Napoli, 17 Settembre 2012

XCVIII Congresso della Società Italiana di Fisica

Premio Giuseppe Occhialini 2012

Eugenio Coccia

U. of Rome "Tor Vergata"

and INFN Gran Sasso Science Institute

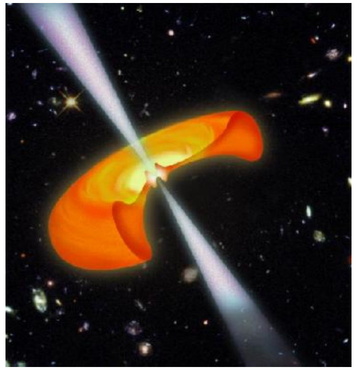
Chair of the Gravitational Wave International Committee

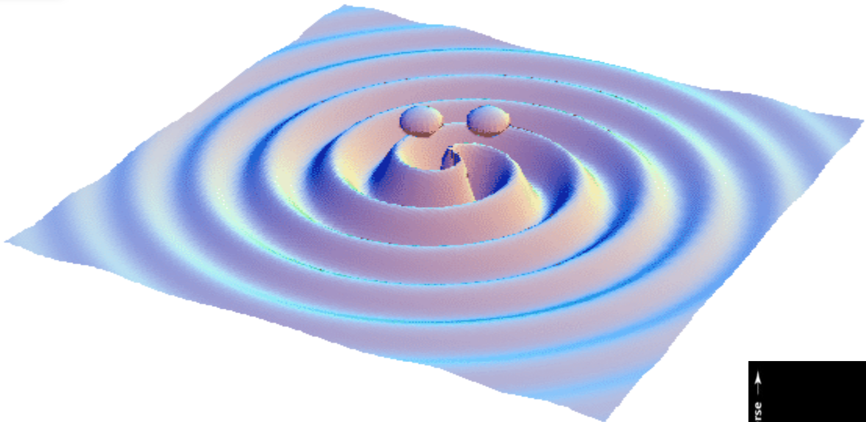
GW OBJECTIVES

FIRST DETECTION
test Einstein prediction

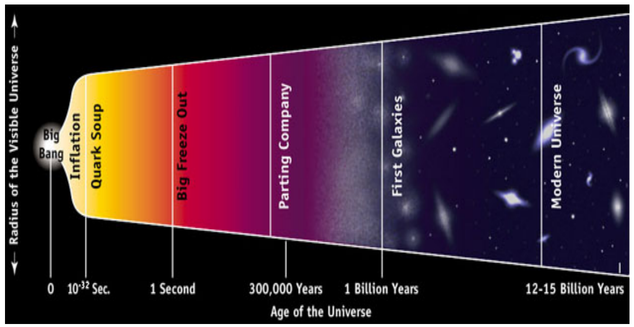
$$\mathbf{G} = \frac{8\pi G}{c^4}\mathbf{T}$$

ASTRONOMY & ASTROPHYSICS
look beyond the visible,
understand Black Holes,
Neutron Stars and supernovae
understand GRB



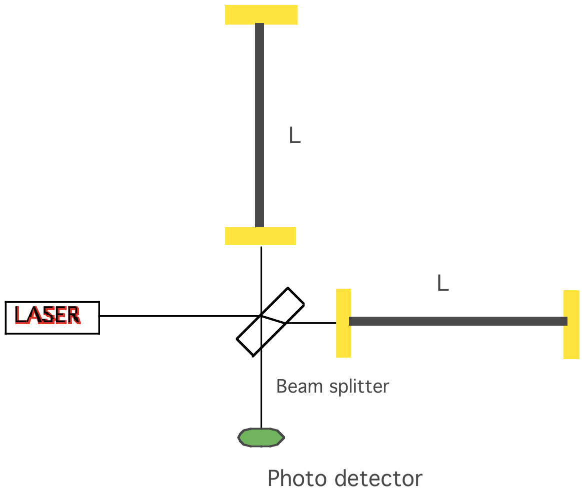


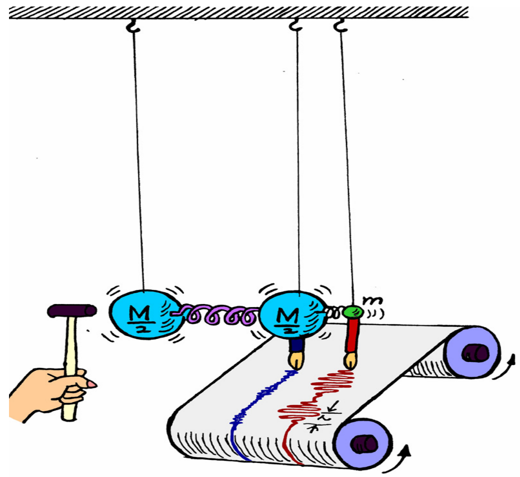
COSMOLOGY
the Planck time:
look as back in time as theorist can conceive



$$h = \frac{\Delta L}{L}$$

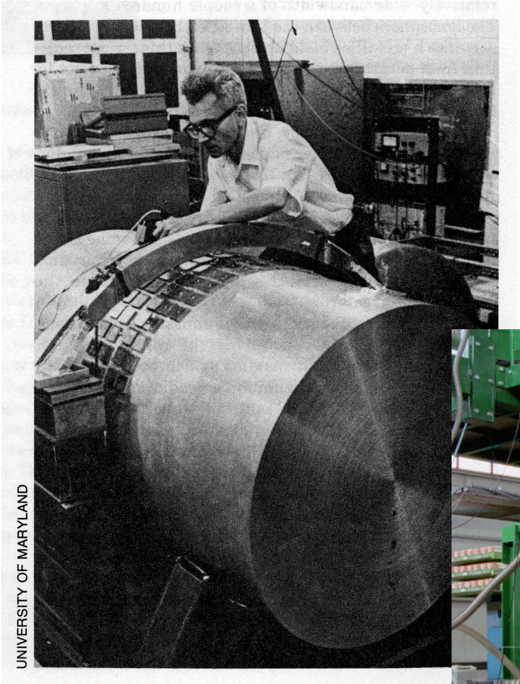
$$\ddot{x}(t) + \tau^{-1}\dot{x}(t) + \omega_0^2 x(t) = \frac{1}{2}\ddot{h}(t)$$



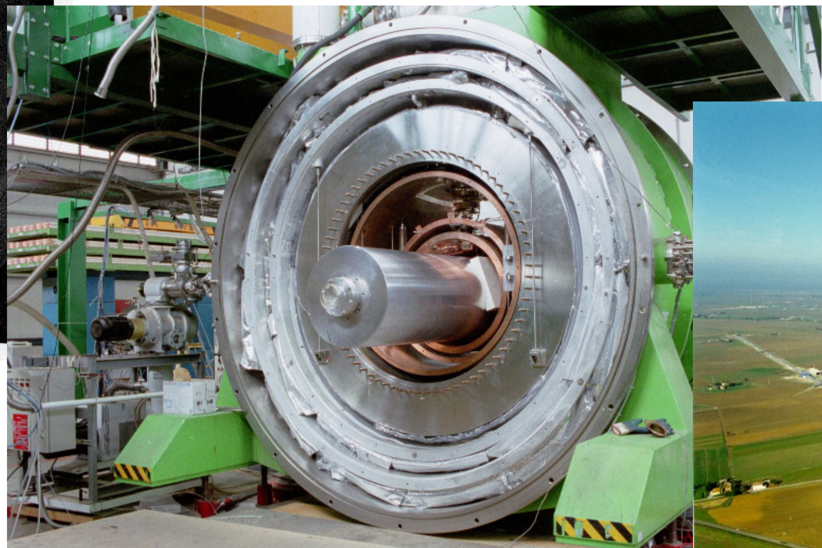


Some perspective: 40 years of attempts at detection:

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:

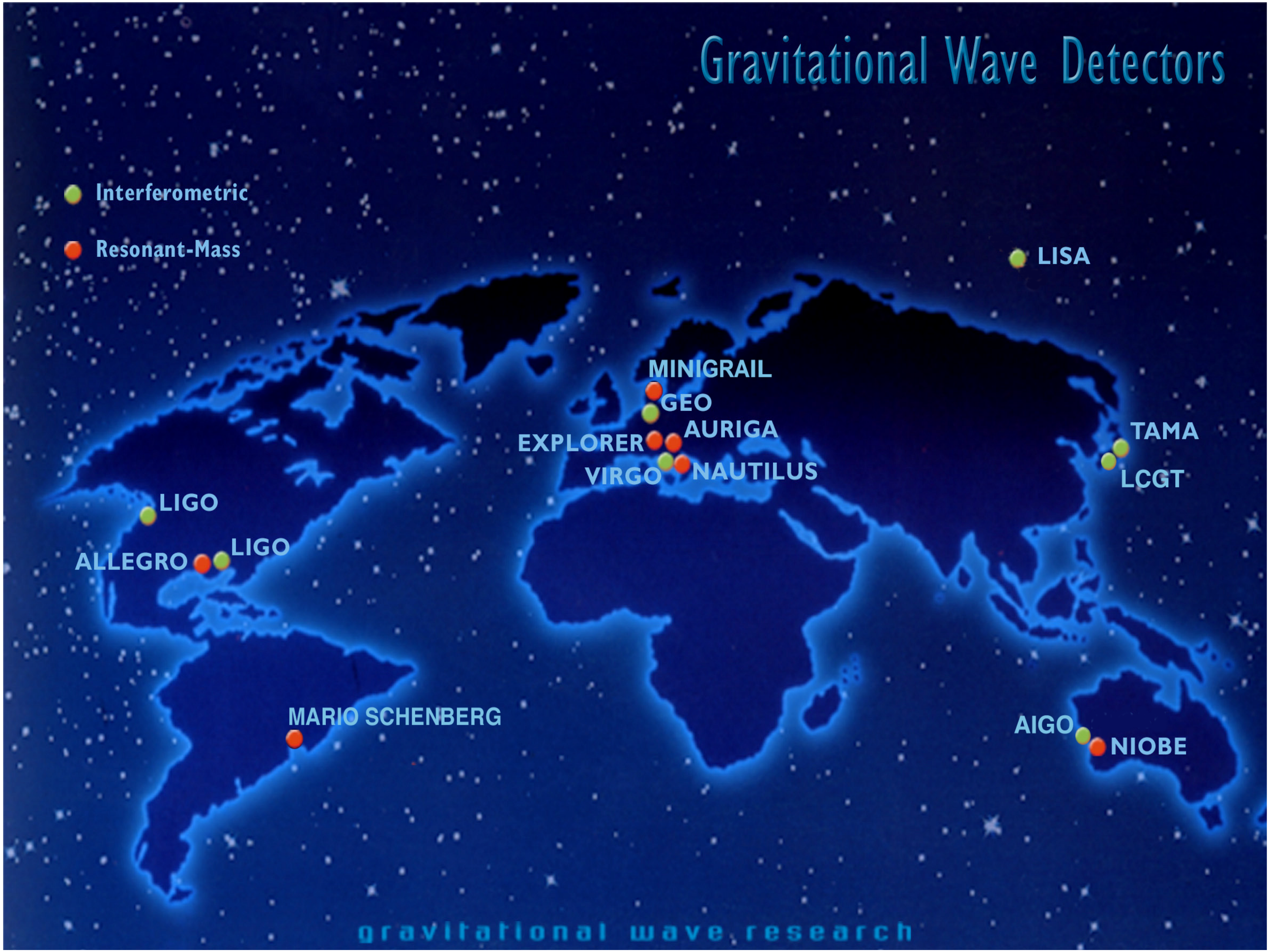


70' : Joe Weber pioneering work

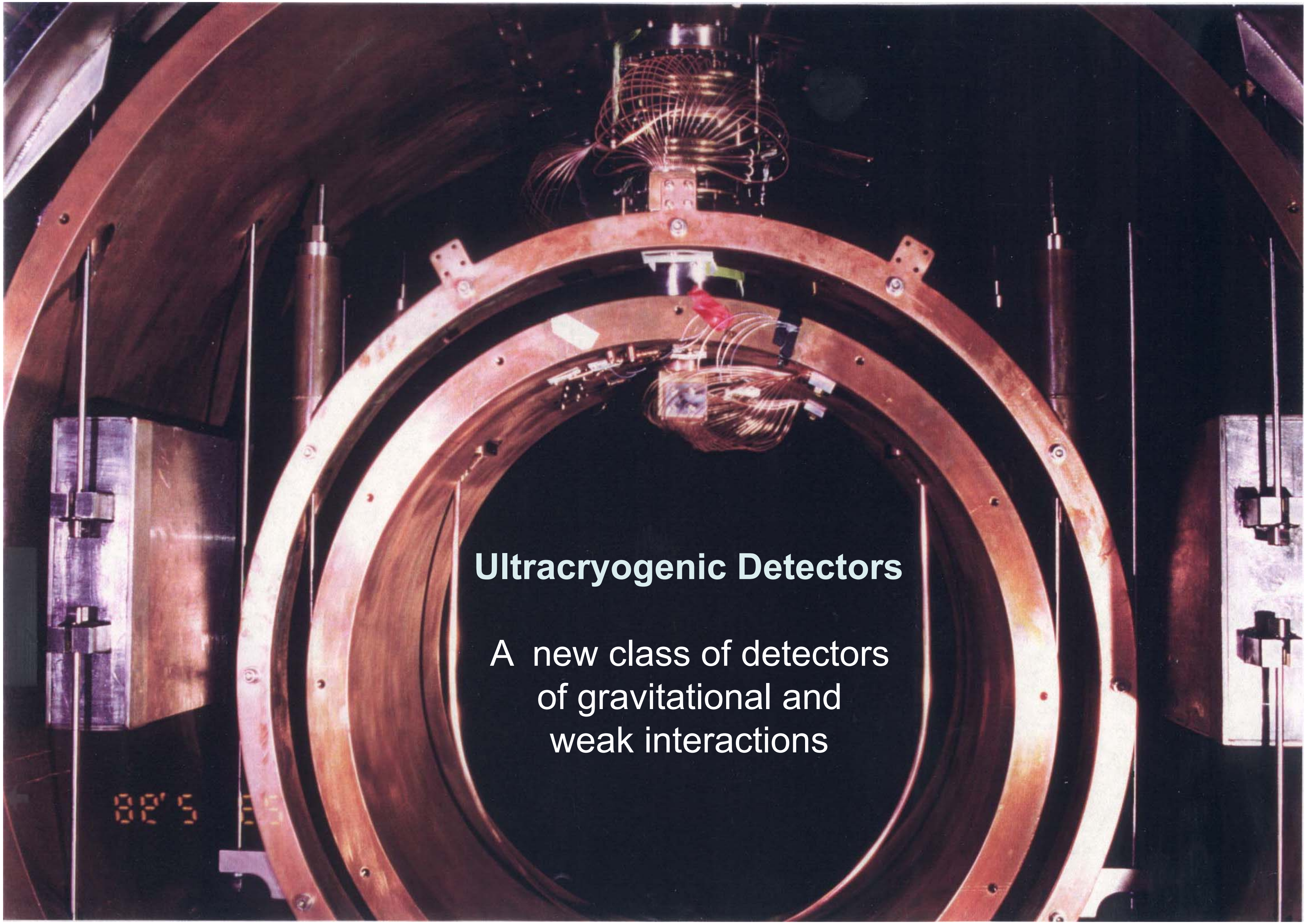


90' : Cryogenic Bars

2005 - : Large Interferometric Detectors


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





Ultracryogenic Detectors
A new class of detectors
of gravitational and
weak interactions

NAUTILUS
LNF - FRASCATI

Bar Al 5056 M = 2270 kg

L = 2.91 m Ø = 0.6 m

ν_A=935Hz @ T = 3 K

Cosmic ray detector

The Records of NAUTILUS

- Coldest massive detector

  2.5 tons at 90 mK *Europhys. Lett.16, 231 (1991)*

- Displacement sensitivity

  7×10^{-22} m/Hz$^{-1/2}$ *Phys. Rev. Lett. 85, 8046 (2000)*

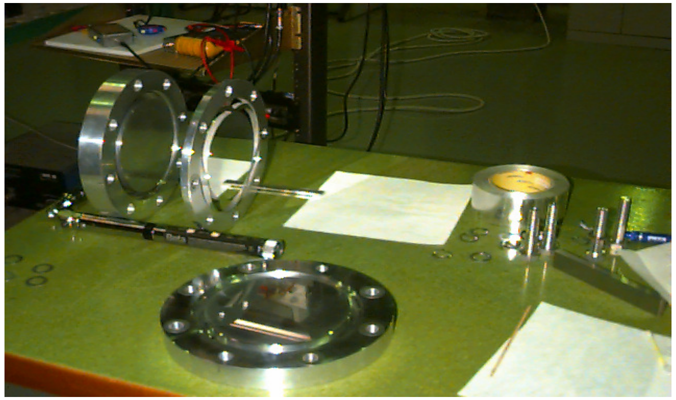
- Acoustic detection of cosmic rays

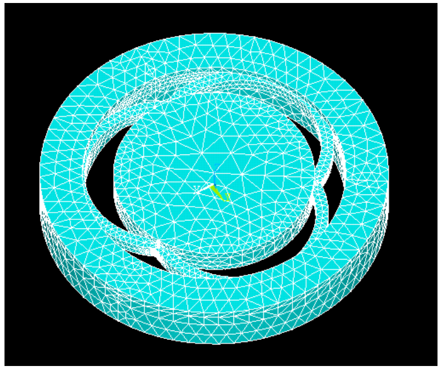
  Cabibbo-De Rujula t-a theory *Phys. Rev. Lett. 84, 14 (2000)*

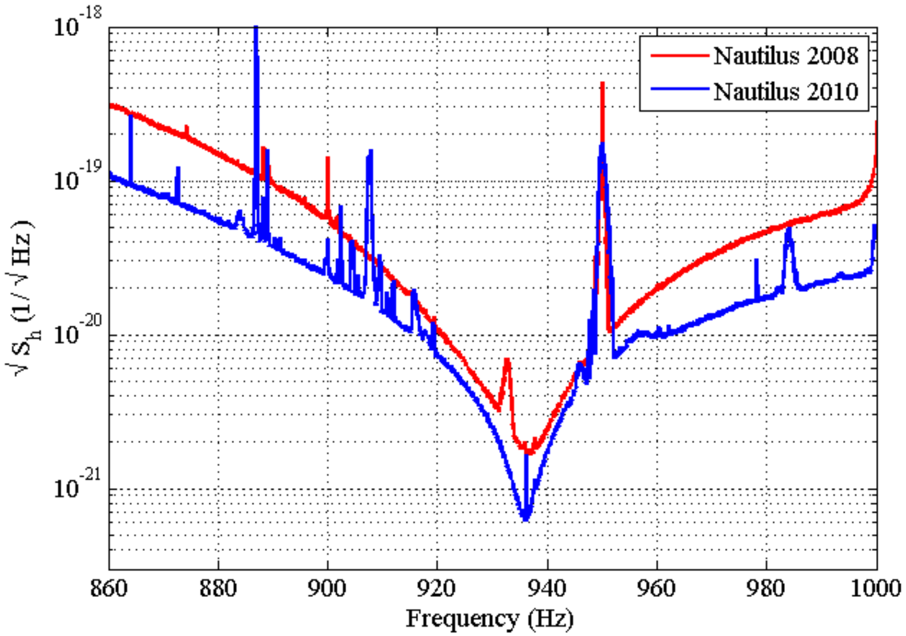
- Longest science run for GW detectors

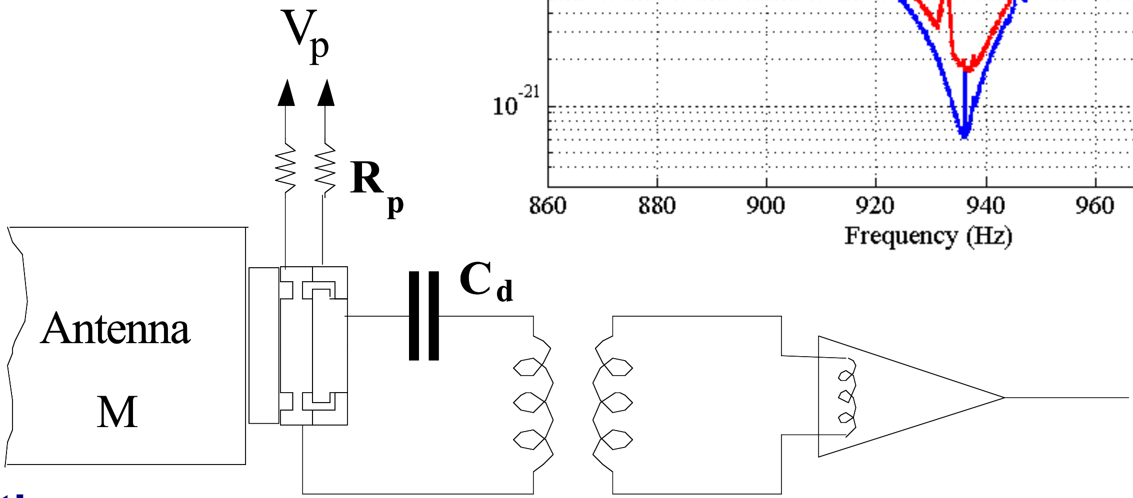
  10 y continuous data taking with 95% duty cycle

  Phys. Rev. D 82, 22003 (2010)









Capacitive transducer

Al 5056
m_t = 0.75 kg
ν_t= 916 Hz
C_t = 11 nF
E = 5 MV/m

Superconducting Low-dissipation Transformer

Lo=2.86 H
Li=0.8μH
K=0.8

dc-SQUID

M_s = 10 nH
Φ_n= 3 ·10^{-6} Φo/√Hz

Some Historical papers

Upper limit for a gravitational-wave stochastic background
with the EXPLORER and NAUTILUS resonant detectors
P. Astone et al. (ROG Collaboration)
Phys. Lett. B 385, 421-424, 1996.

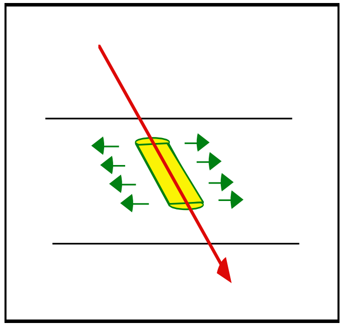
Upper limit for nuclearite flux from the Rome gravitational wave resonant detectors
P. Astone et al. (ROG Collaboration)
Phys.Rev.D47:4770-4773, 1993

Cosmic rays observed by the resonant gravitational wave detector NAUTILUS
P. Astone et al. (ROG Collaboration)
Phys.Rev.Lett.84:14-17, 2000.

Search for correlation between GRB's detected by BeppoSAX and the gw detectors EXPLORER and NAUTILUS
P. Astone et al. (ROG Collaboration)
Phys.Rev.D66:102002, 2002.

Increasing the bandwidth of resonant gravitational antennas
P. Astone et al. (ROG Collaboration)
Phys.Rev.Lett.91:111101, 2003.

Nautilus as acoustic particle detector



Interaction of a particle with a bar: ionization energy lost is converted in thermal heating and therefore pressure wave. The detection mechanism is quite simple, no threshold in β
"calorimetric measurement"

Nautilus is equipped with streamer tubes particle detectors

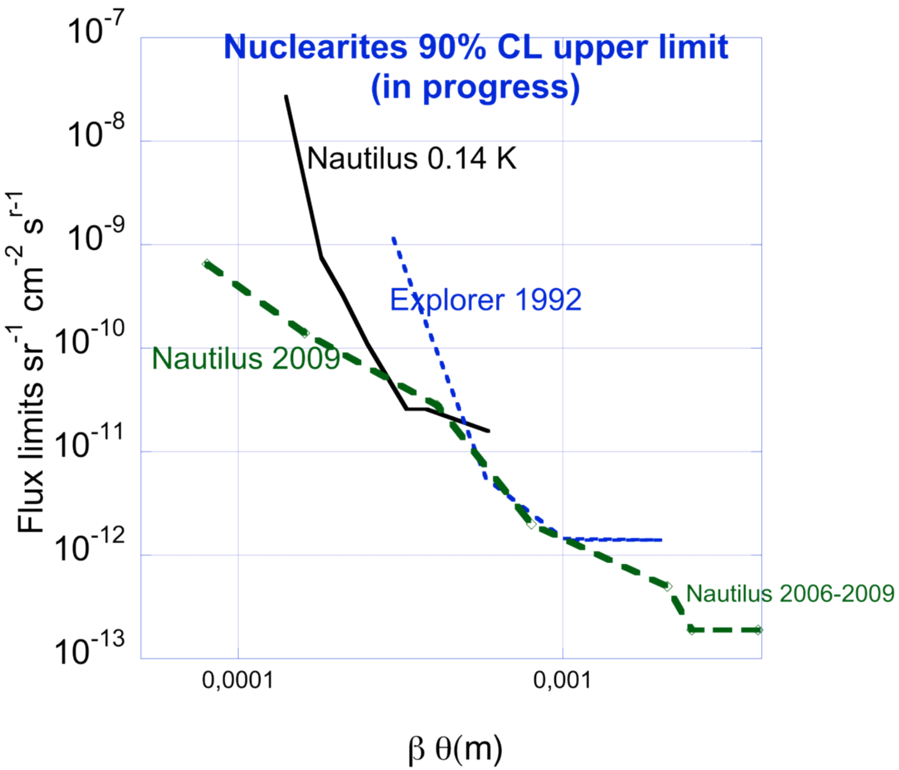
Nautilus is able to detect energy releases as low as 10^{-7} eV (10^{-26} J) by measuring the excitation of the longitudinal mode of Vibration.

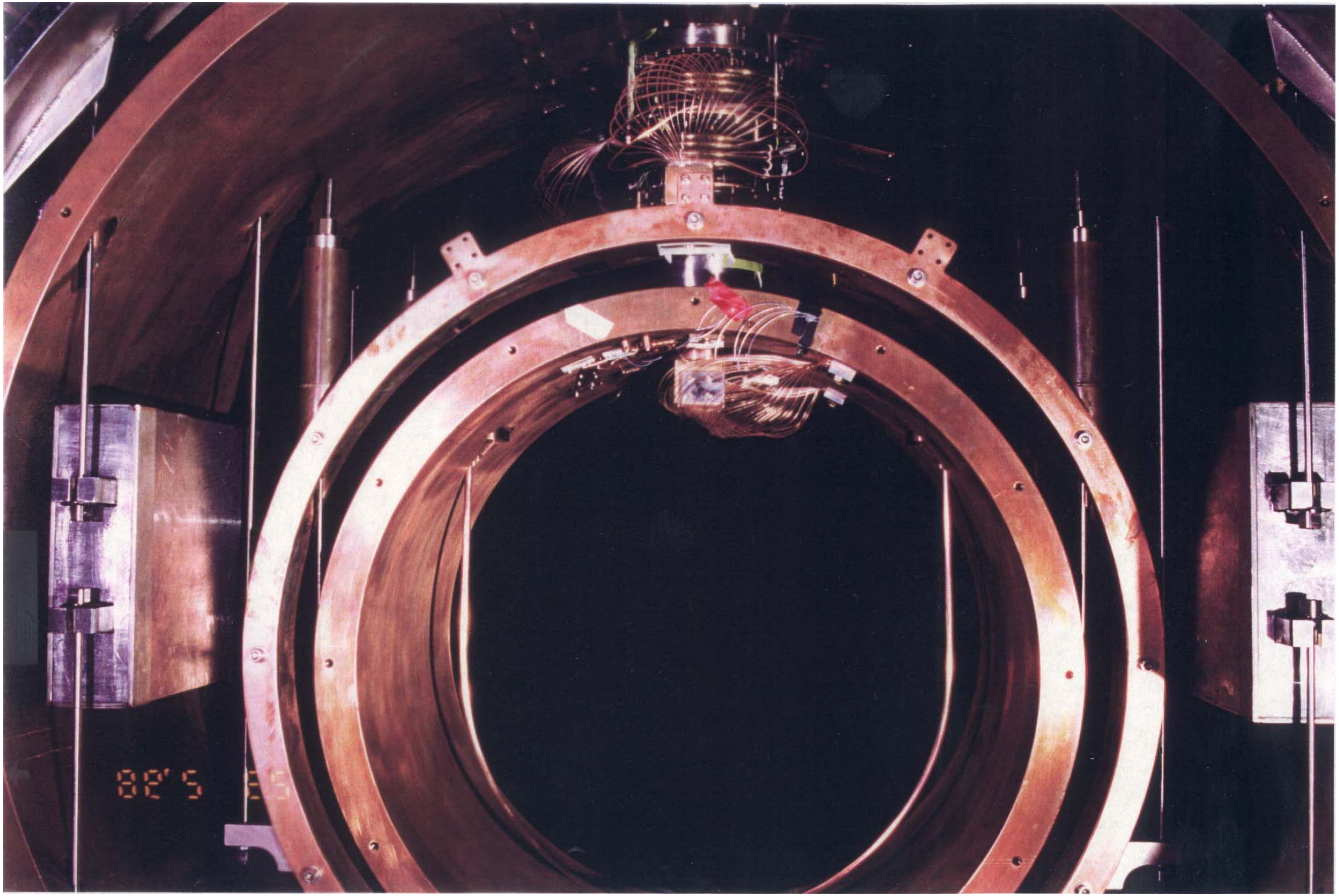
Cosmic rays: observed
Exotic form of matter: observable

Upper limit for nuclearite flux from the Rome GW resonant detectors
Phys.Rev. D47:4770-4773, 1993

Cosmic rays observed by NAUTILUS
Phys.Rev.Lett. 84:14-17, 2000.

Detection of high energy cosmic rays with NAUTILUS
Astropart.Phys. 30:200-208, 2008.





Suspension and thermal link of an ultralow temperature GW antenna.
E. Coccia, V. Fafone, I. Modena
Rev.Sci.Instrum. 63:5432-5434, 1992.

He-3 / He-4 mixing chamber for an ultralow temperature GW antenna.
E. Coccia, I. Modena.
Cryogenics 31:712-714, 1991.

Acoustic Quality Factor Of Aluminum Alloy For Gravitational Wave Antennas Below 1K.
E. Coccia and T.O. Niinikoski
Lett. Nuovo Cim. 41 (1984) 242

Nodal point supported GW antennas
E. Coccia
Rev. Sci. Instrum. 55, 1980 (1984)

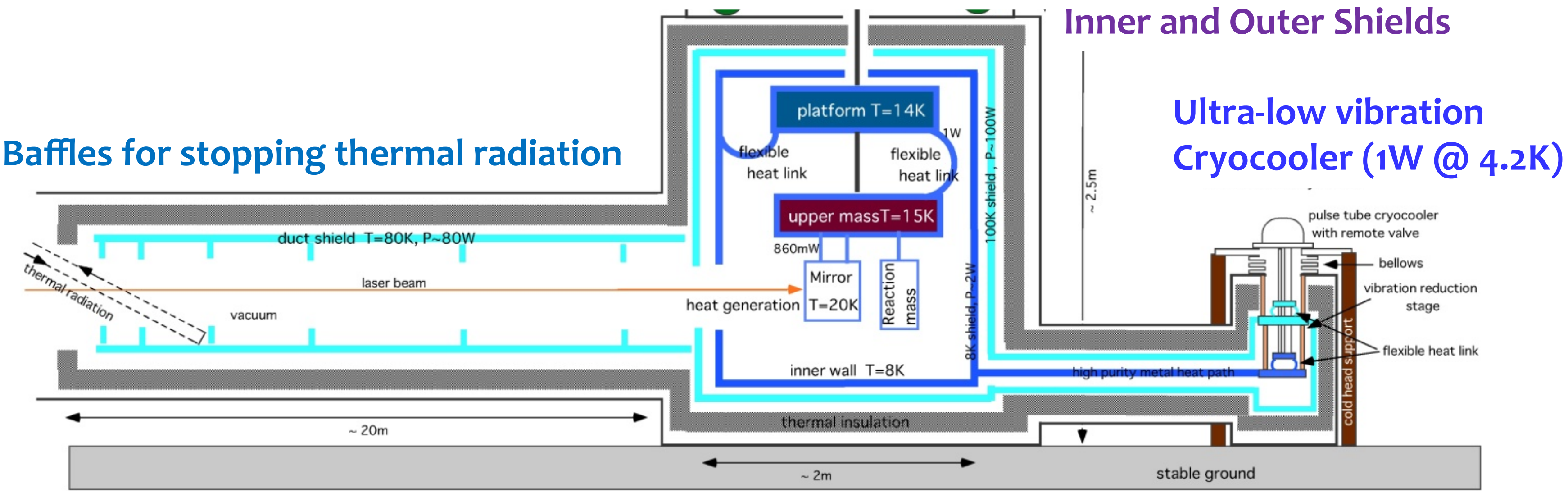
Thermal And Superconducting Properties Of Aluminum Alloy For GW Antennas Below 1-K.
E. Coccia and T.O. Niinikoski
J. Phys. E 16:695-699, 1983.

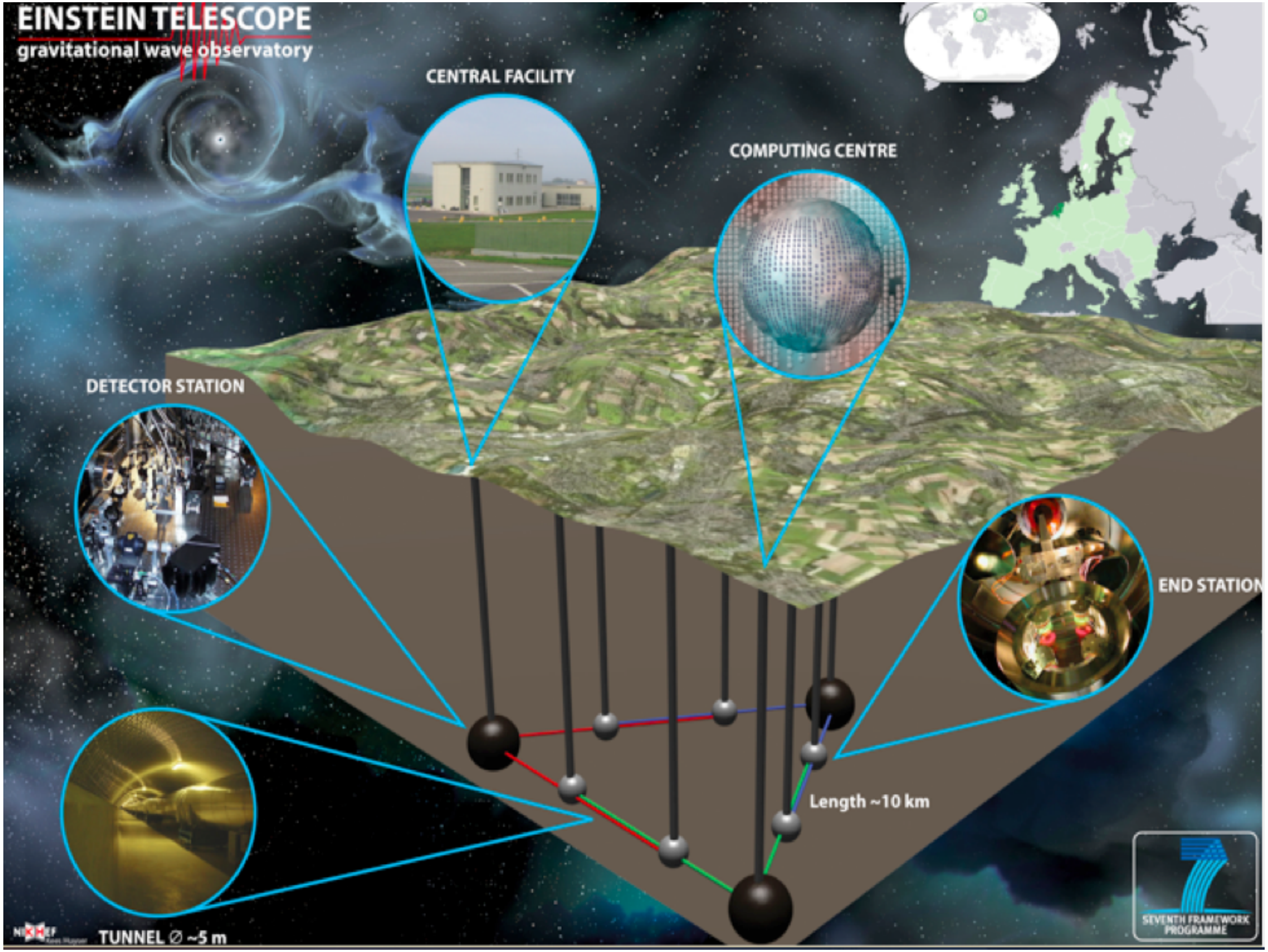
Mechanical Filter For The Suspension Of Gravitational Wave Antennas.
E. Coccia
Rev.Sci.Instrum. 53 (1982) 148-153


Gravitational Wave Detectors
Interferometric
Resonant-Mass
MiniGRAIL
The Netherlands
Auriga,
Italy
MINIGRAIL
GEO
AURIGA
EXPLORER
VIRGO
NAUTILUS
LIGO
ALLEGRO
LIGO
Nautilus, Italy
Schenberg,
Brazil
MARIO SCHENBERG
AIGO
NIOBE
gravitational wave research

Cryogenic Interferometers: KAGRA

- Temperature of the test mass/mirror < 20 K.
- Inner radiation shield have to be cooled < 8 K.
- The mirror have to be cooled without introducing excess noise, especially vibration from the cryo-coolers.
- Accessibility and enough volume for the installation work around the mirror.
- Satisfy ultra high vacuum specification < 10^{-7} Pa.



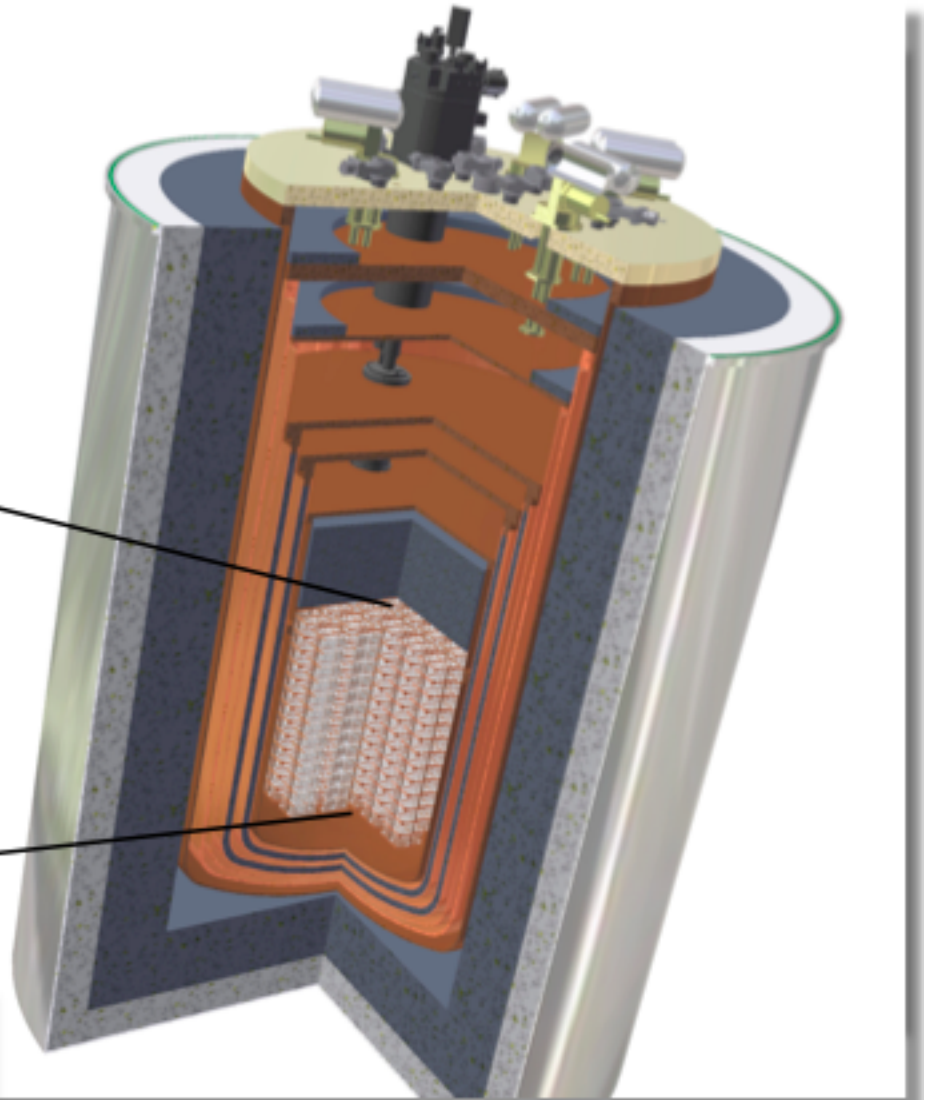

EINSTEIN TELESCOPE
gravitational wave observatory
CENTRAL FACILITY
COMPUTING CENTRE
DETECTOR STATION
END STATION
Length ~10 km
TUNNEL ∅ ~5 m
SEVENTH FRAMEWORK PROGRAMME

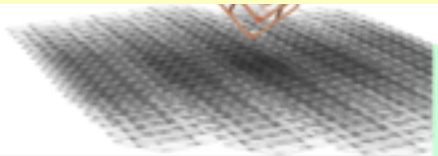
Cryogenic Underground Observatory for Rare Events

CUORE will be a closely packed array of 988 detectors
M = 741 kg of TeO_2

Special cryostat & dilution unit

- Cryogenic liquids free: 5 Pulse Tubes with 40W @ 45K & 1.0 W @ 4.2K
- JT cycle instead of the 1K Pot
- Dimensions: 1.6 m Ø x 3 m
- (almost) all in Copper for radiopurity
- huge mass to cooldown (mainly Pb shielding)
  - 1.5 ton @ 10mK
  - 6 ton @ 50 mK
  - 4 ton @ 600 mK
  - 5 ton between 40 & 4 K





19 towers with
13 planes of
4 crystals each

The phase change and the future

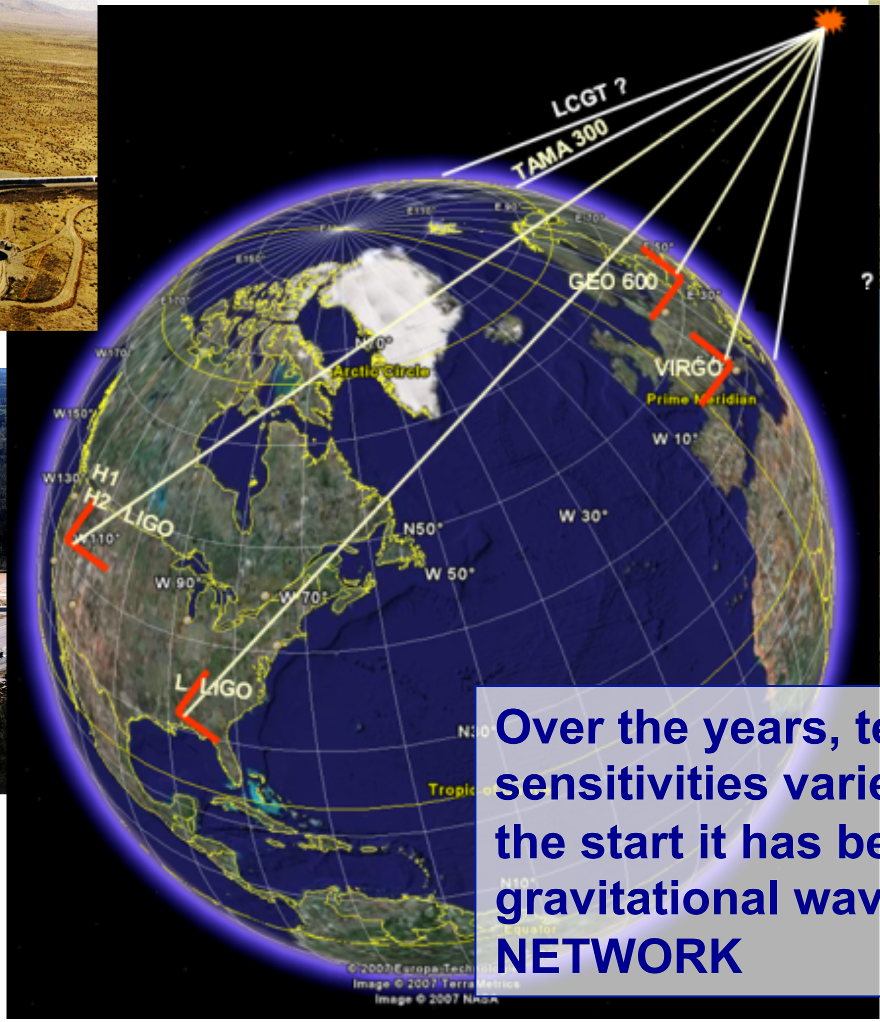
1960 - 2005
Given the uncharted territory that gravitational-wave detectors are probing, unexpected sources may actually provide the first detection.

2005 -
Only new high sensitivity detectors can provide the first detection and open the GW astronomy

The contribution of Resonant Bars has been essential in establishing the field, giving interesting results and putting some important upper limits on the gravitational landscape around us, but now the hope for guaranteed detection is in the Network of long arm interferometers.

THE INTERFEROMETER NETWORK

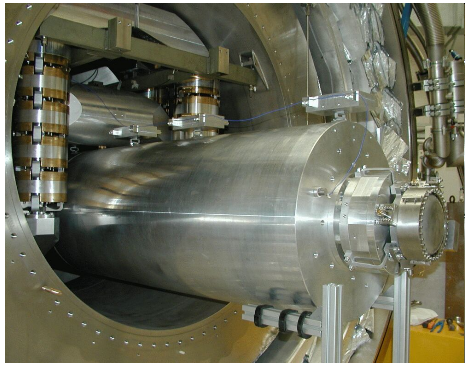
A network of 4 (5) GW detectors



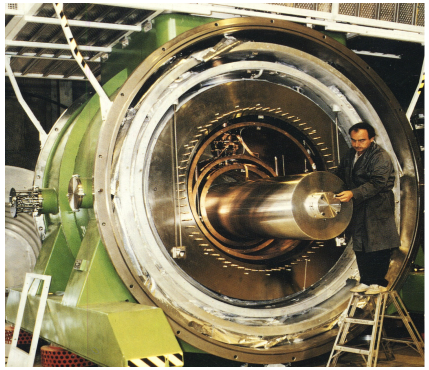
Over the years, techniques and sensitivities varied greatly, but since the start it has been clear that to detect gravitational waves we need a NETWORK

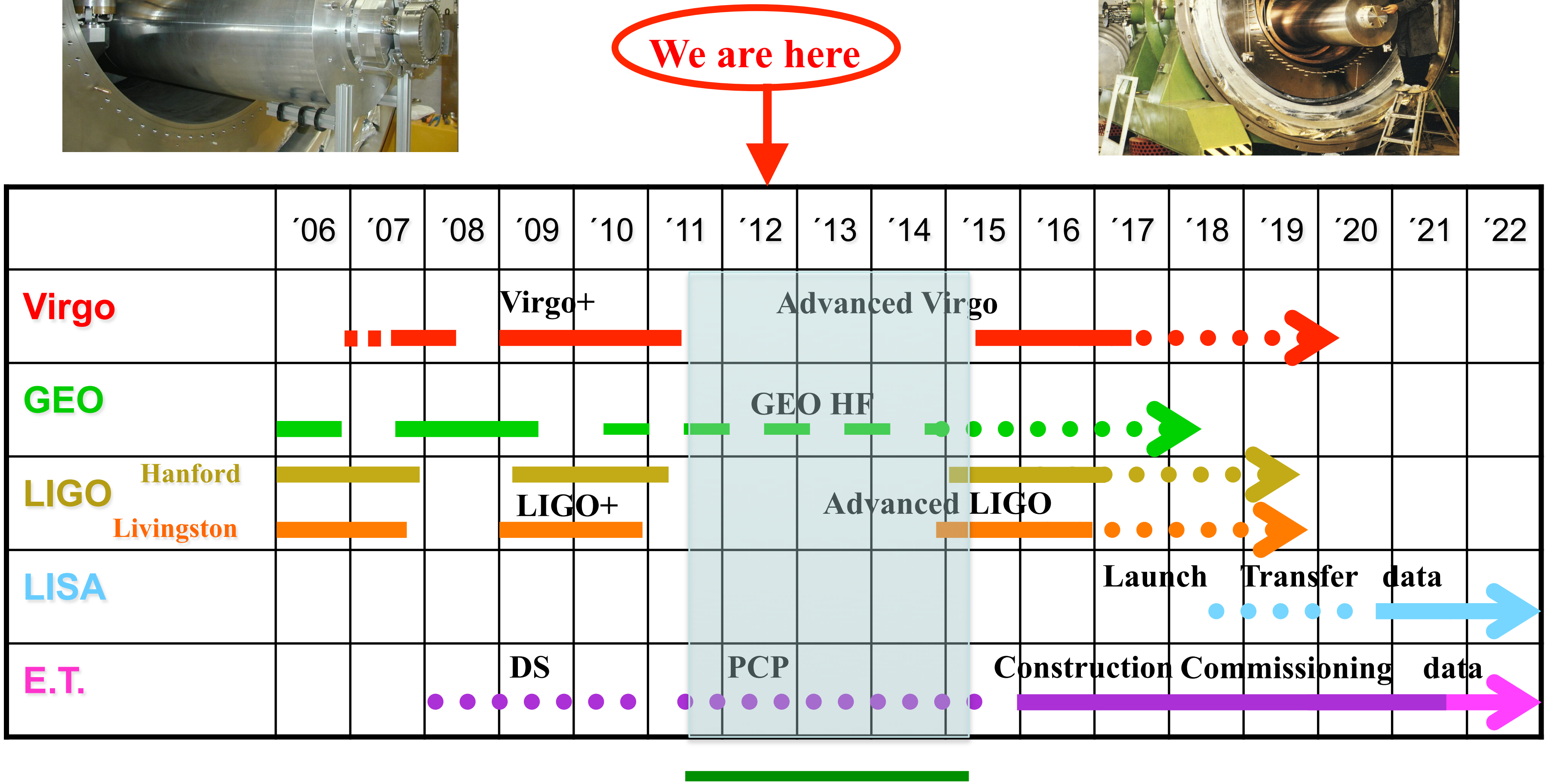
AUNA

AURIGA - LNL



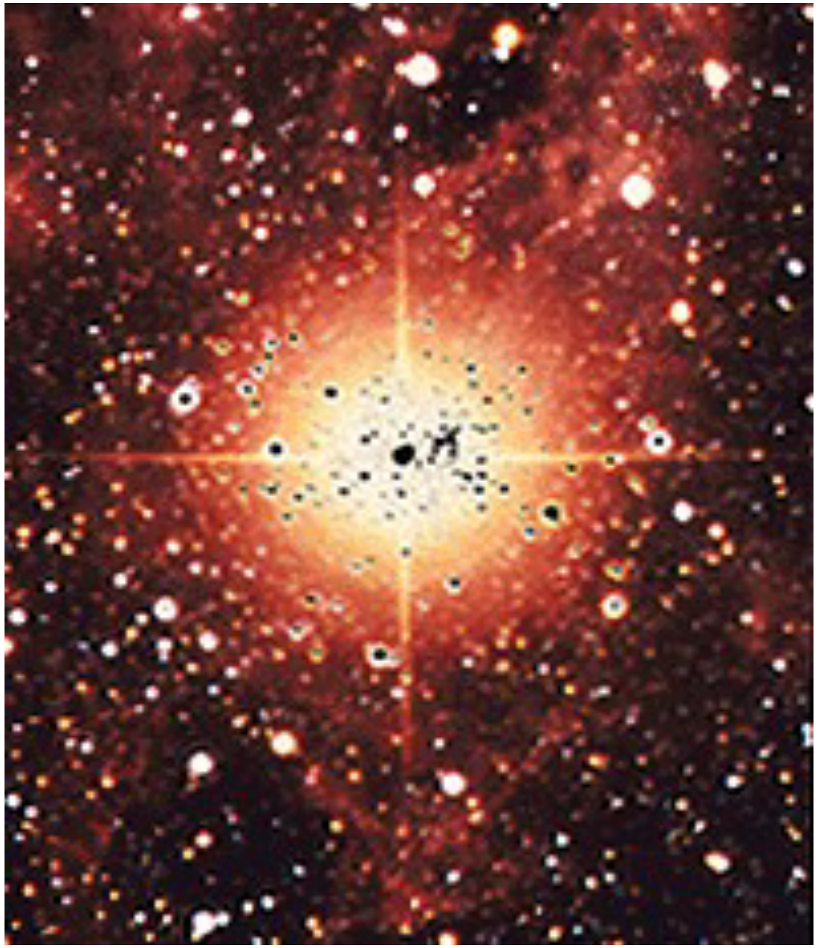
NAUTILUS - LNF





Window of opportunity
for AURIGA and NAUTILUS

Sn 1987a February 23, 1987



Quarter of a century ago

Every newly opened astronomical window has found unexpected results

Window	Opened	1st Surprise	Year
Optical	1609 (Galileo)	Jupiter's moons	1610
Cosmic Rays	1912	Muon	1930s
Radio	1930s	Giant Radio Galaxies CMB Pulsars	1950s 1964 1967
X-ray	1948	Sco X-1 X-ray binaries	1962 Uhuru (1969)
γ-ray	1961 (Explorer 11)	GRBs	Late 1960s++ (Vela)