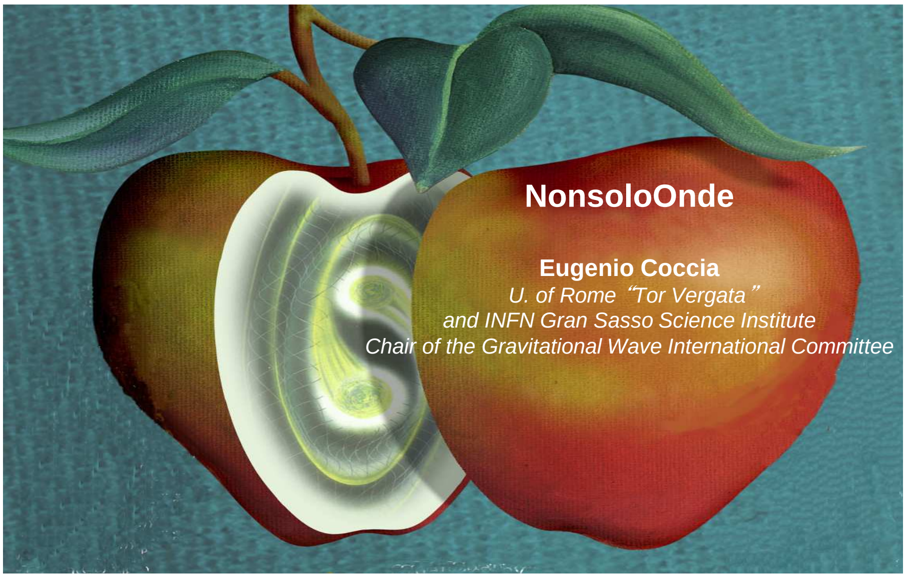
Associazione Nazionale Fisica e Applicazioni
STATI GENERALI - PROFESSIONE FISICO – ROMA 13.12.2013



NonsoloOnde

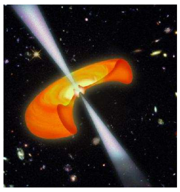
Eugenio Coccia
U. of Rome "Tor Vergata"
and INFN Gran Sasso Science Institute
Chair of the Gravitational Wave International Committee

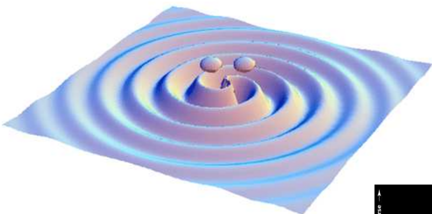
GW OBJECTIVES

FIRST DETECTION
test Einstein prediction

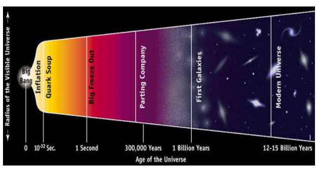
$$\mathbf{G} = \frac{8\pi G}{c^4}\mathbf{T}$$

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

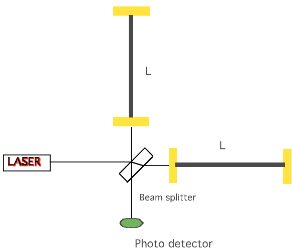


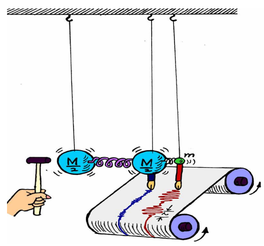
Every newly opened astronomical window has found unexpected results

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)

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

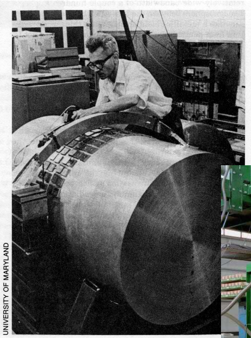
$$\ddot{x}(t) + \tau^{-1}\dot{x}(t) + \omega_0^2 x(t) = \frac{1}{2}\ddot{h}(t)$$





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:



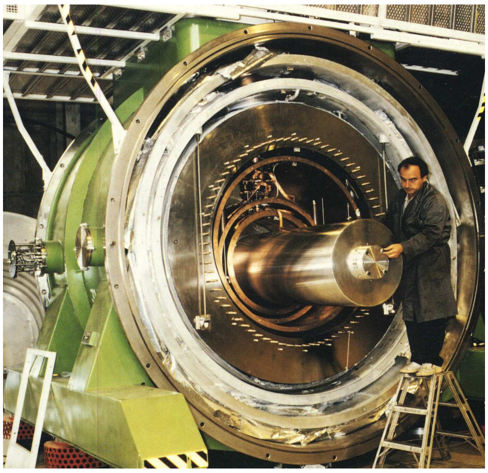
70’ : Joe Weber pioneering work

90’ : Cryogenic Bars

2005 - : Large Interferometric Detectors


Gravitational Wave Detectors
ROG Collaboration
LNF, Roma1, Roma2
Interferometer
Resonant-Mass
GEO
EXPLORER
AURIGA
VIRGO
NAUTILUS
EXPLORER
CERN RE 5
LNF INFN
gravitational wave

NAUTILUS
LNF - FRASCATI

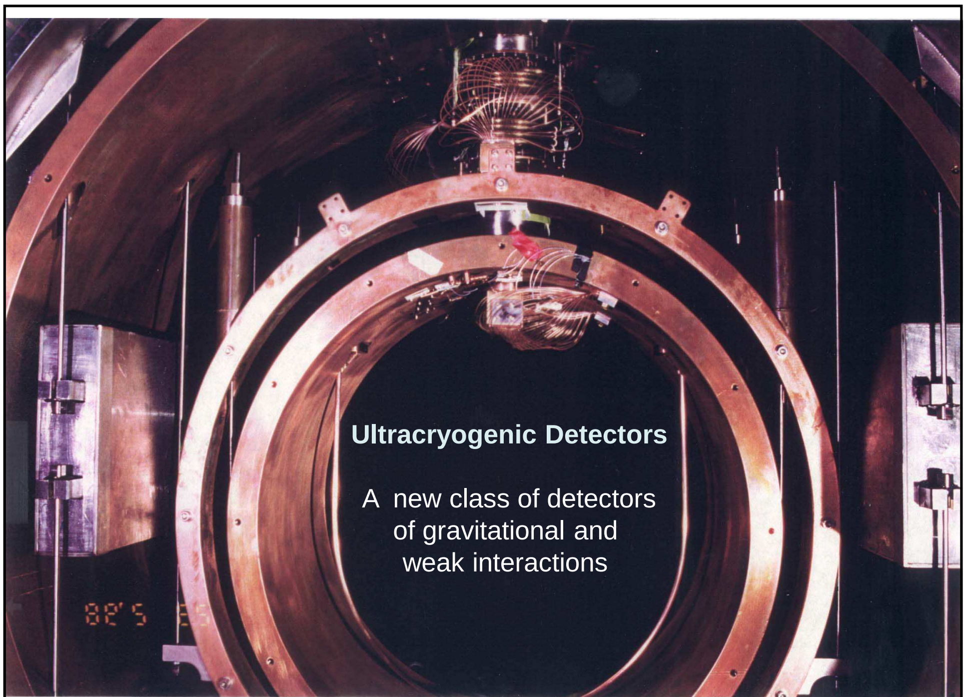


Bar Al 5056 **M = 2270 kg**

L = 2.91 m **Ø = 0.6 m**

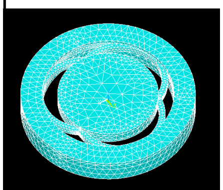
ν_A=935Hz @ T = 3 K

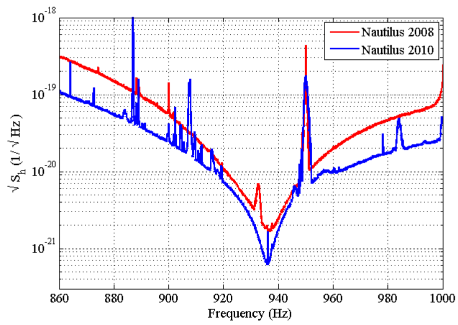
Cosmic ray detector

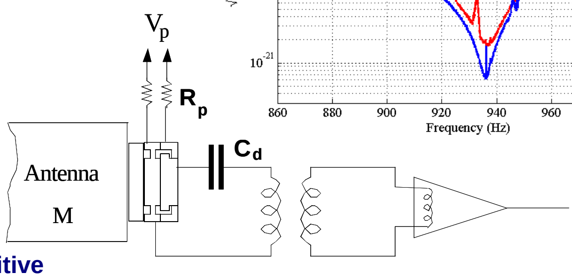


The Records of NAUTILUS

- 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
$\Phi_n = 3 \cdot 10^{-6}\ \Phi o/\sqrt{Hz}$

Some Historical papers

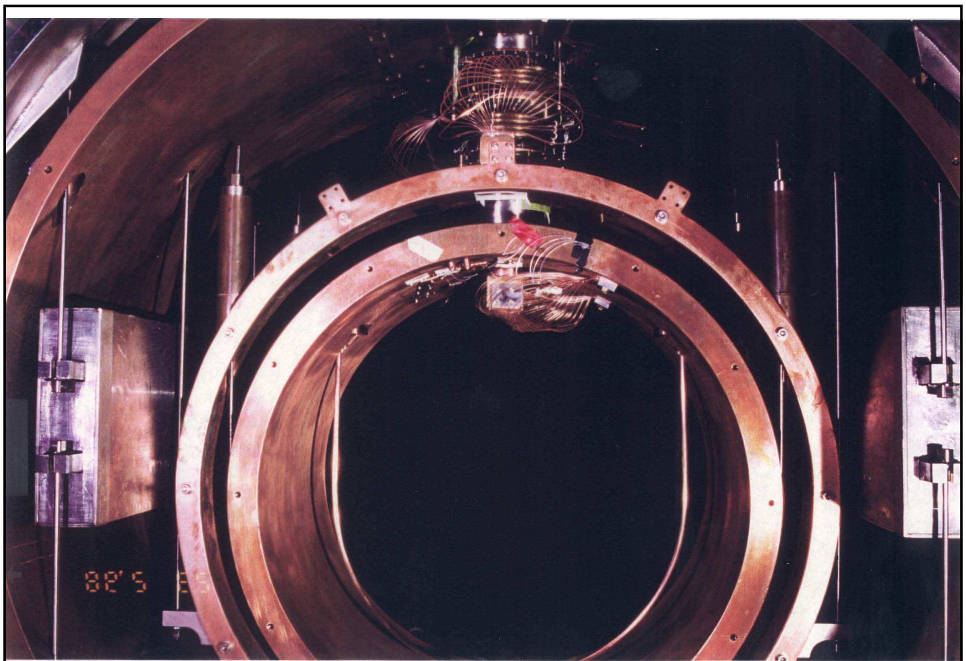
Upper limit for a gravitational-wave stochastic background with the EXPLORER and NAUTILUS resonant detectors
P. Astone et al. (ROG Collaboration)
Phys. Lett. B 385, 421-424, 1996.

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.



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.

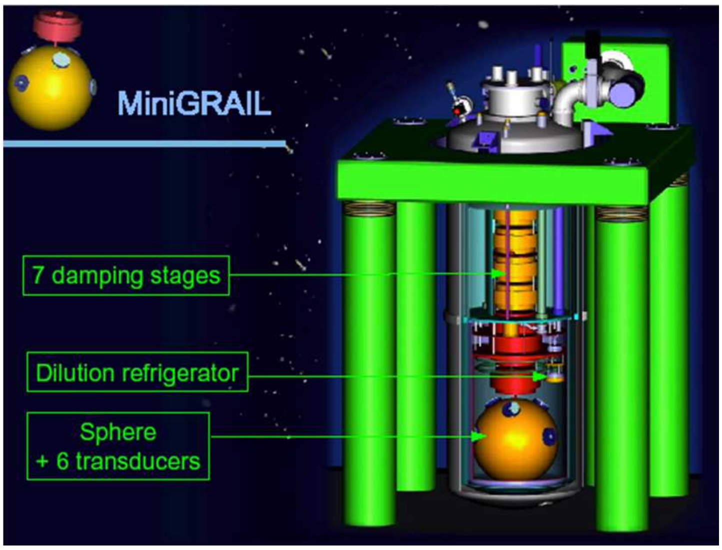
Acoustic Quality Factor Of Aluminum Alloy For Gravitational Wave Antennas Below 1K.
E. Coccia and T.O. Niinikoski
Lett. Nuovo Cim. 41 (1984) 242

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.

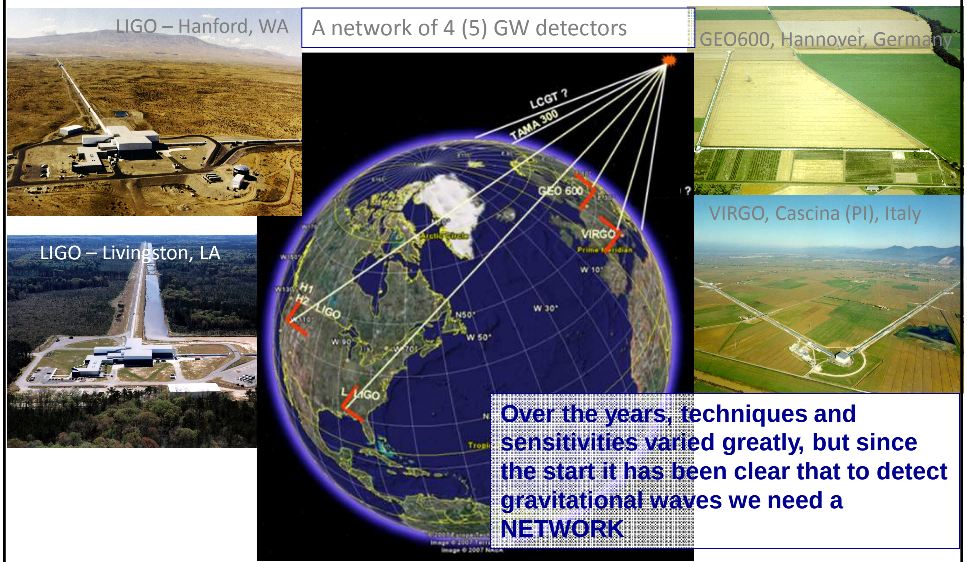
Mechanical Filter For The Suspension Of Gravitational Wave Antennas.
E. Coccia
Rev.Sci.Instrum. 53 (1982) 148-153

G. Frossati, E. Coccia
Cryogenics (1994)


MiniGRAIL
7 damping stages
Dilution refrigerator
Sphere
+ 6 transducers


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

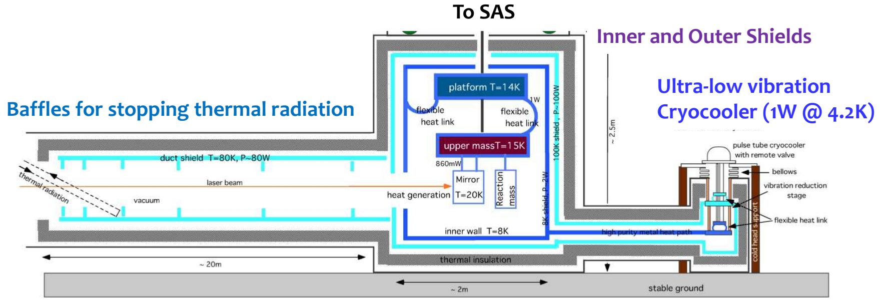
THE INTERFEROMETER NETWORK



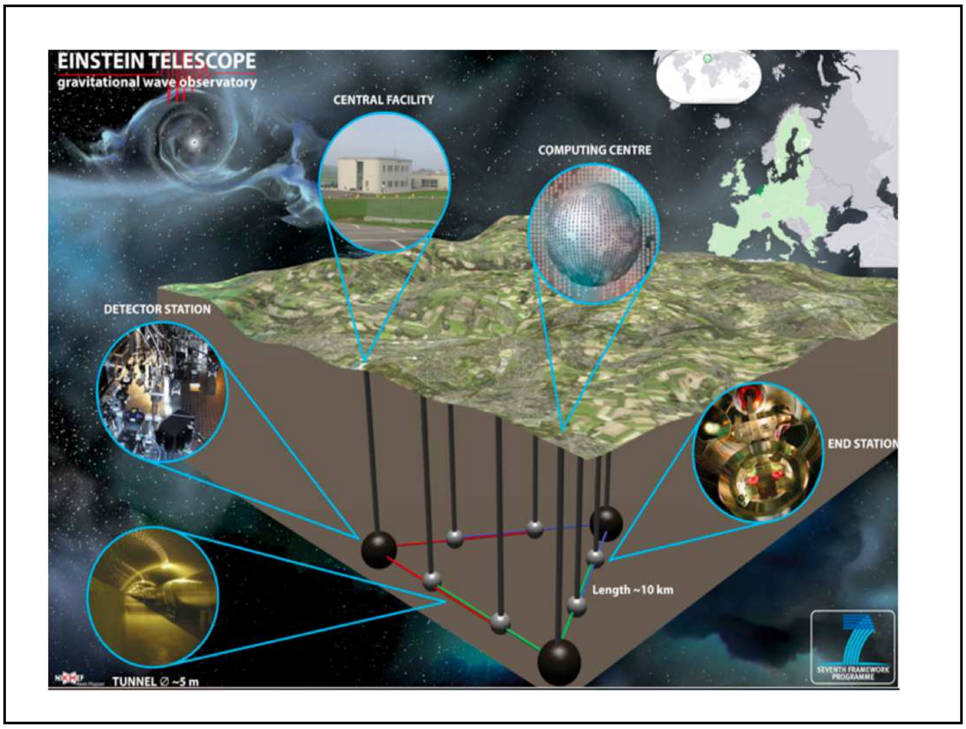
Over the years, techniques and sensitivities varied greatly, but since the start it has been clear that to detect gravitational waves we need a NETWORK

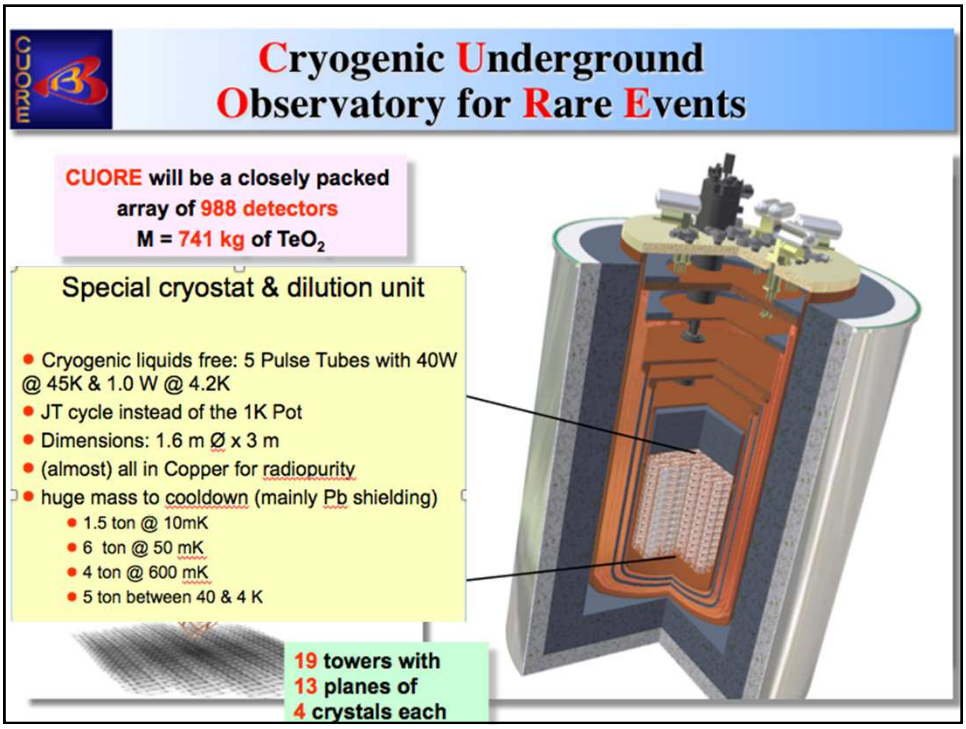
Cryogenic Interferometers: KAGRA

- 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.

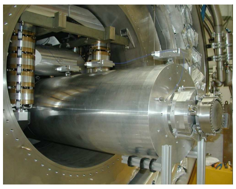


GWIC, 2012/9/11/ in Rome University La Sapienza, Rome, Italy N.Kimura, T.Suzuki


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

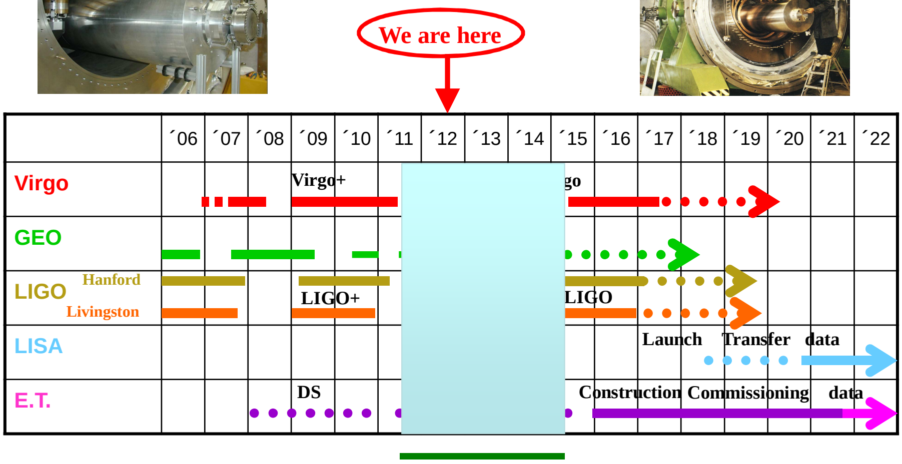

CUORE
Cryogenic Underground
Observatory for Rare Events
CUORE will be a closely packed
array of 988 detectors
M = 741 kg of TeO_2
Special cryostat & dilution unit
• Cryogenic liquids free: 5 Pulse Tubes with 40W @ 45K & 1.0 W @ 4.2K
• JT cycle instead of the 1K Pot
• Dimensions: 1.6 m Ø x 3 m
• (almost) 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

AURIGA - LNL



AUNA

NAUTILUS - LNF

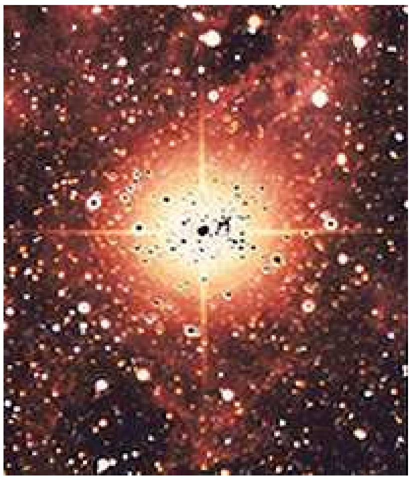


Window of opportunity
for AURIGA and NAUTILUS

23

Sn 1987a

February 23, 1987



Quarter of a century ago

2002 - 2013

LABORATORI NAZIONALI DEL GRAN SASSO - INFN

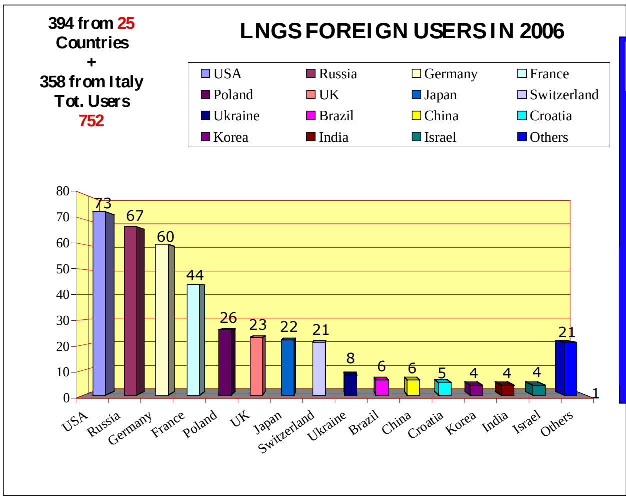
Largest underground laboratory for astroparticle physics

Laboratori Nazionali del Gran Sasso

1400 m rock coverage
underground area: 17 300 m^2
752 scientists from 24 countries
17 000 visitors per year
10 M Euros invested in the region

Research lines
- Neutrino physics
  (mass, oscillations, stellar physics)
- Dark matter
- Nuclear reactions of astrophysics interest
- Geophysics
- Biology

The scientific community



The contributions of the cultures of different Countries are a fundamental component of the scientific vitality of LNGS

GSI
THE NEST OF THE EAGLE'S FUTURE

United States

PRINCETON UNIVERSITY

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

UCLA

BERKELEY LAB

Fermilab

Europe

UNIVERSITY OF OXFORD

MAX-PLANCK-GESELLSCHAFT

CERN

CNRS CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

Japan

Nagoya University

KOBE UNIVERSITY

Russia

JINR

ИЯИ РАН

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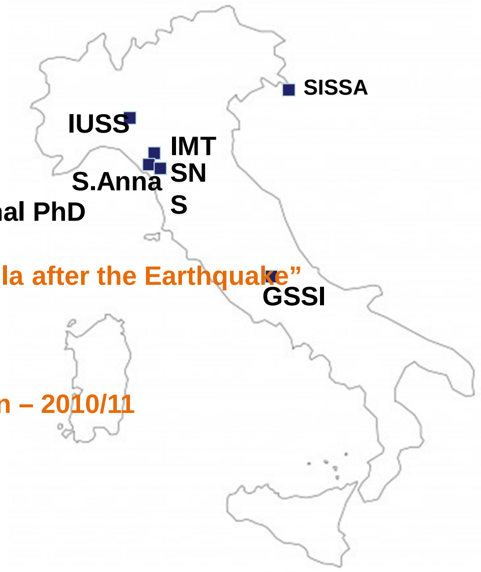
6 April 2009
L'Aquila earthquake

GSSI GRAN SASSO SCIENCE INSTITUTE
CENTER FOR ADVANCED STUDIES INFN



Initial project of an International PhD School presented at:
OECD – MEF Meeting "L'Aquila after the Earthquake"
Rome 3.7.2009

Endorsed by the Report from
OECD-University of Groningen – 2010/11

Joint activities approved by:
SISSA Trieste
Sant'Anna Pisa
IMT Lucca

L'Aquila, Viale Francesco Crispi 7

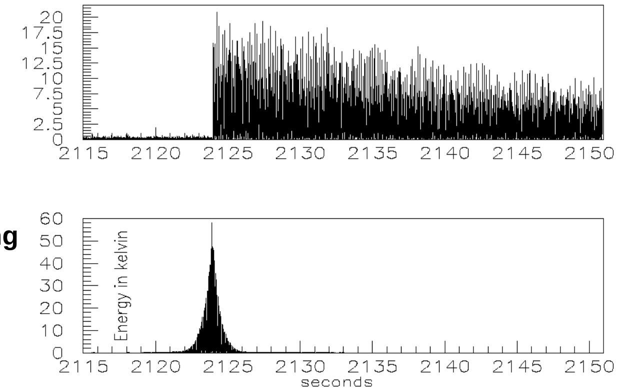
Inaugurazione Anno Accademico 2013/2014
L'Aquila 14 Novembre 2013

Burst event for a present bar: a millisecond pulse, a signal made by a few millisecond cycles, or a signal sweeping in frequency through the detector resonances. The burst search with bars is therefore sensitive to different ki of gw sources such as a stellar gravitational collapse, the last stable orbits inspiraling NS or BH binary, its merging, and its final ringdown.

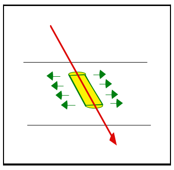
Real data: the arrival of a cosmic ray shower on NAUTILUS

Unfiltered signal (V^2)

The signal after filtering (kelvin)



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

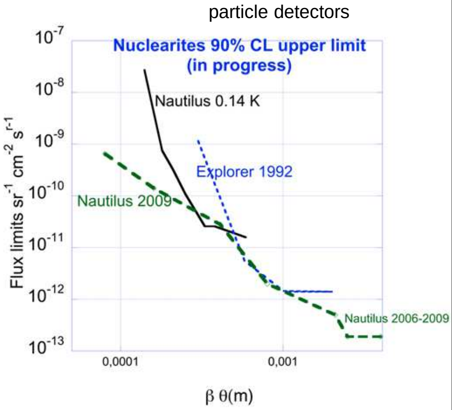
Nautilus is able to detect energy releases as low as 10^{-7} eV (10^{-26} J) by measuring the excitation of the longitudinal mode of Vibration.

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.



RESULTS

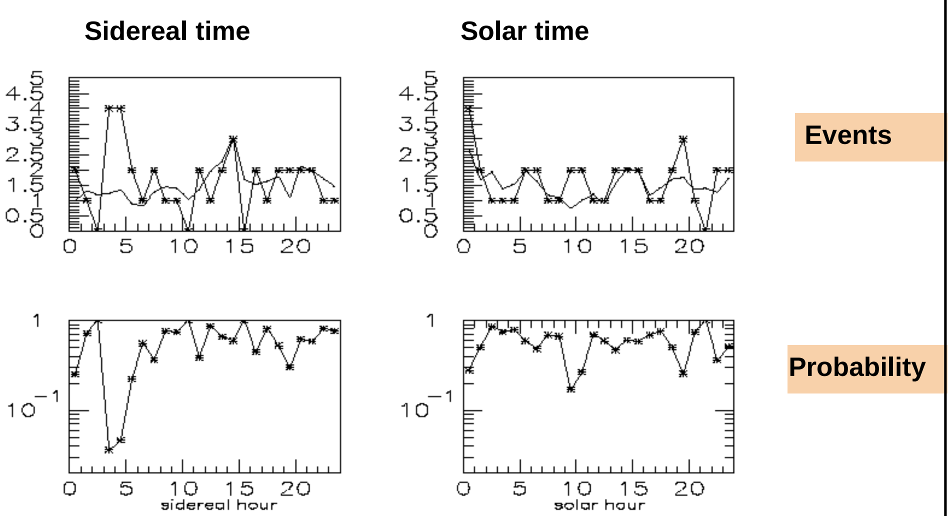
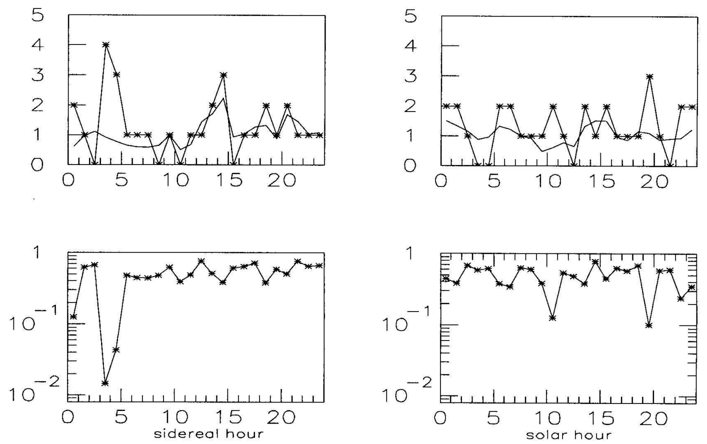


Fig. 7: Result with events in time periods ≥ 1 hour of continuous operation. As in fig.5.

***= coincidences** **________= accidentals**

RESULTS
"12 hours continuous operation"

Sidereal time **Solar time**



Events

Probability

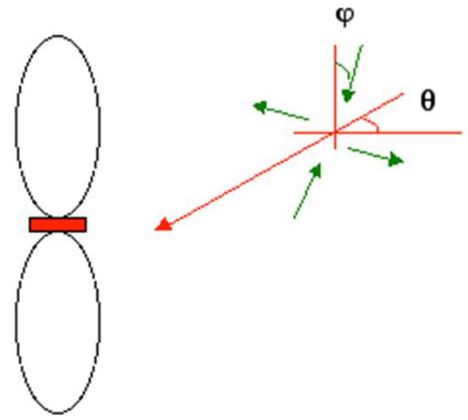
***= coincidences** **________= accidentals**

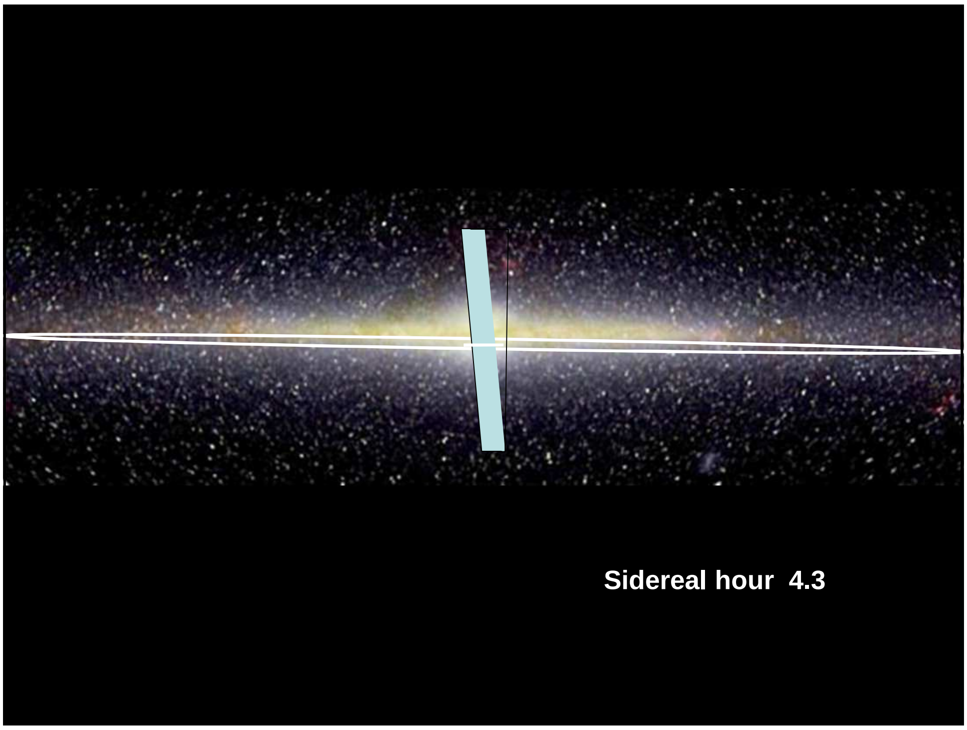
Poisson probabilities

n. of hours, around 4	n_c	<n>	P(%)
2	7	1.69	0.18
4	8	3.45	2.5
6	10	5.01	3.2
8	13	6.2	1.1

The cross section of a bar detector depends on the wave propagation direction and polarization

$$\sigma_c = \frac{8}{\pi}\frac{G}{c^3} M v_s^2 \left[\sin^4(\theta)\cos^2(2\varphi)\right]$$





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.