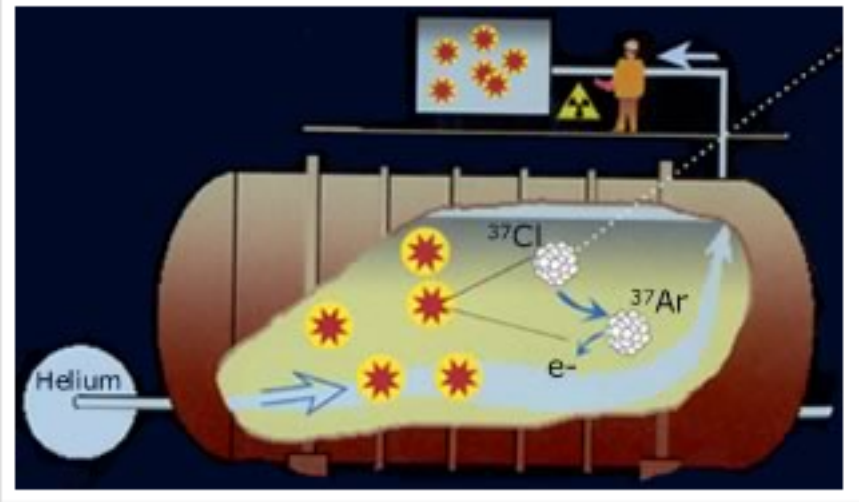


Pontecorvo proposed a detection method.

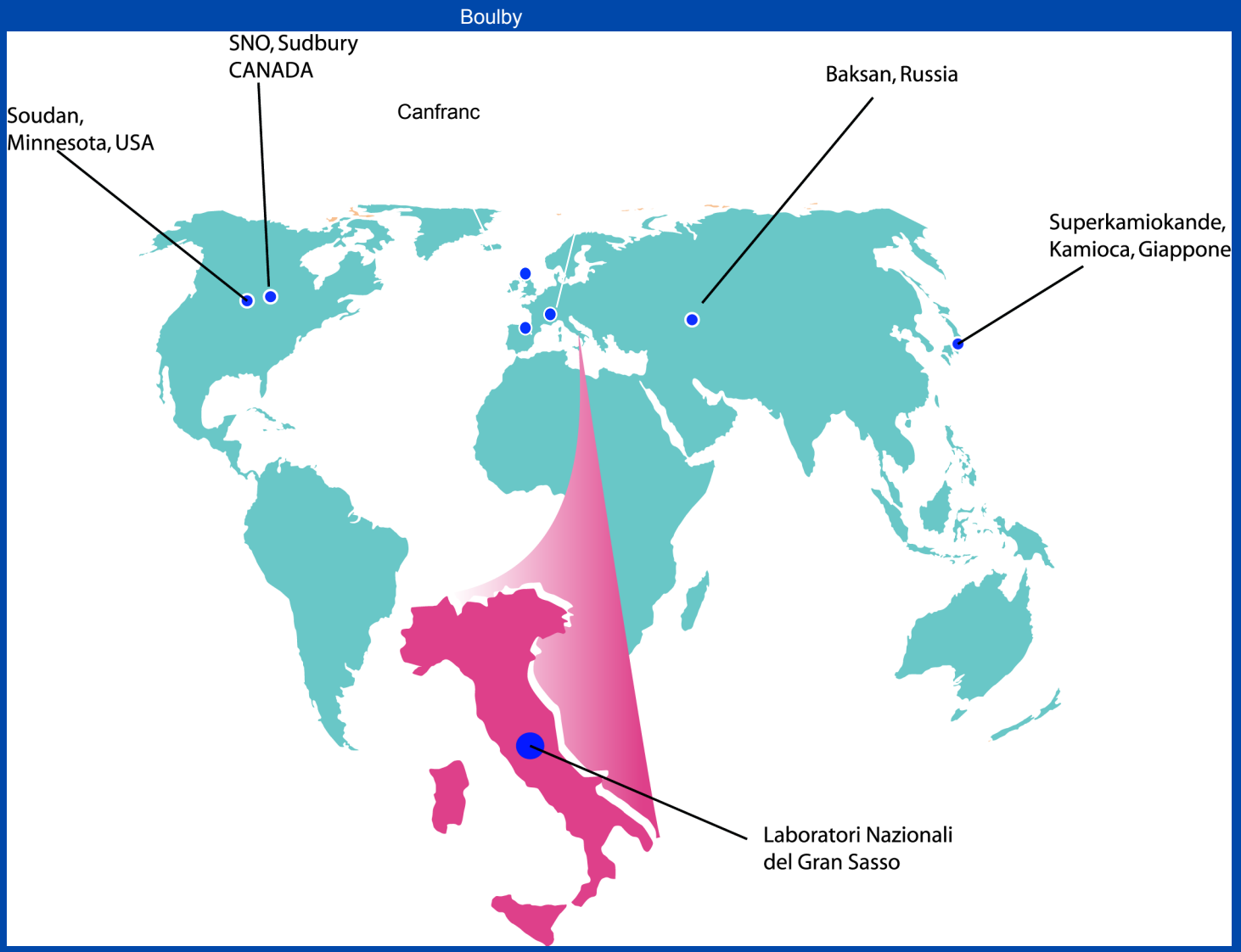
Solar neutrinos can sometimes turn a chlorine atom into a radioactive argon atom, which is easy to detect.

Years later, Raymond Davis Jr. placed an enormous tank filled with chlorine-rich cleaning fluid in a deserted gold mine.

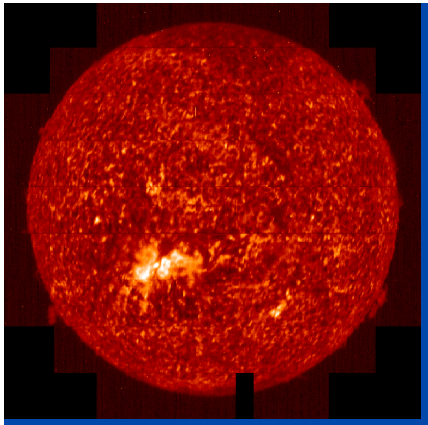
He collected and counted the argon atoms produced in the tank – an almost impossible task since there were so few of them.



Underground Laboratories



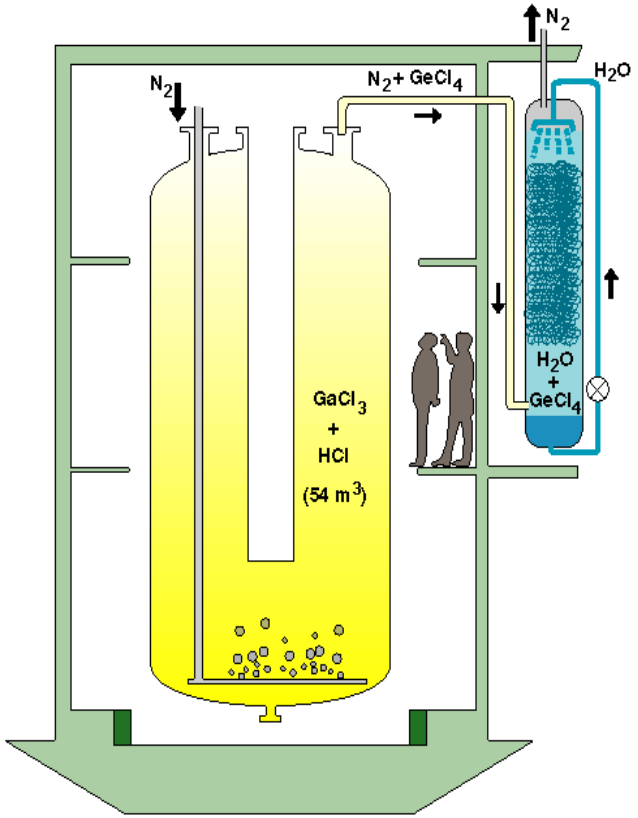
Laboratori Nazionali del Gran Sasso - INFN

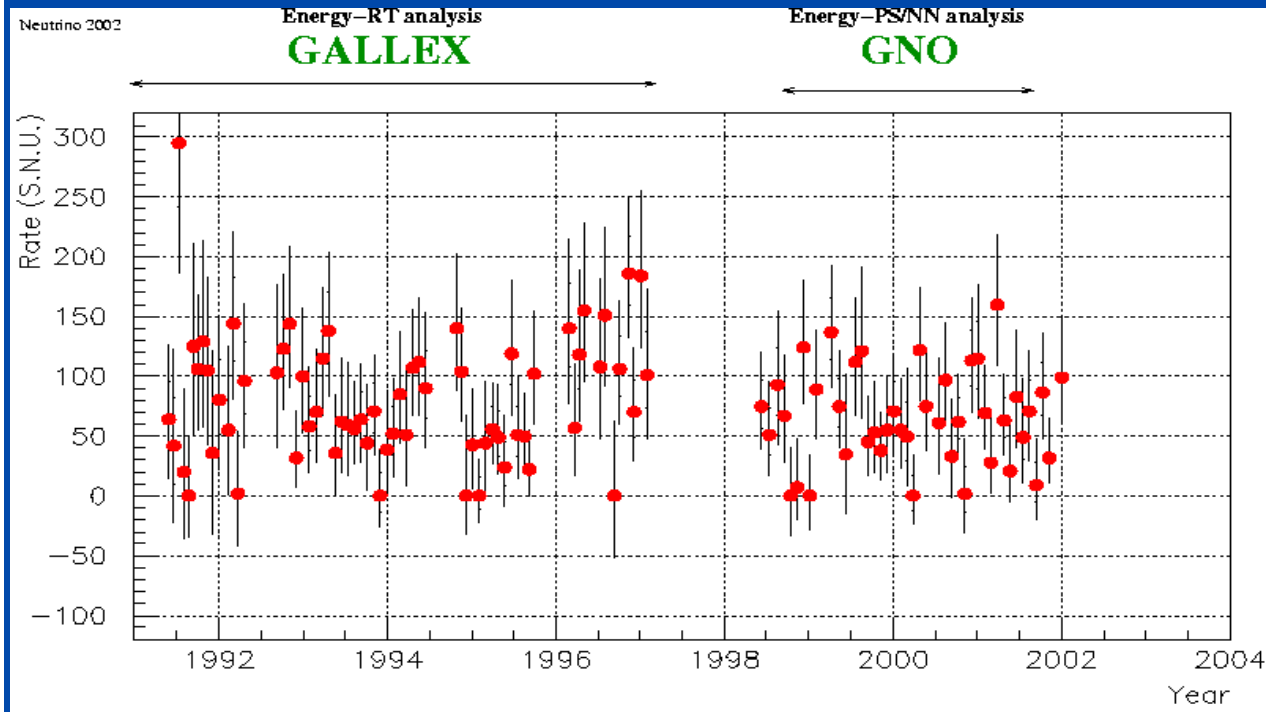


Gallex

Collab.:
Italy, France, Germany

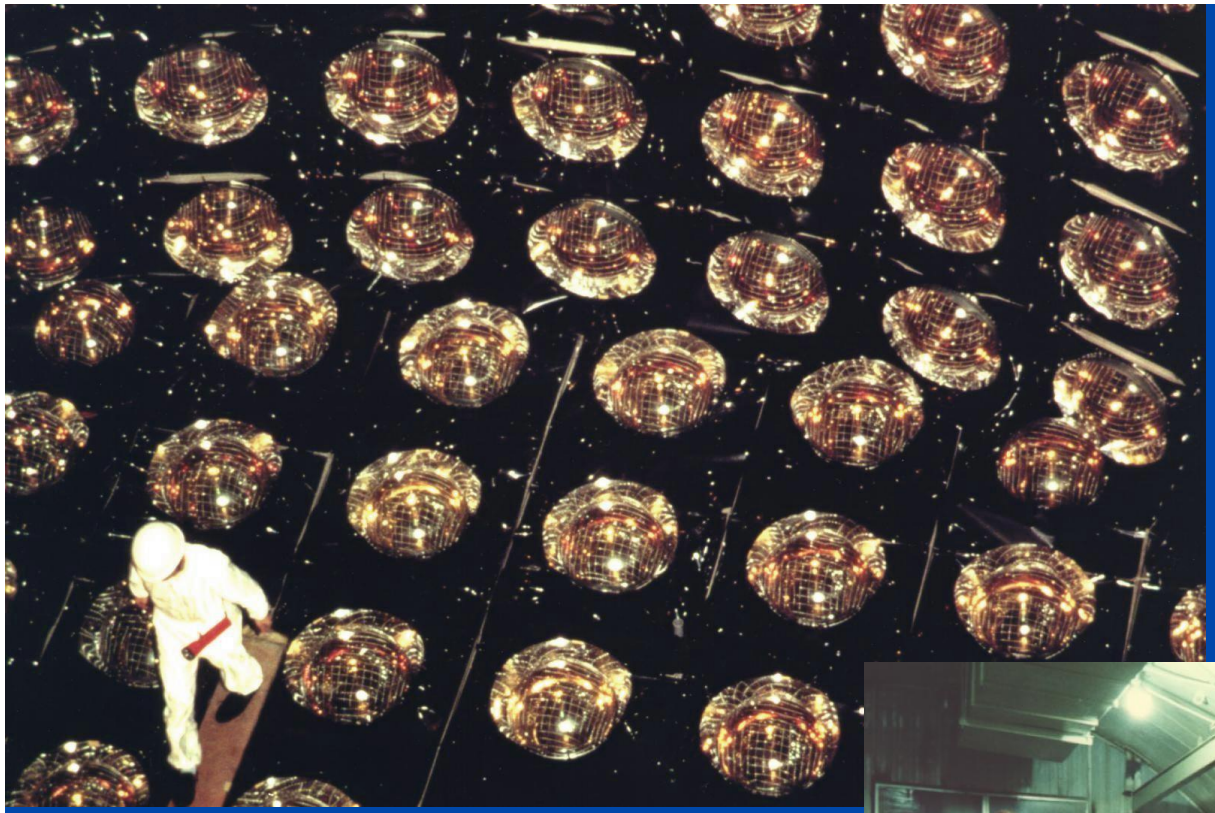
Flux = 0.5





GALLEX	65 SR	77.5 +– 6.2 (stat) +– 4.5 (sys) SNU
GNO	43 SR	65.2 +– 6.4 (stat) +– 3.0 (sys) SNU
GNO+GALLEX	108 SR	70.8 +– 4.5 (stat) +– 3.8 (sys) SNU

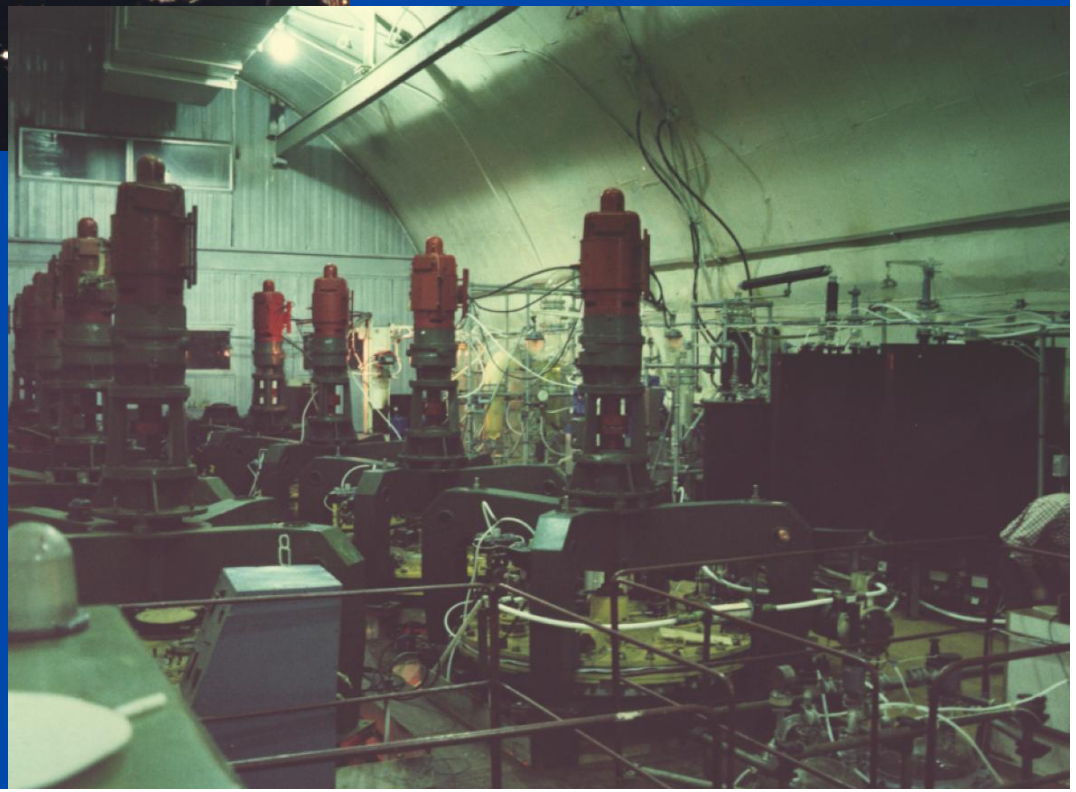
INFN



Kamiokande

Japan

Flux = 0.5



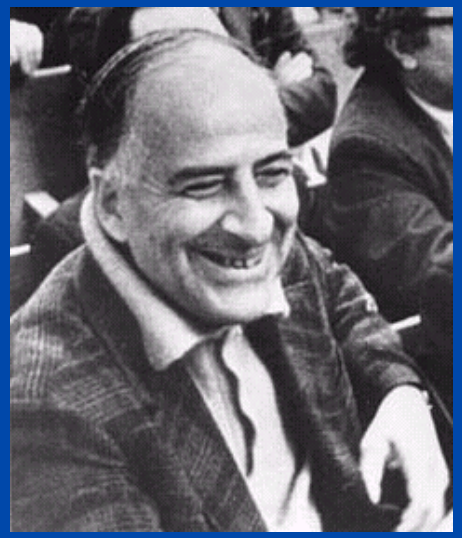
SAGE

Russia

Flux = 0.5

The mystery of the missing neutrinos

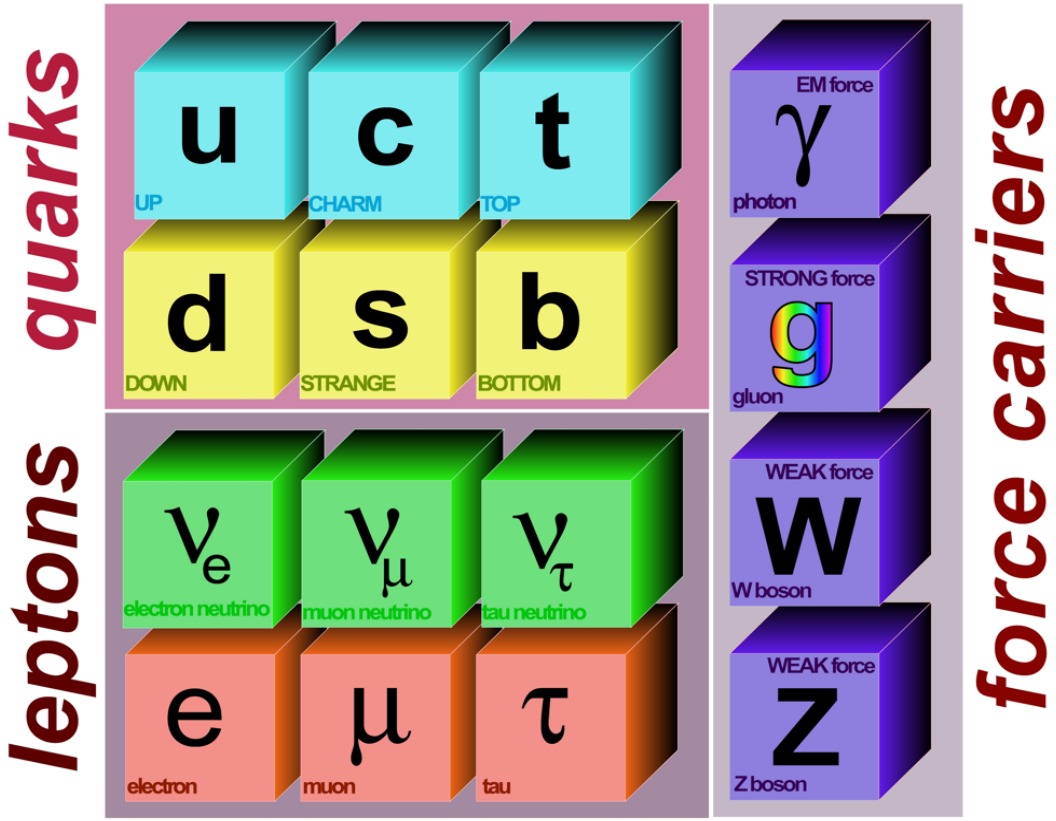
Pontecorvo, once more



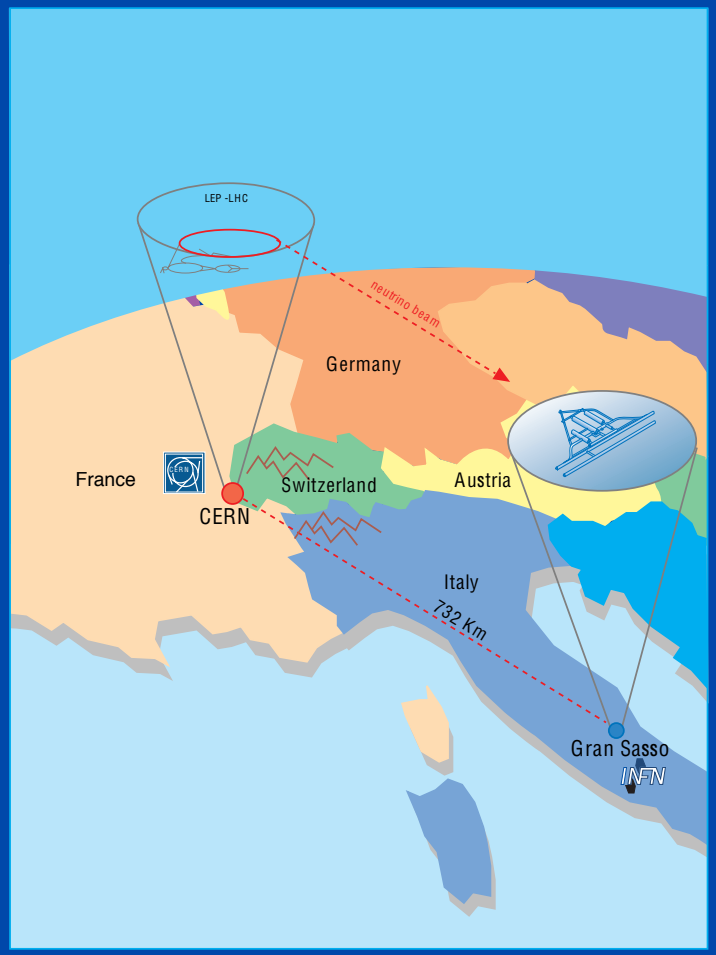
Neutrinos oscillate!


Vm ≠ Ve
PISA 22·8·1
24·9·
FISICO

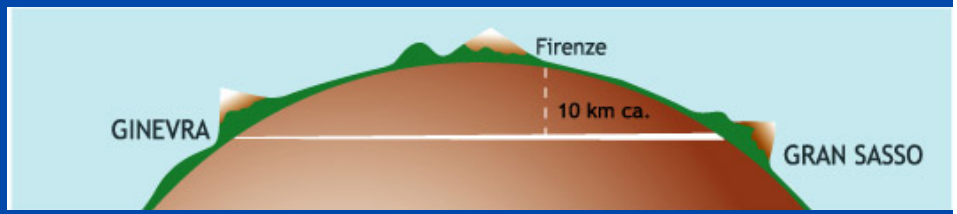
The Standard Model of Elementary Particles



CNGS CERN to Gran Sasso Neutrino Project

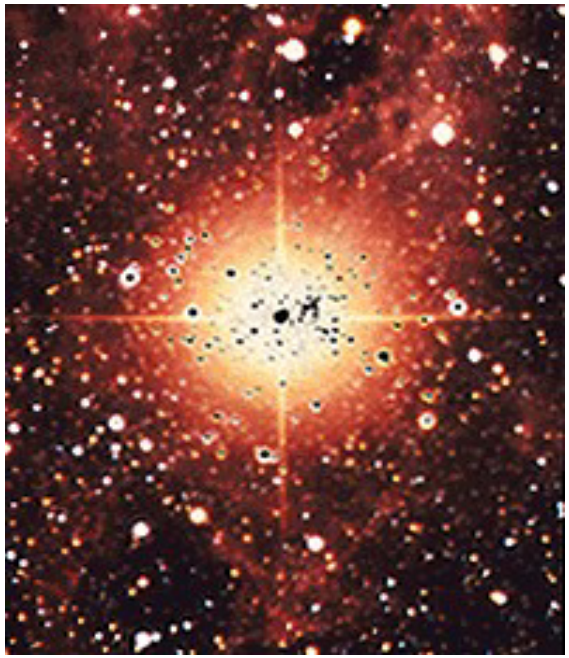


ν_μ beam produced at CERN and detected at LNGS after a travel of 730 km

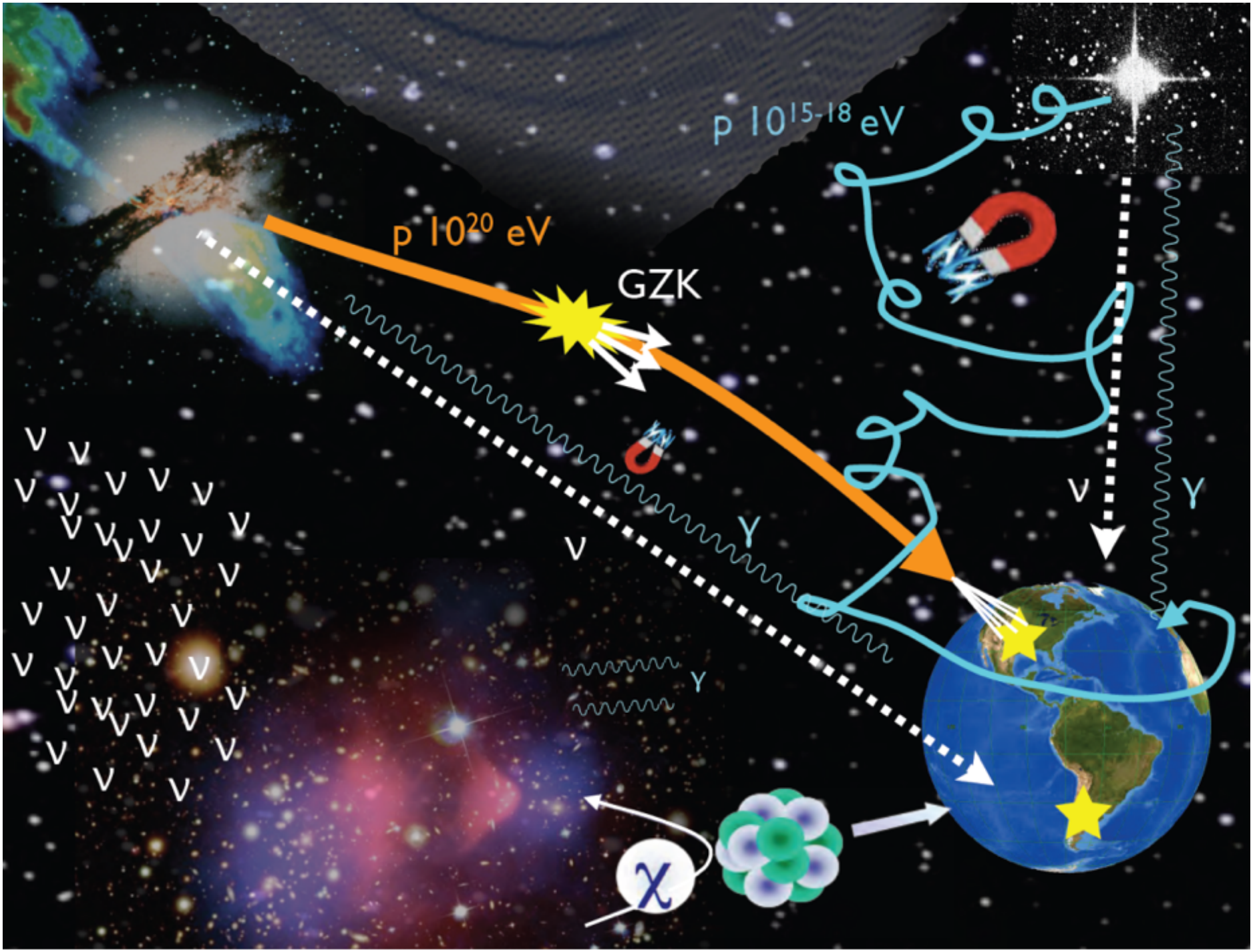


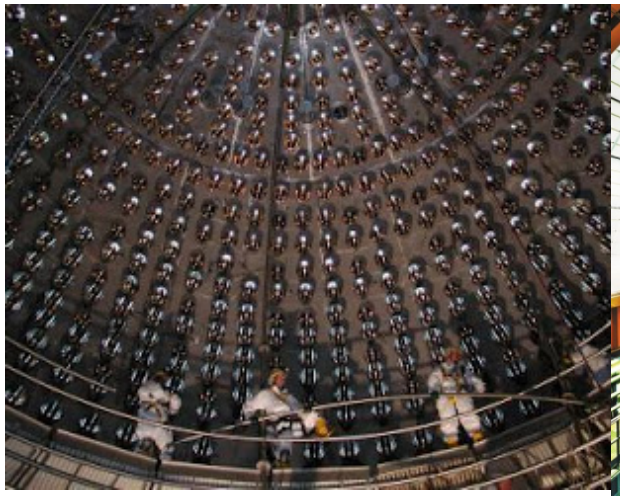
INFN

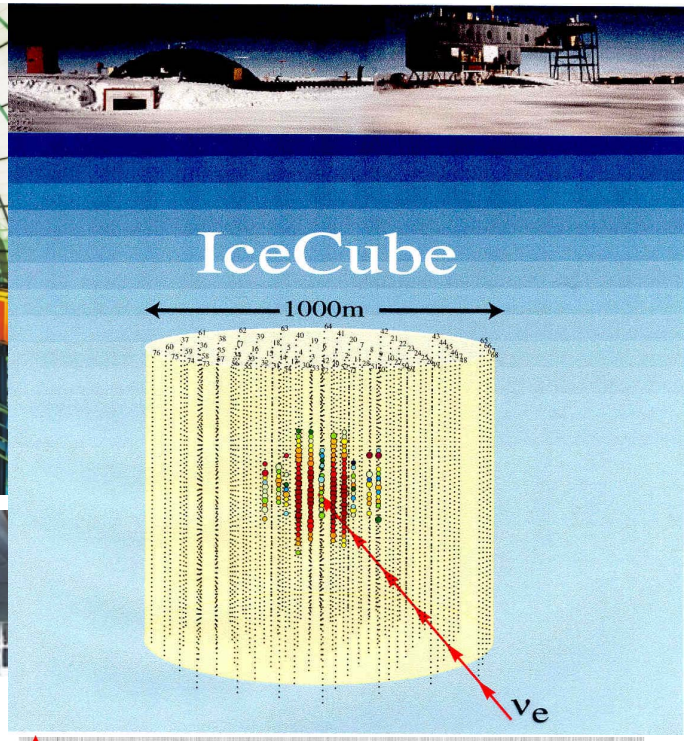
Masatoshi Koshiba followed up on the measurements made by Raymond Davis Jr by developing a large water-filled detector, called Kamiokande, in a Japanese mine. Kamiokande was direction sensitive and could confirm that neutrinos came from the sun.

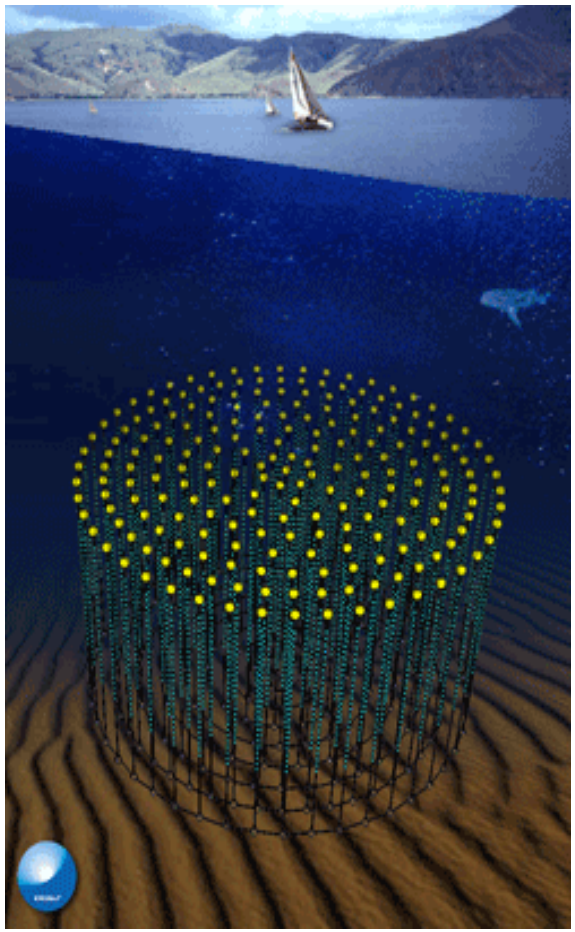


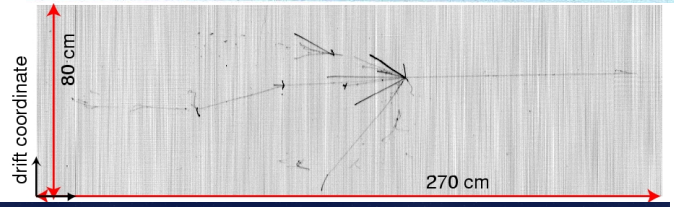
The detector was operating on 23 February 1987 and detected 12 of the 10^{58} neutrinos emitted by supernova 1987A when it exploded 170,000 light years from the earth – the first observation of neutrinos produced outside our galaxy

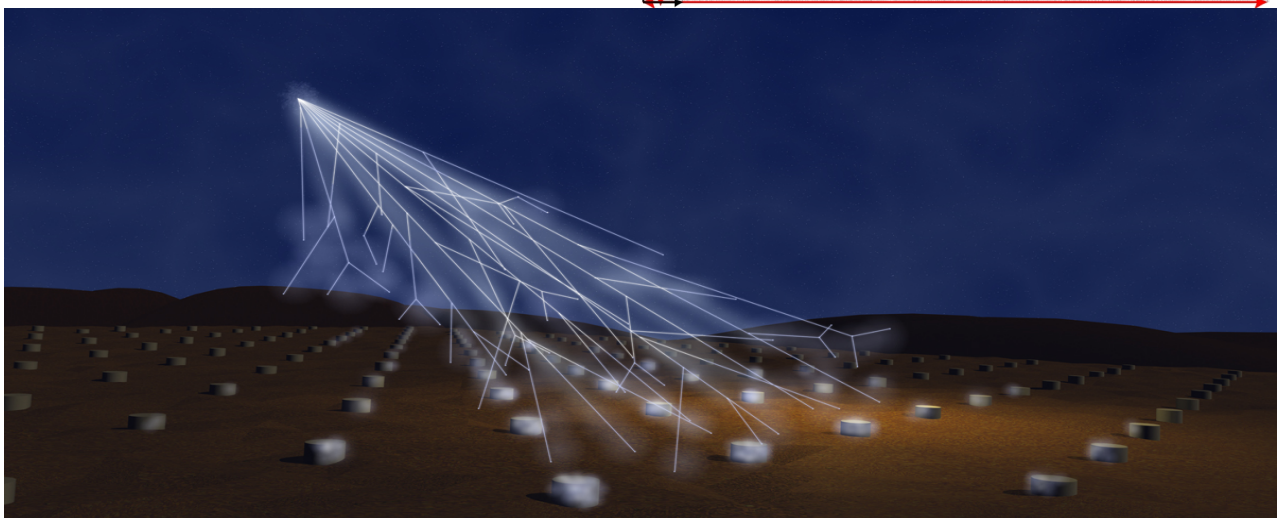

p $10^{15\text{-}18}$ eV
p 10^{20} eV
GZK
ν
γ
χ




IceCube
1000m
ν_e




drift coordinate
80 cm
270 cm

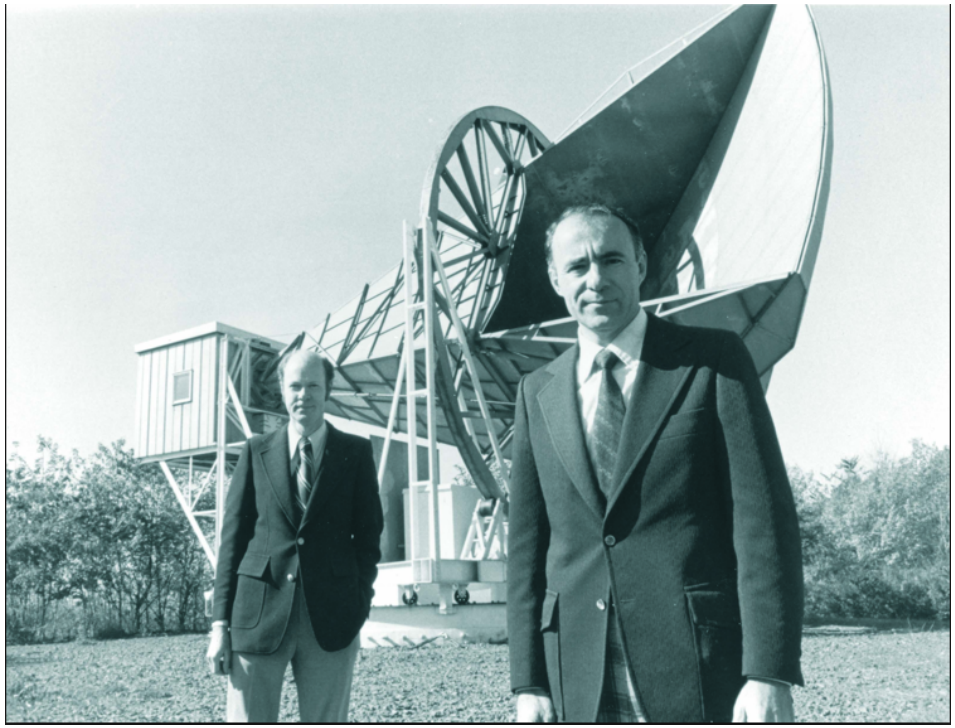


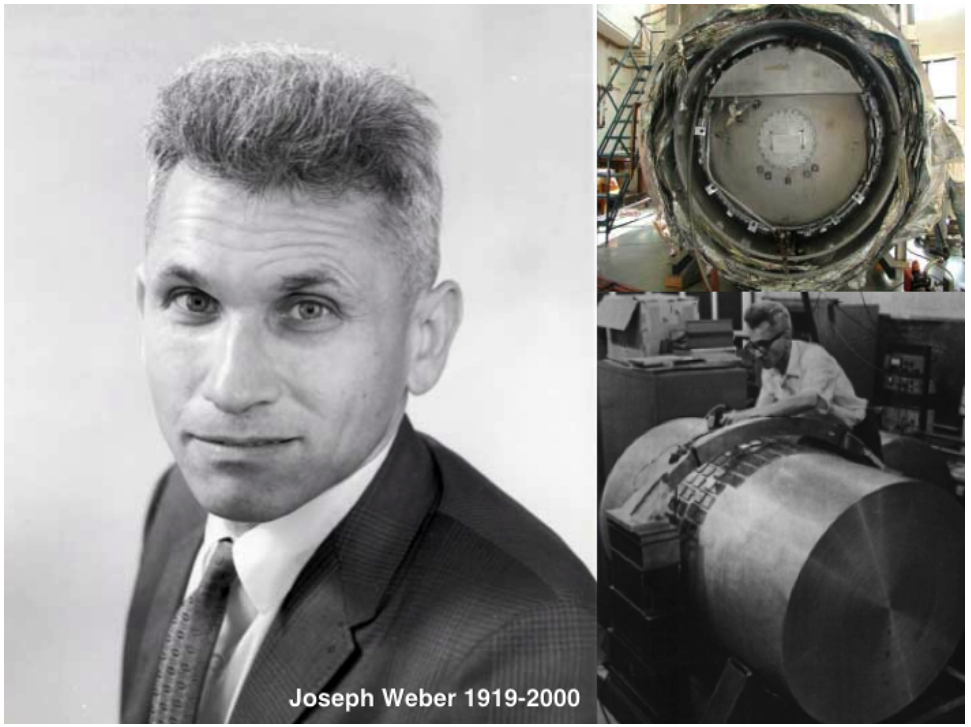
The Italian physicist Edoardo Amaldi, who was born 105 years ago, worked in nuclear physics in the Fermi group before the Second World War and, afterwards, gave fundamental contributions to particle physics and to gravitational-wave research.
He also played a key role in the setting up of CERN and the European Space Agency, and in promoting arms control.

U. Amaldi "Renaissance man", Physics World, September 2008.

During the sixties Amaldi tried to push the Italian physicists in the direction of new researches in the birth phase:

Infrared Background radiation and Gravitational Waves (after Penzias & Wilson and Weber's experiments).





Guido Pizzella was Amaldi's assistant and wanted to change its activity from space research (he worked with Van Allen in USA) to a more fundamental field. His decision was: Gravitational Waves (Francesco Melchiorri later choose the infrared background).

In the words of Guido:

"On September 3rd 1970, I said to Amaldi: *Professor, I want to make an experiment for the search of gravitational waves*. His eyes lighted and immediately we agreed to proceed."

What kind of experiment?

"In January 1971 Amaldi received the Stanford and Louisiana proposal for a detector consisting in a 5 ton aluminum bar cooled to very low temperature (0.003 K) employing a dcSQUID amplifier coupled to a resonant transducer.

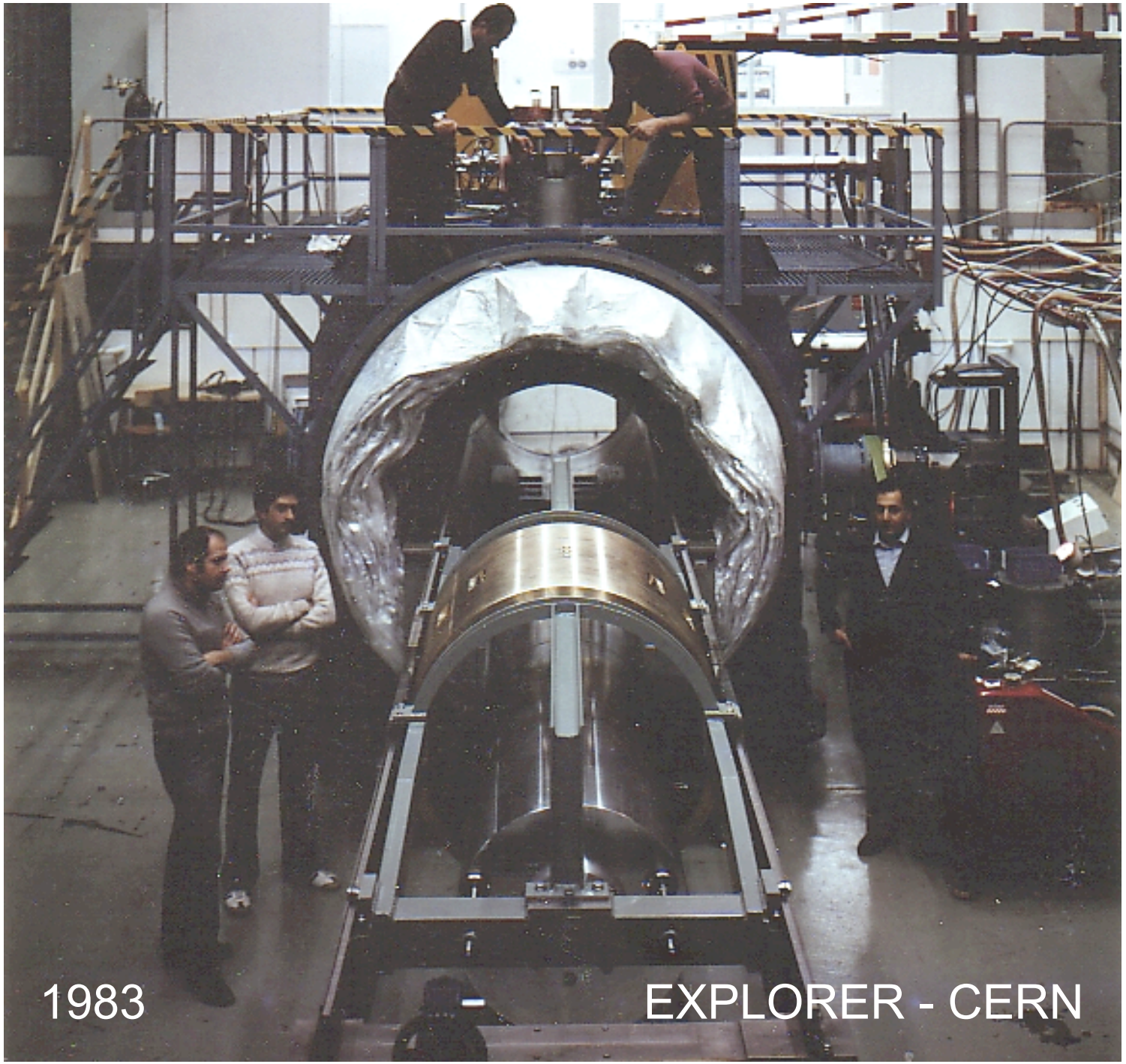
It was clear to Amaldi and me that this was the kind of experiment we should have aimed to realize."

Bill Fairbank

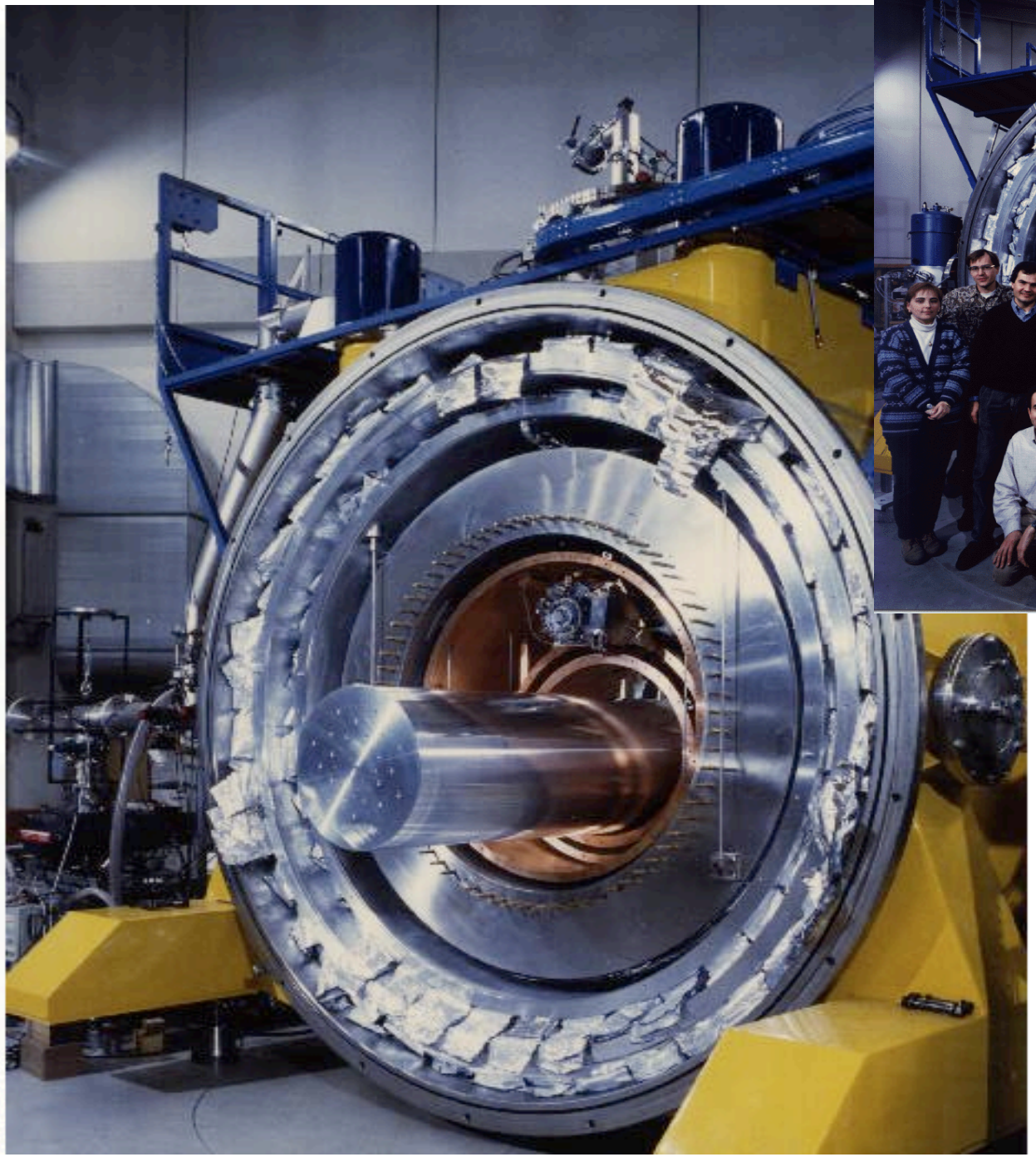
Bill Hamilton

Gravitational wave research was Amaldi main scientific interest in its last twenty years.
Since the beginning, he considered this research within the INFN mission, as part of the astroparticle physics sector.

First nucleus working with Amaldi and Pizzella


1983
EXPLORER - CERN


NAUTILUS
INFN Frascati

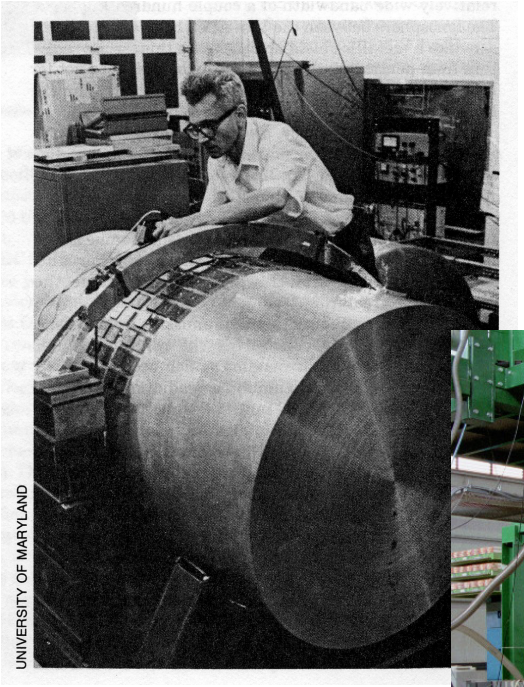


AURIGA

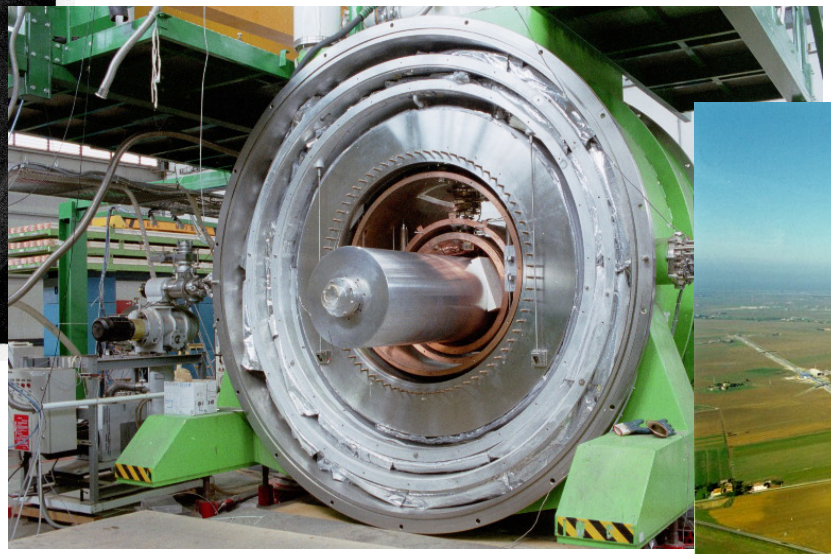
INFN Legnaro

Some perspective: 40 years of attempts at detection:

Since the pioneering work of Joseph Weber in the ‘70, the search for Gravitational Waves has never stopped, with an increasing effort of manpower and ingenuity:



70’: Joe Weber pioneering work



90’: Cryogenic Bars

2005 - : Large Interferometer Detectors

GW OBJECTIVES

FIRST DETECTION

test Einstein prediction

$$\mathbf{G} = \frac{8\pi G}{c^4}\mathbf{T}$$

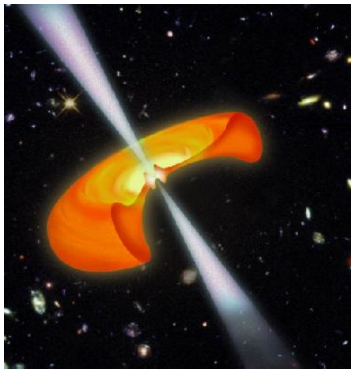
ASTRONOMY & ASTROPHYSICS

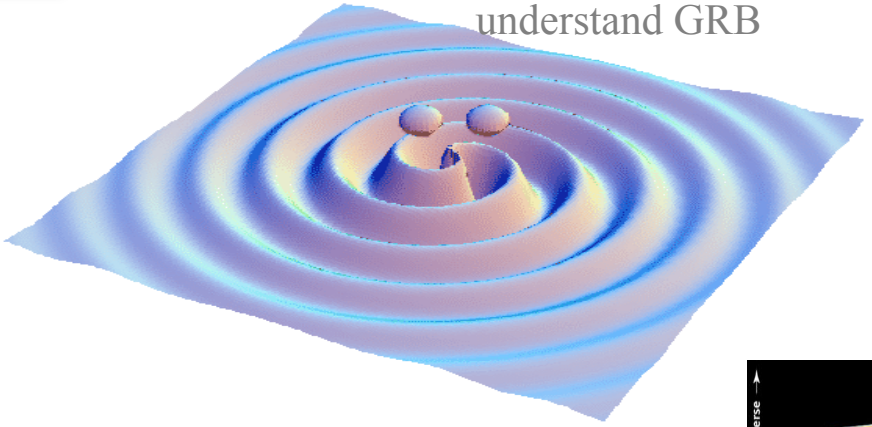
look beyond the visible,

understand Black Holes,

Neutron Stars and supernovae

understand GRB

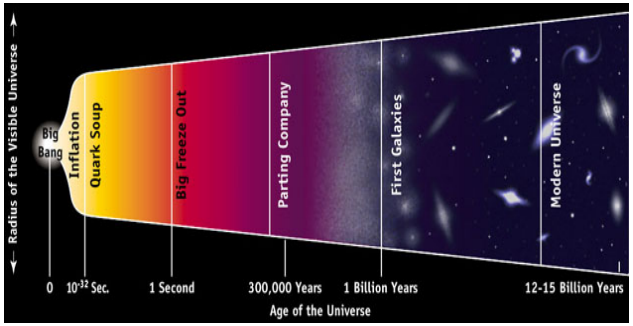


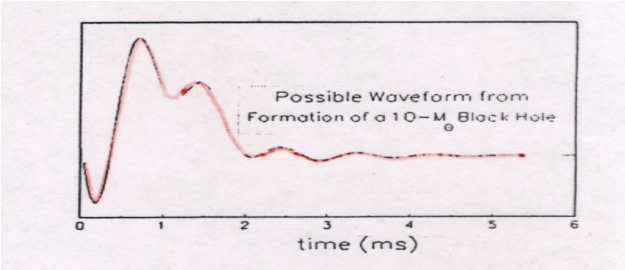


COSMOLOGY

the Planck time:

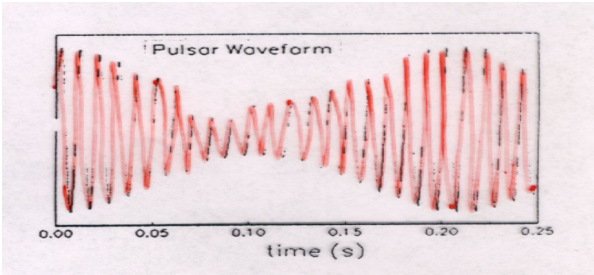
look as back in time as theorist can conceive





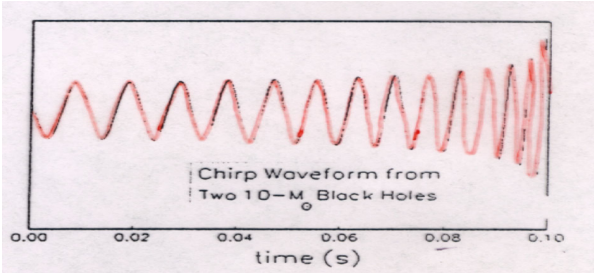
SUPERNOVAE.
If the collapse core is non-symmetrical, the event can give off considerable radiation in a millisecond timescale.

Information
Inner detailed dynamics of supernova
See NS and BH being formed
Nuclear physics at high density



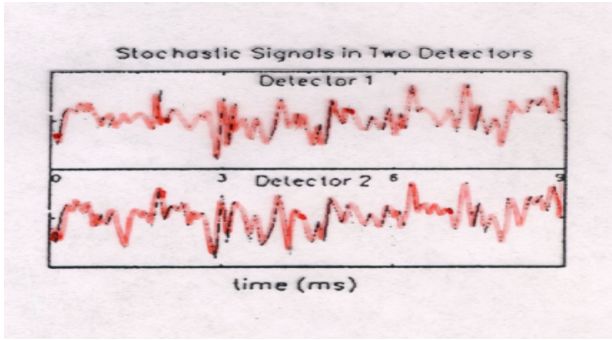
SPINNING NEUTRON STARS.
Pulsars are rapidly spinning neutron stars. If they have an irregular shape, they give off a signal at constant frequency (prec./Dpl.)

Information
Neutron star locations near the Earth
Neutron star Physics
Pulsar evolution



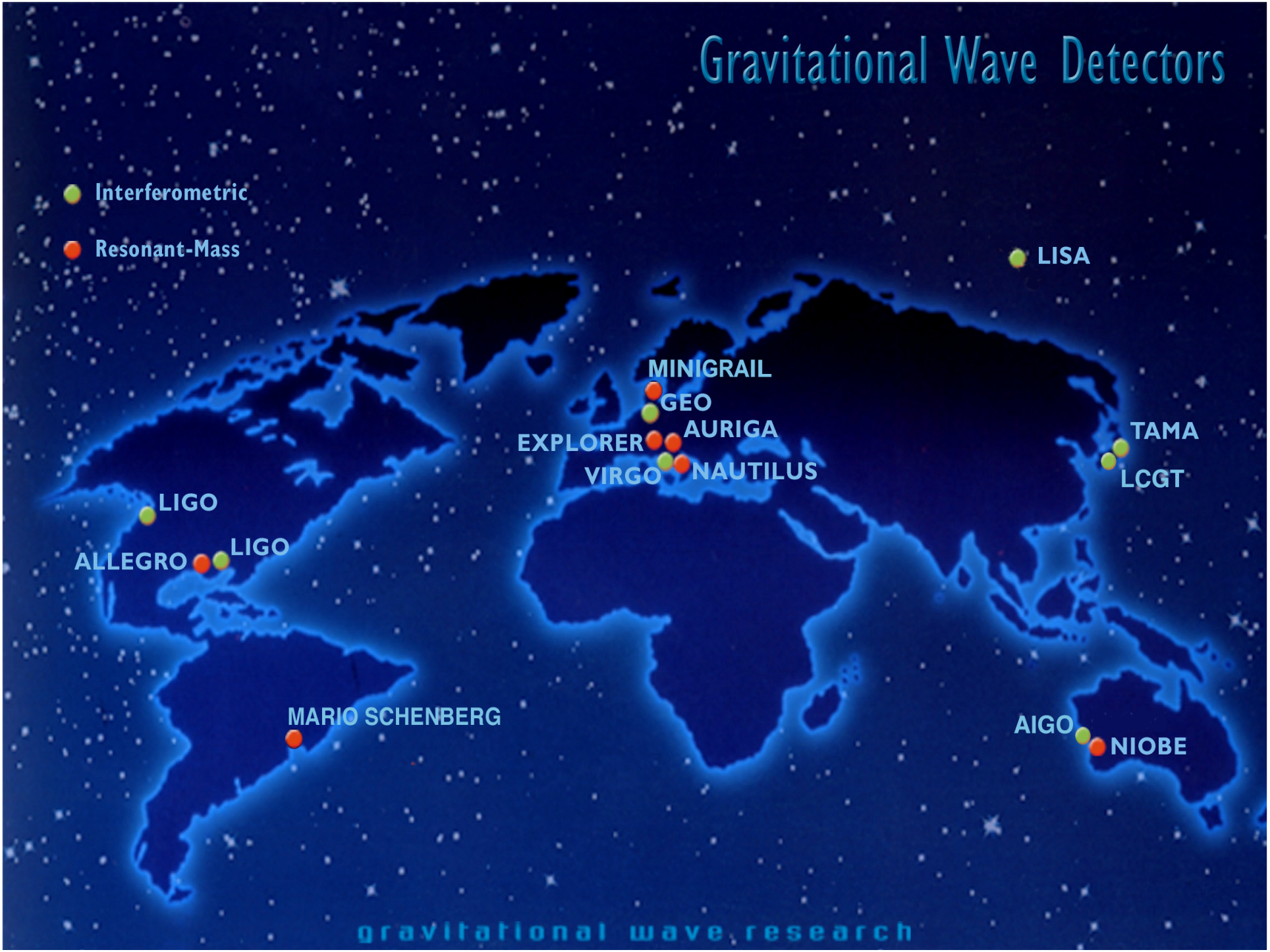
COALESCING BINARIES.
Two compact objects (NS or BH) spiraling together from a binary orbit give a chirp signal, whose shape identifies the masses and the distance

Information
Masses of the objects
BH identification
Distance to the system
Hubble constant
Test of strong-field general relativity



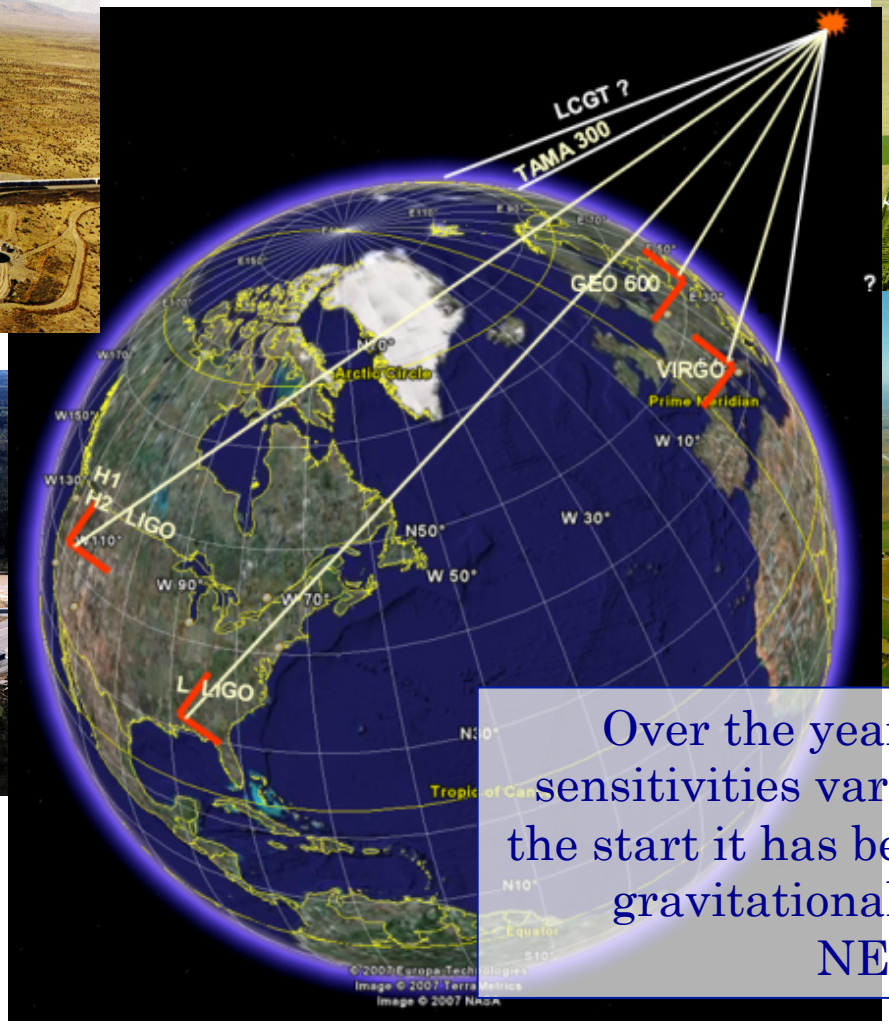
STOCHASTIC BACKGROUND.
Random background, relic of the early universe and depending on unknown particle physics. It will look like noise in any one detector, but two detectors will be correlated.

Information
Confirmation of Big Bang, and inflation
Unique probe to the Planck epoch
Existence of cosmic strings


Gravitational Wave Detectors
Interferometric
Resonant-Mass
LISA
MINIGRAIL
GEO
AURIGA
EXPLORER
NAUTILUS
VIRGO
TAMA
LCGT
LIGO
LIGO
ALLEGRO
MARIO SCHENBERG
AIGO
NIOBE
gravitational wave research

THE INTERFEROMETER NETWORK

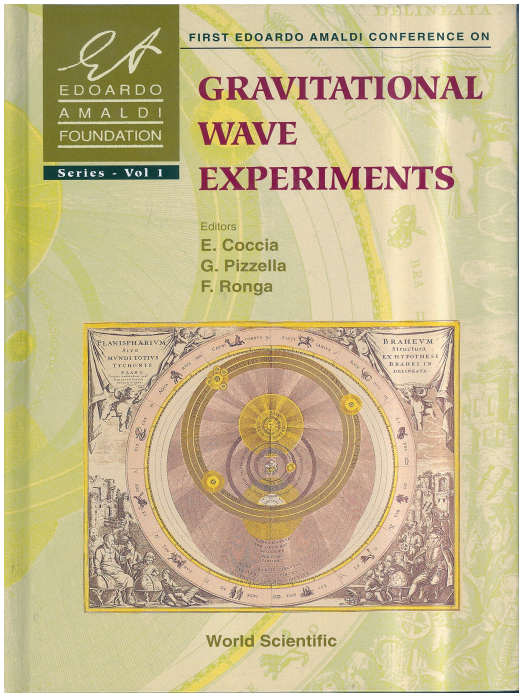
A network of 4 (5) GW detectors

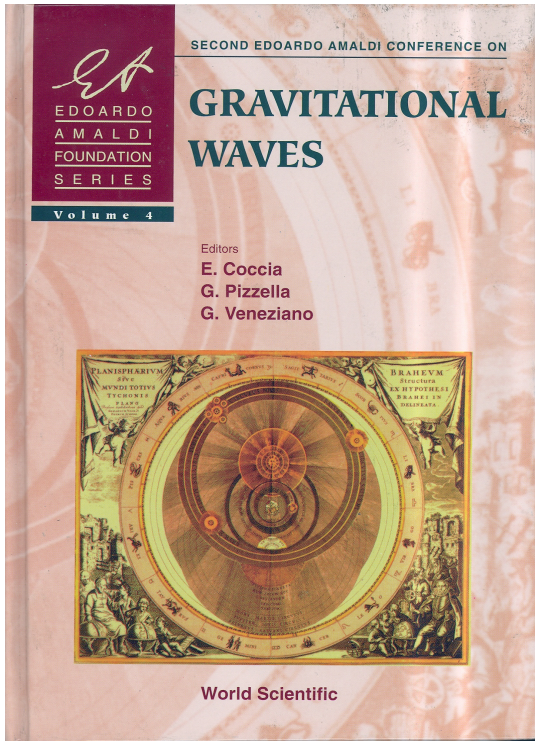


Over the years, techniques and sensitivities varied greatly. But since the start it has been clear that to detect gravitational waves we need a NETWORK

The Edoardo Amaldi Conference series on Gravitational Waves

In 1993 Nautilus, the first ultracryogenic bar detector, started operating at the INFN Frascati Lab. It seemed natural to me to organize a new conference on GW experiments in Frascati, and to dedicate it to Amaldi. The idea was that this conference could be the first of a series. So the first Amaldi conference was held in Frascati in 1994, with 120 participants from 13 countries.





The second edition was held at CERN in 1997, with a massive participation of the GW community. During the conference, the Gravitational-Wave International Committee (GWIC) was formed, under the chairmanship of Barry Barish. Barry agreed to organize the third edition in the US.
Since then, Caltech 1999, EAC is biennial and coordinated by GWIC as the cornerstone conference for the GW community worldwide.

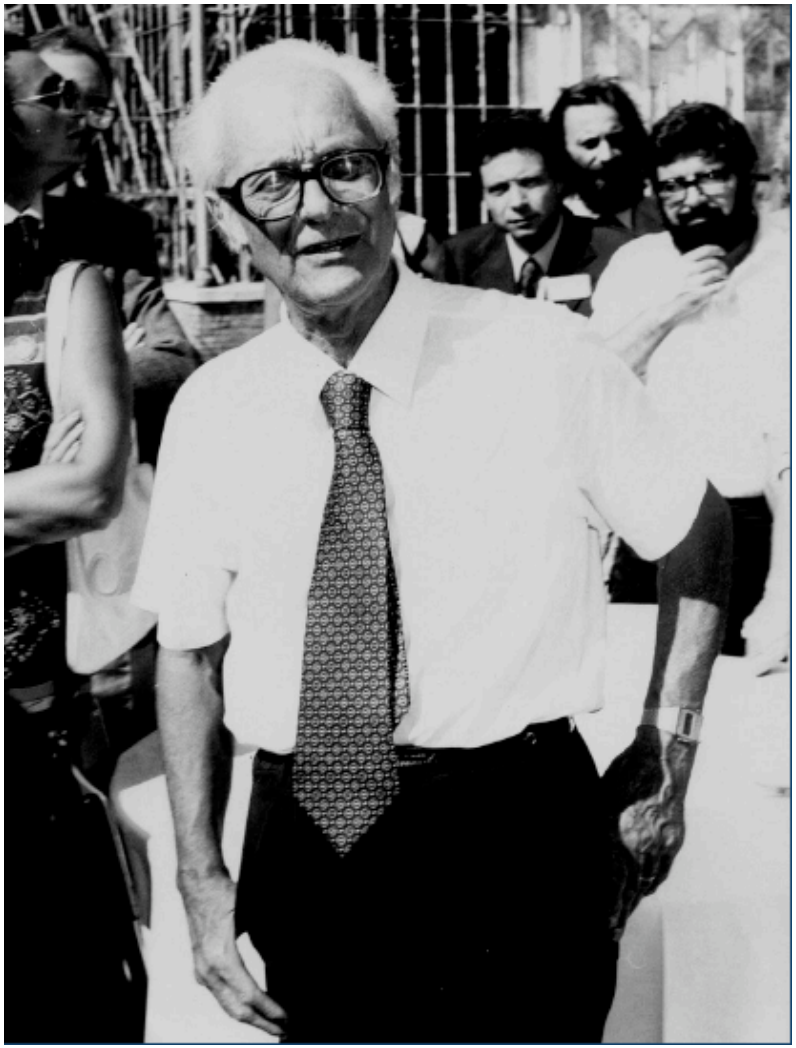
Amaldi contributions and qualities are perhaps best summarized by the particle physicist and Nobel laureate Carlo Rubbia, who was director general of CERN between 1989 and 1993.

In his biography of Amaldi for the Royal Society, Rubbia wrote:

Though Edoardo Amaldi considered himself above all as a man of science, there can be no doubt that he was one of Europe great postwar scientific statesmen.

Historian, teacher, man of ideals, it is also because of his human qualities that he will be remembered. His exemplary coolness of mind, his total sincerity,

his respect for the deserving, his unwavering intellectual and moral honesty, and his constant affection to his family were the hallmarks of this remarkable man.



We shall not cease from exploration

And the end of all our exploring

Will be to arrive where we started

And know the place for the first time.

T.S. Eliot, Four quartets