Tenth Marcel Grossmann Meeting on General Relativity
Rio de Janeiro, July 20-26, 2003

EXPLORER & NAUTILUS: Present status

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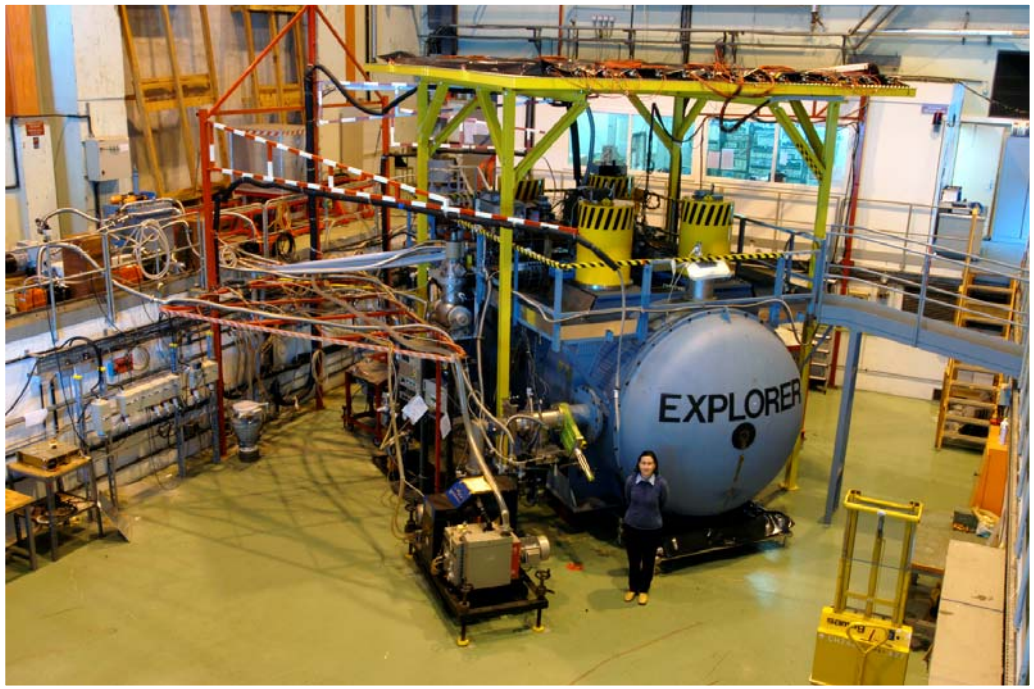
University of Rome “Tor Vergata” and INFN Roma 2
ROG Collaboration

G.W. ANTENNA EXPLORER
CERN - GINEVRA



Bar Al 5056 M = 2270 kg

L = 2.97 m Ø = 0.6 m

ν_A= 915 Hz @ T = 2.5 K

Cosmic ray detector (recently completed)

G.W. ANTENNA NAUTILUS
LNF - FRASCATI

Al 5056 bar M = 2270 kg

L = 2.97 m Ø = 0.6 m

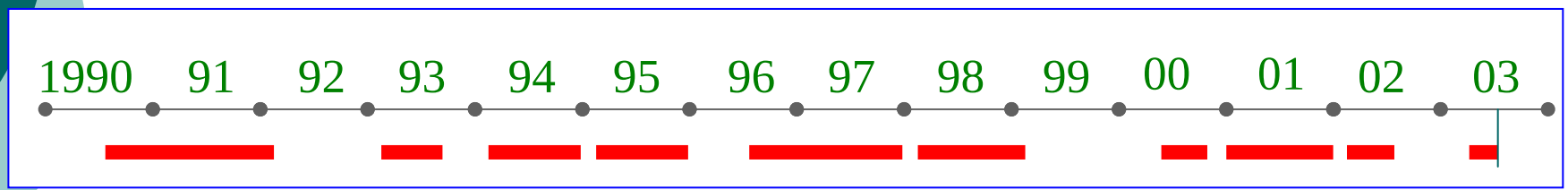
ν_A= 935 Hz

Cooled by a dilution refrigerator T=130 mK

Cosmic ray telescope

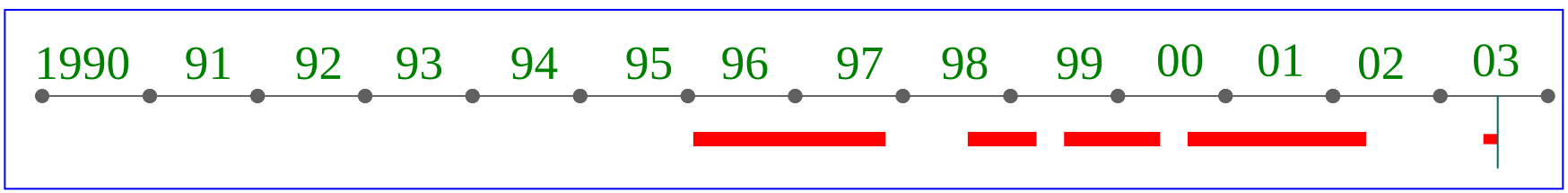
Data taking during the last 10 years

EXPLORER



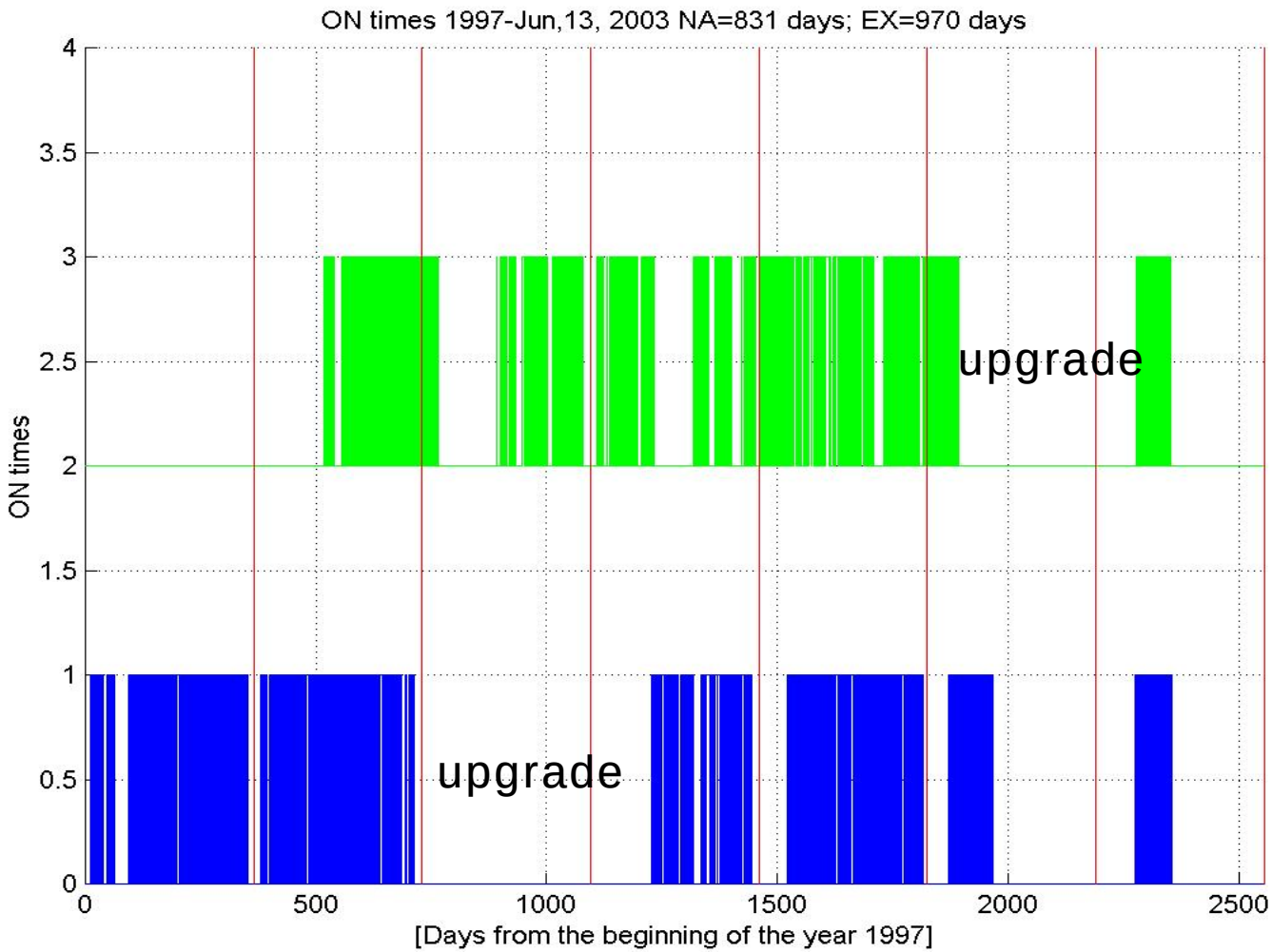
h from 10^{-18} to $3 \cdot 10^{-19}$

NAUTILUS

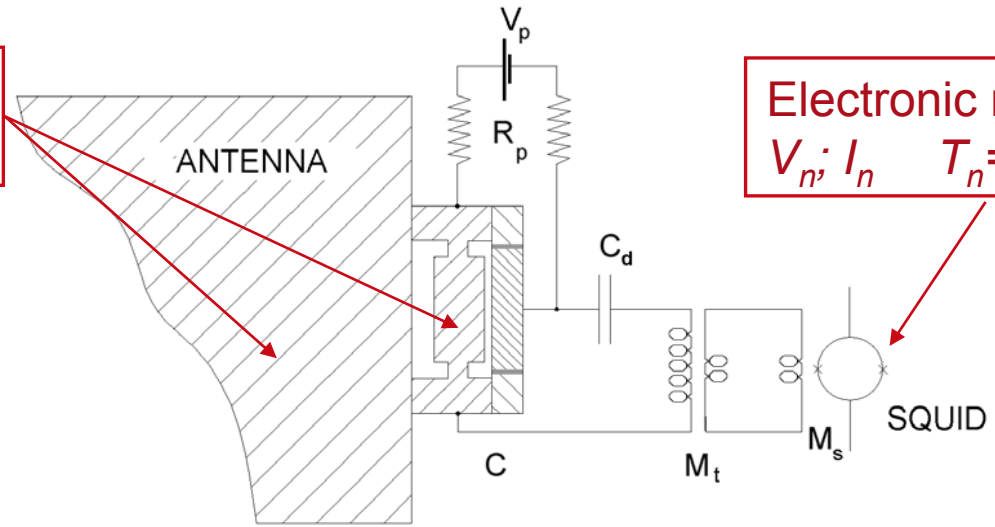


h from 10^{-18} to $3 \cdot 10^{-19}$

Data taking since 1997



Thermal noise
$S_F = MkT\omega_r/Q$



Electronic noise
V_n; I_n $T_n=\sqrt{V_n^2 I_n^2}/k$

The mechanical oscillator

Mass **M**
Speed of sound $\mathbf{v_s}$
Temperature **T**
Quality factor **Q**
Res. frequency $\mathbf{f_r}$

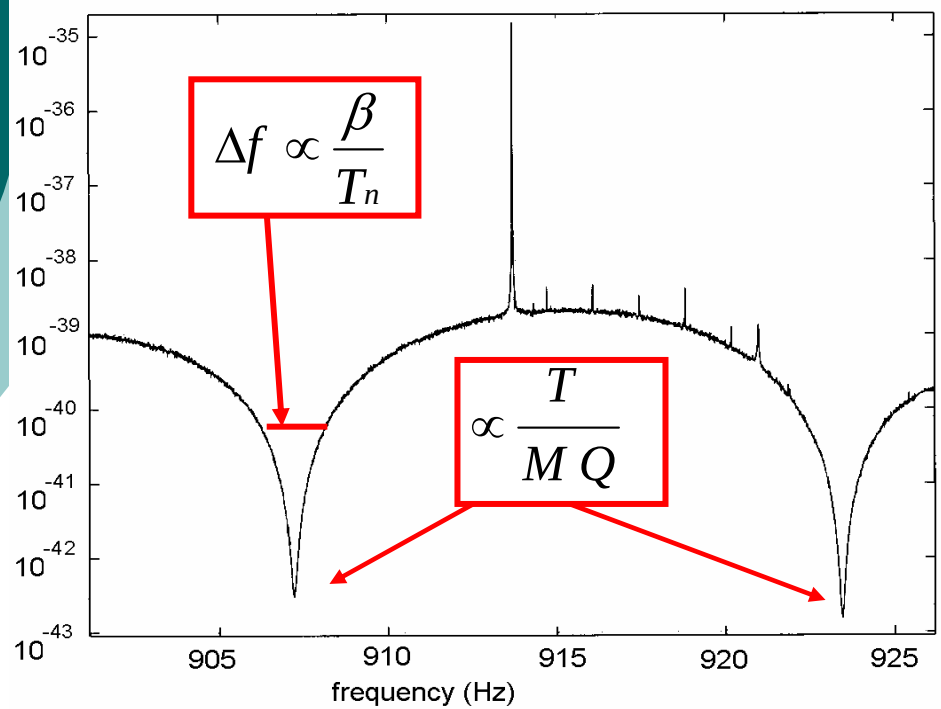
The transducer

Efficiency β

The amplifier

Noise temperature $\mathbf{T_n}$

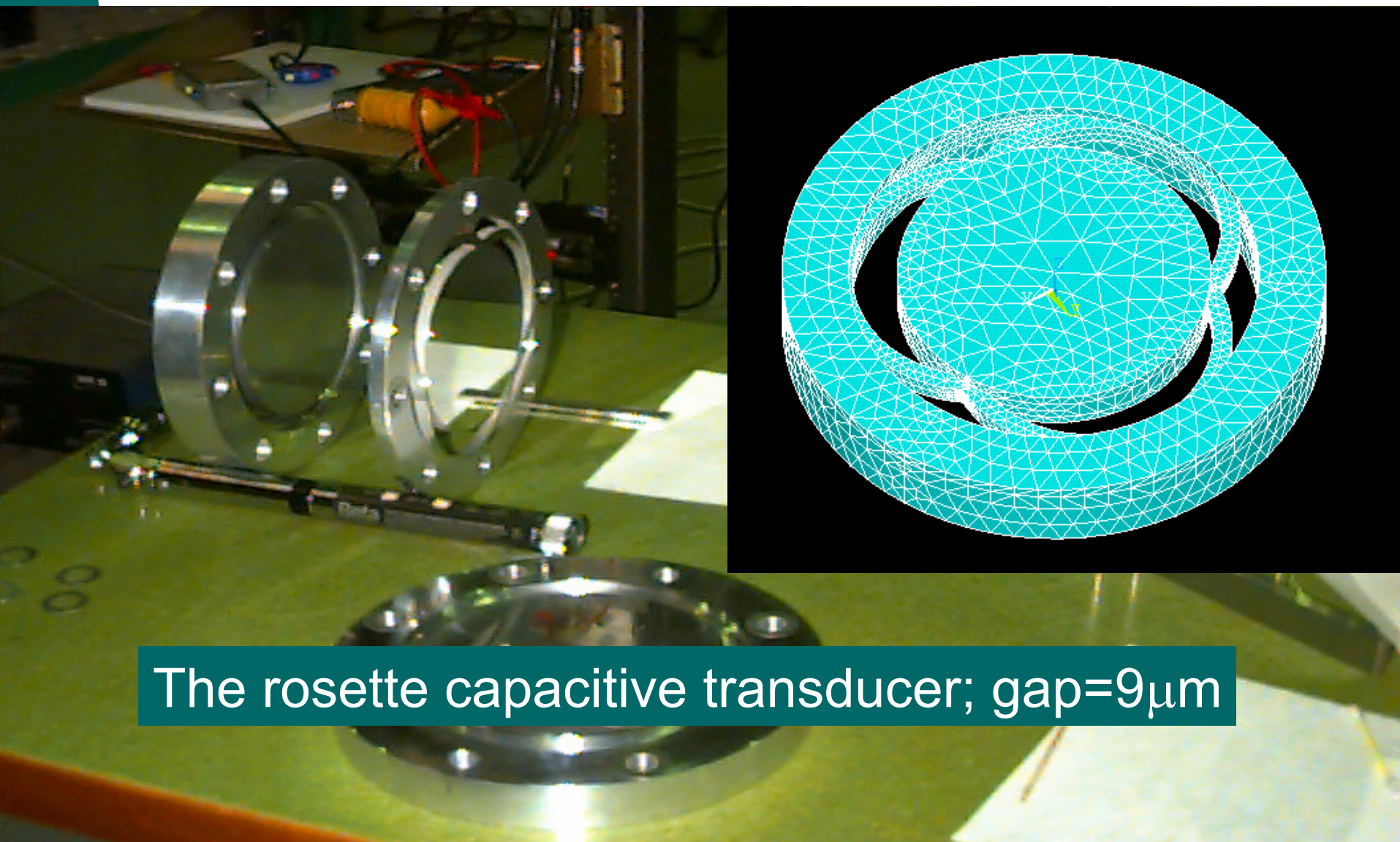
SENSITIVITY OF BAR DETECTORS



The sensitivity of a detector is usually given in terms of the noise spectral density referred to the input of the antenna

The “peak” sensitivity depends on “physical” parameters (T,M,Q). To increase the overall sensitivity a larger bandwidth is required. It can be obtained decreasing the electronics noise contribution and increasing the energy transfer

MICROMECHANICS



The rosette capacitive transducer; gap=9μm

EXPLORER STATUS

- EXPLORER was upgraded in 1999. After a tune-up period, it has been on the air since 2000 with a duty cycle close to 84% excluding six months in 2002 and the yearly stop for CERN winter holydays

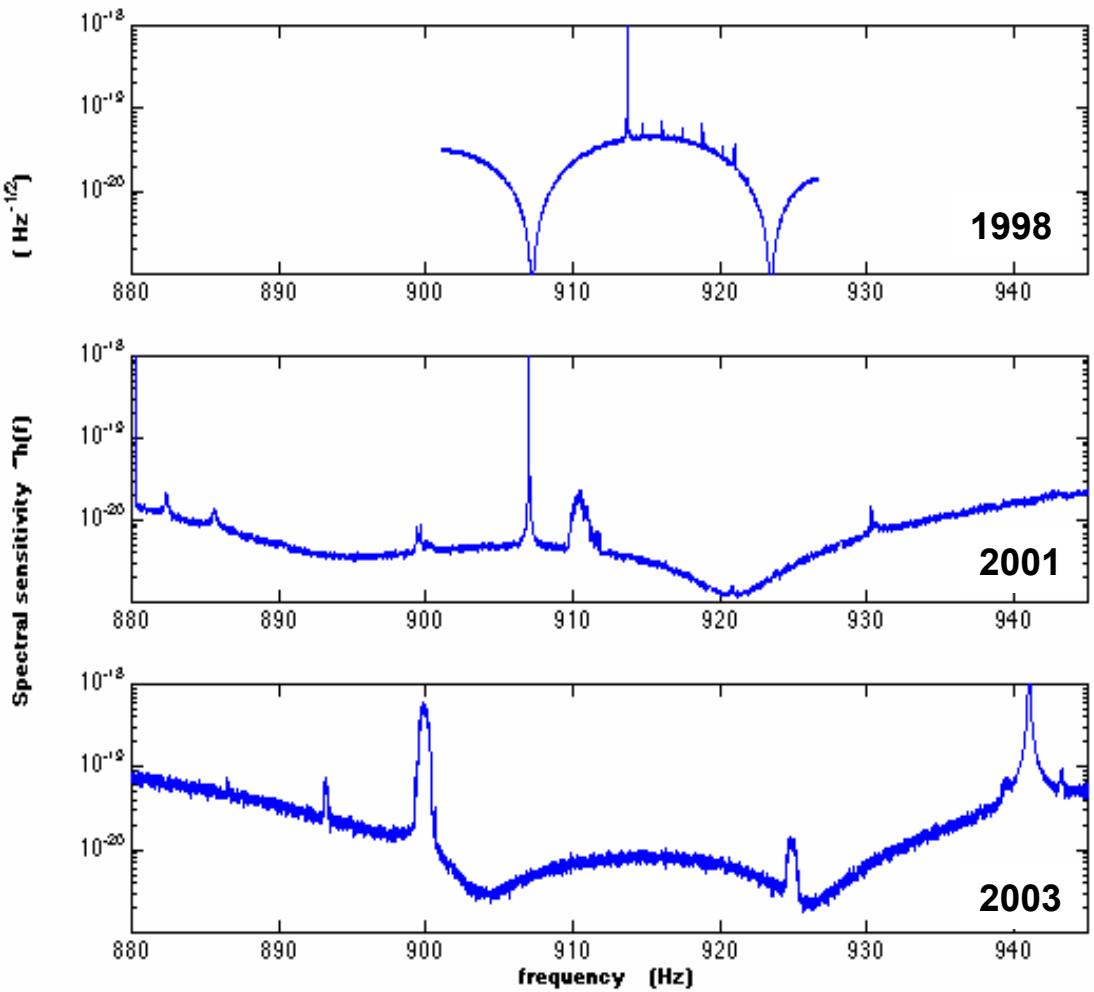
- The apparatus is now equipped with a cosmic ray detector consisting of plastic scintillators: 1 layer of 6 m^2 below the cryostat and 2 layers of 13 m^2 above

EXPLORER

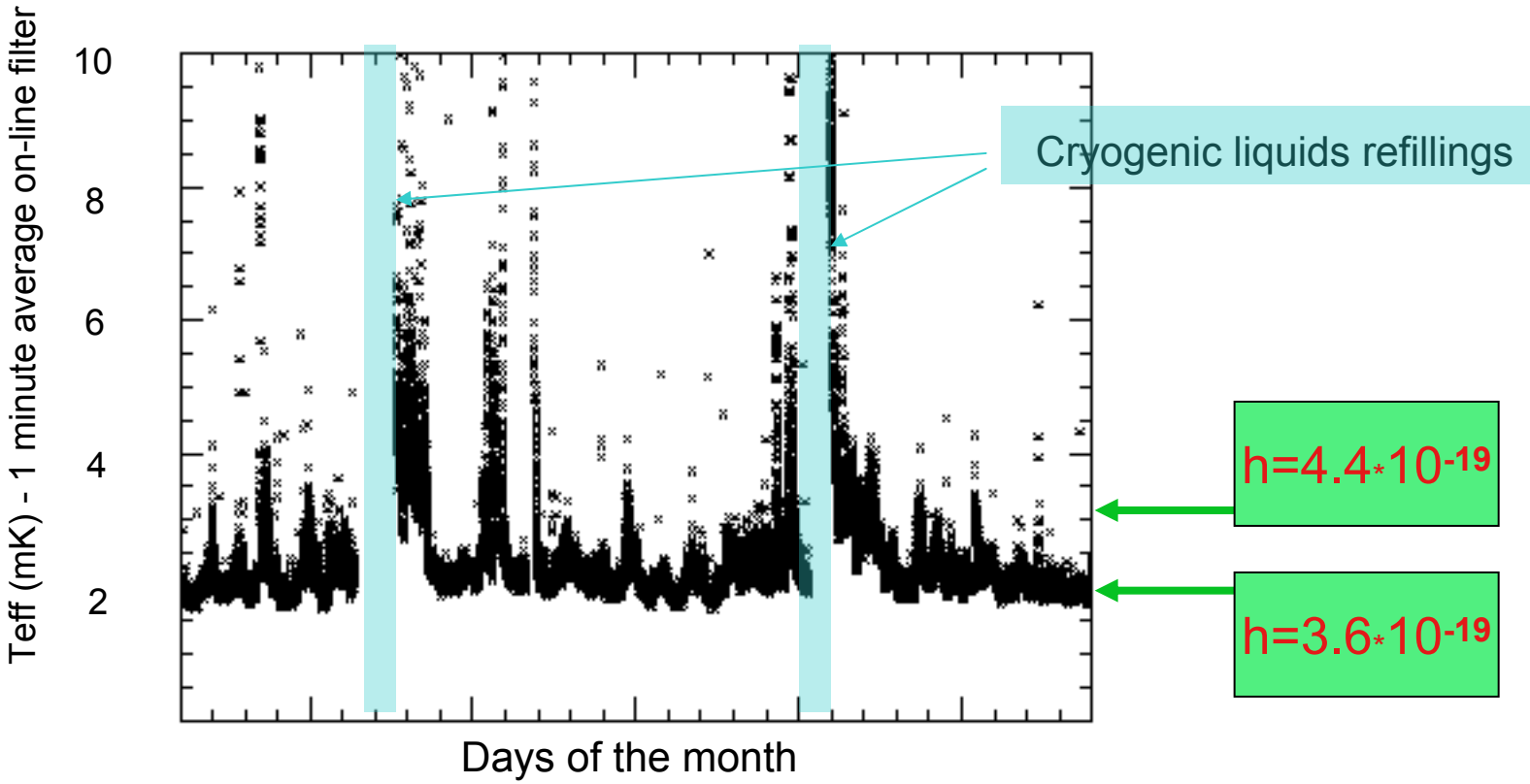
EXPLORER has been on the air since May 2000 with:
-new, 10 μm gap transducer
-new, high coupling SQUID

The noise temperature is < 3 mK (h=4.4 10^{-19}) for 84% of the time.

Bandwidth: the detector has a sensitivity better than 10^{-20} $Hz^{-1/2}$ on a band larger than 30 Hz



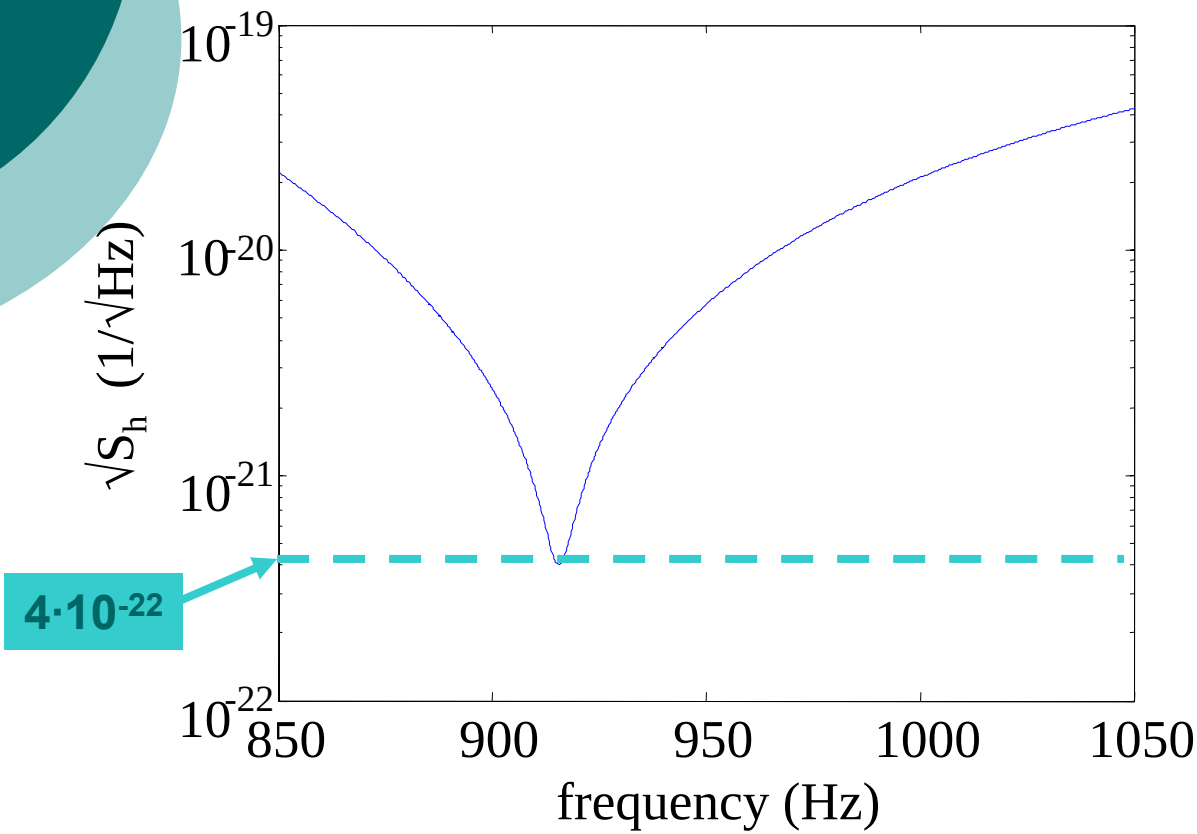
EXPLORER June 2003



For ~ 80% of time the sensitivity to short gw bursts is better than $h=4.4*10^{-19}$

TARGET SENSITIVITY OF EXPLORER

EXPLORER can reach a sensitivity of T_{eff}=150 μK and h = 10^{-19}



- New transducer double gap
- New transformer higher elect. Q
- New SQUID lower noise

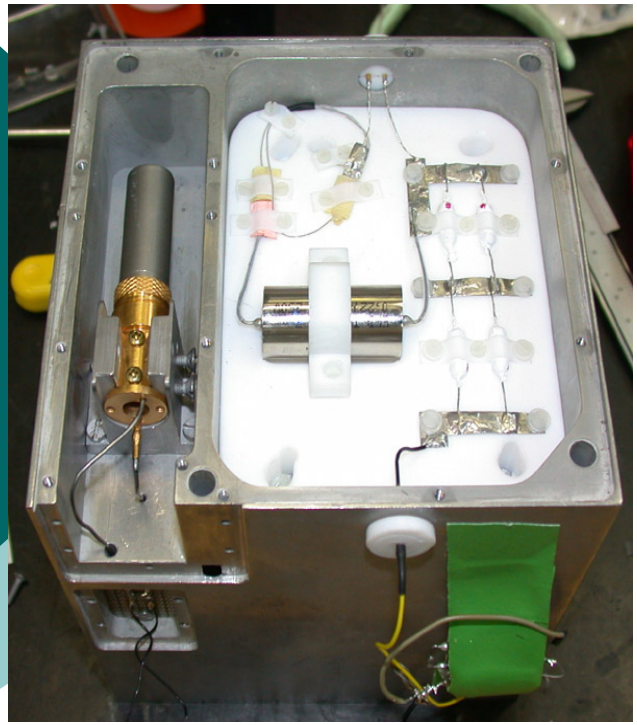
NAUTILUS 2003

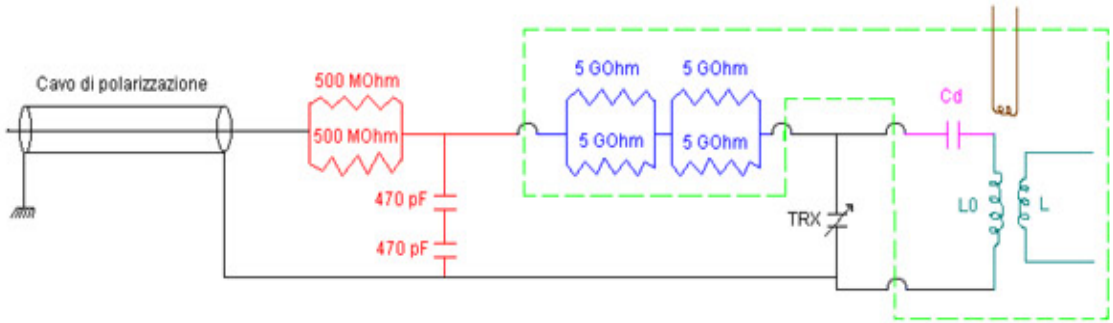
- ν_a= 935 Hz
- new antenna suspension cable
- new capacitive transducer
- Quantum Design dc SQUID

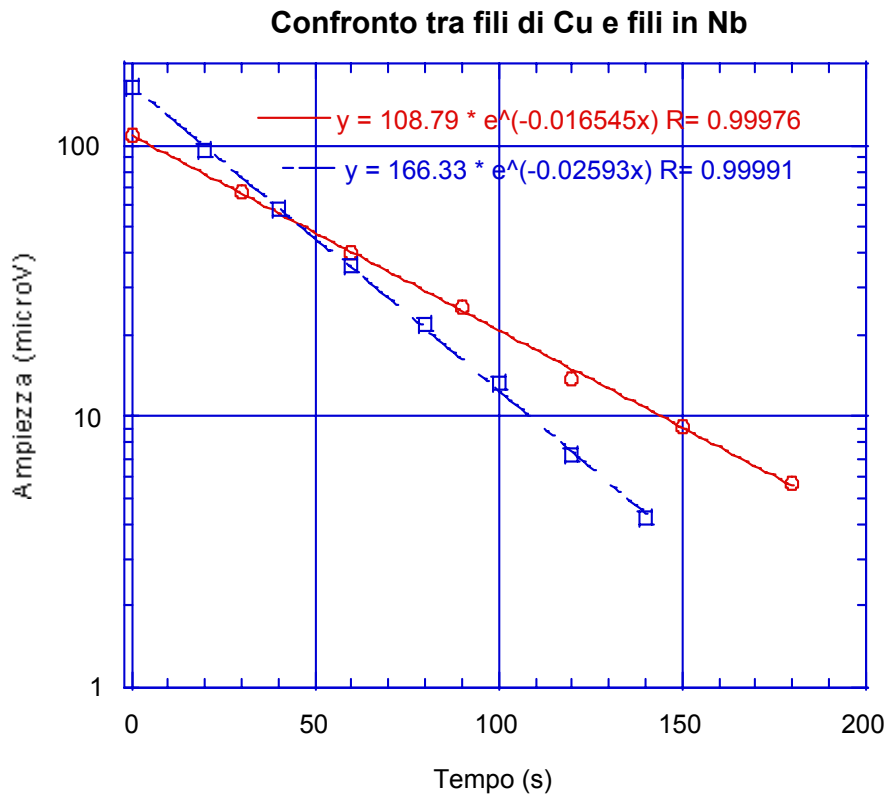
The bar was cooled down to 3.5 K in april. Data taking is under way. Improvement of performances with optimal tuning.

NAUTILUS STATUS

- It has worked from 1999 to March 2002 with a duty-cycle greater then 80% and an effective temperature smaller then 5 mK corresponding to $h = 6 \cdot 10^{-19}$
- NAUTILUS operations has been stopped on March 2002 for an upgrade, restarted March 2003
- The apparatus is approaching optimum performance



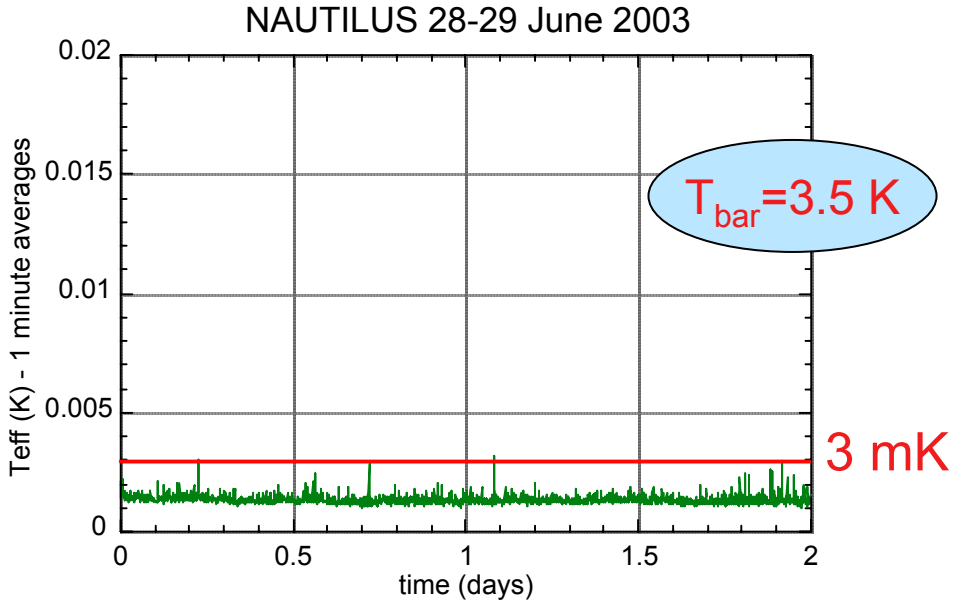


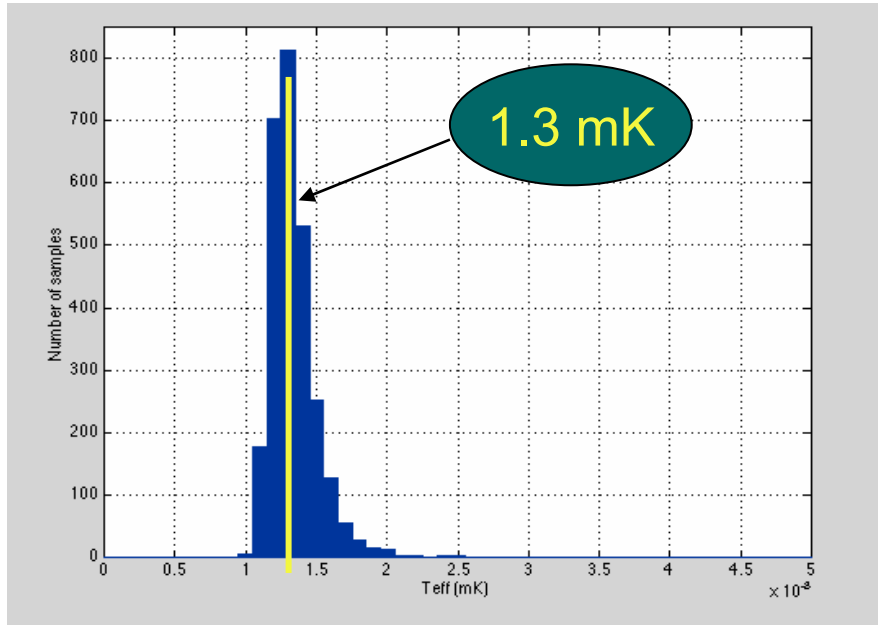


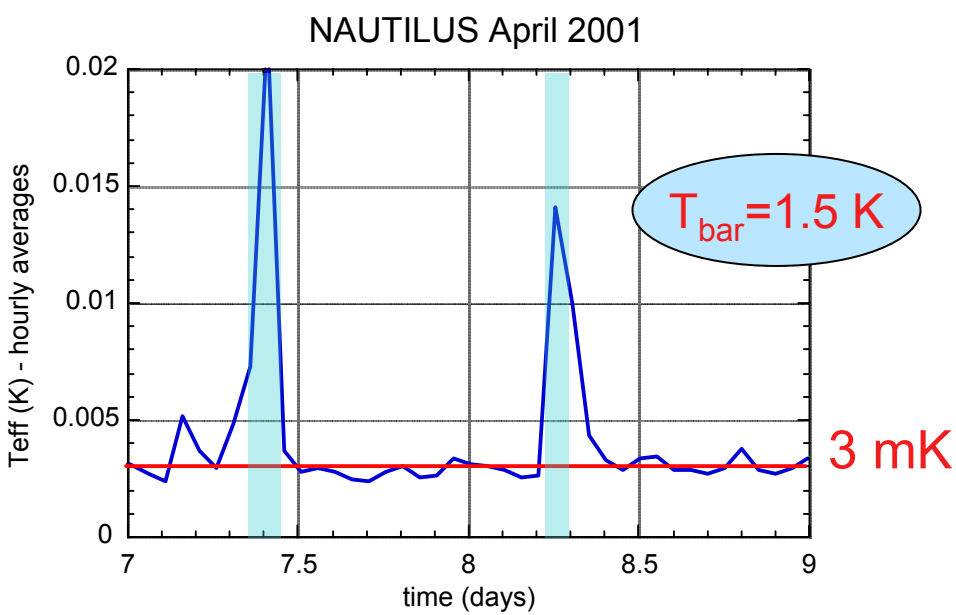
The electrical Q is of the order of 1-2 · 10^5. Each component has been tested to determine its effect on the Q.

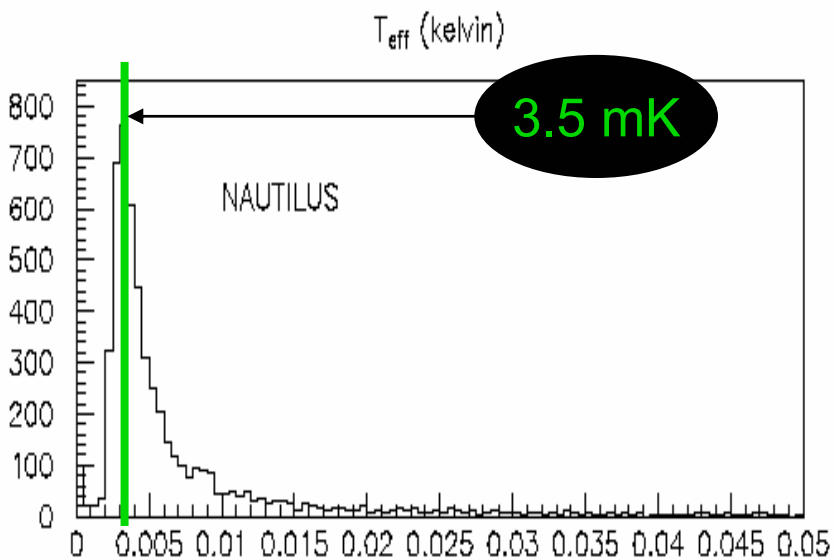
SQUID noise around

$3.9 \cdot 10^{-6}\ \phi_0/\sqrt{\text{Hz}}$

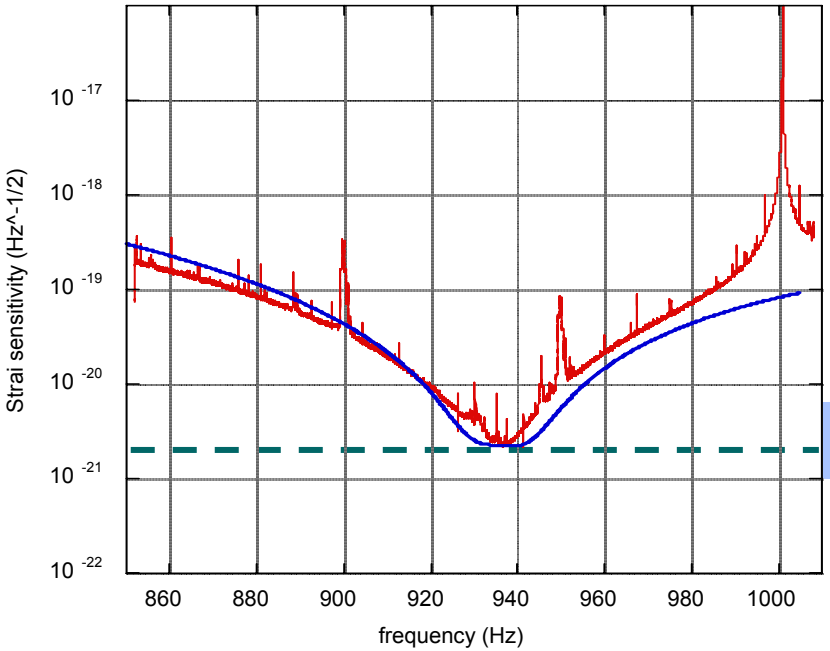

NAUTILUS 28-29 June 2003
Teff (K) - 1 minute averages
time (days)
T bar=3.5 K
3 mK


1.3 mK
Number of samples
Teff (mK)


NAUTILUS April 2001
Teff (K) - hourly averages
time (days)
T bar=1.5 K
3 mK

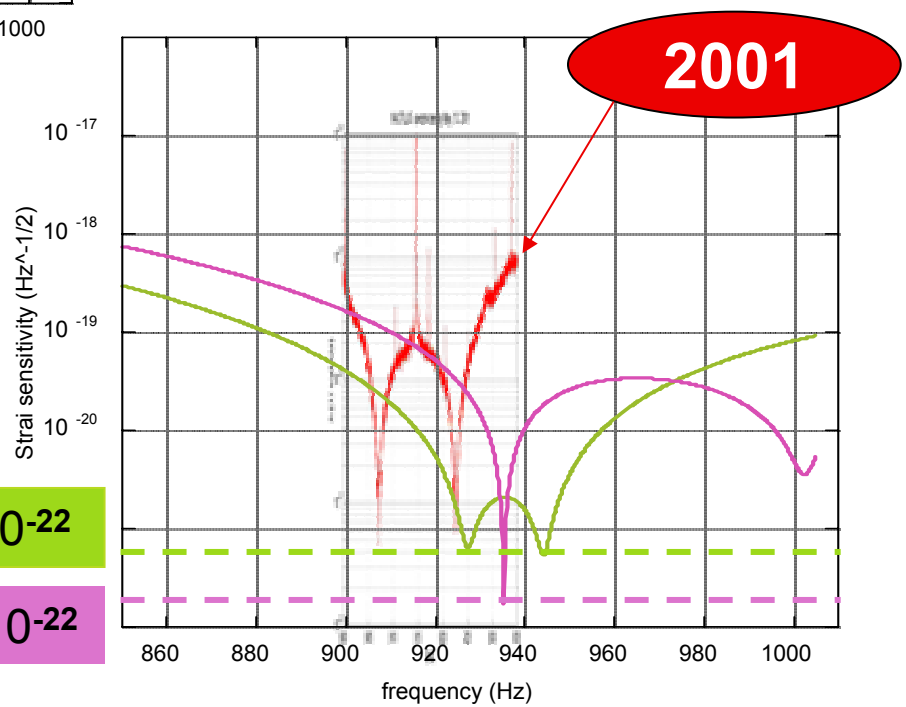

T eff (kelvin)
3.5 mK
NAUTILUS

NAUTILUS spectral density at 3.5 K
June 2003



$2 * 10^{-21}$

Expected spectral density at 0.15 K

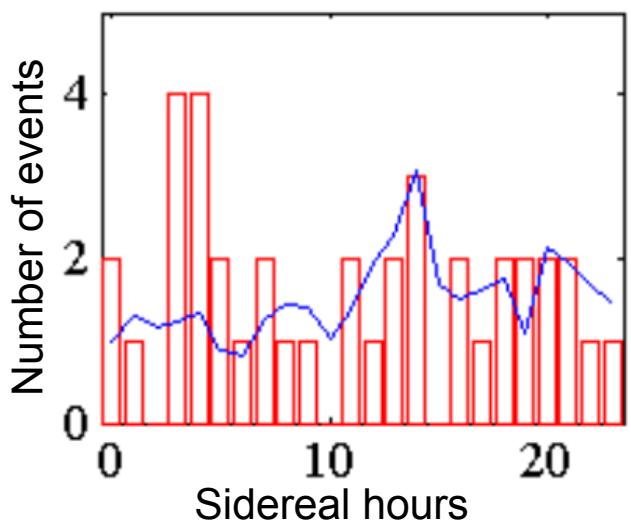


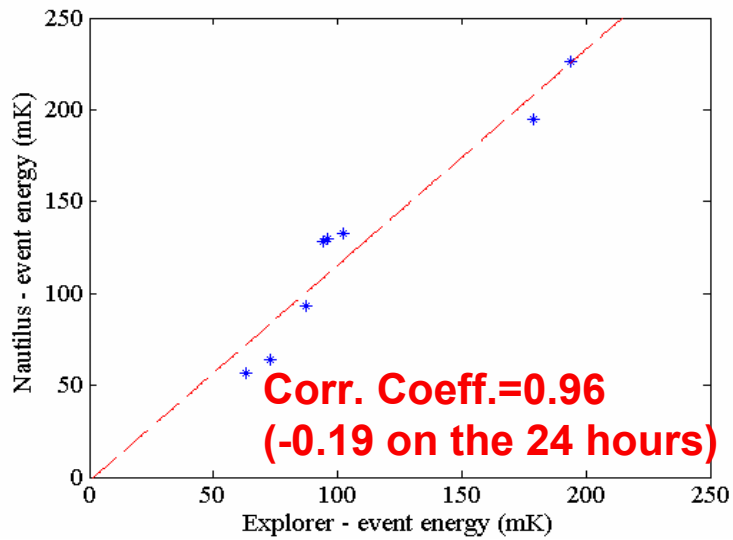
$6 * 10^{-22}$

$1.6 * 10^{-22}$

EXPLORER-NAUTILUS 2001 data analysis

During 2001 EXPLORER and NAUTILUS were the only two operating resonant detectors, with the best ever reached sensitivity.
A new algorithm based on energy compatibility of the event was applied to reduce the “background”





*ROG Coll.: CQG **19**, 5449 (2002)*
*L.S.Finn: CQG **20**, L37 (2003)*
P.Astone, G.D’Agostini, S.D’Antonio: CQG Proc. Of GWDAW 2002, gr-qc/0304096
E. Coccia ROG Coll.:CQG Proc. Of GWDAW 2002
ROG Coll.: gr-qc/0304004

Talk by G. Pizzella on Wednesday

DOES THE EXCESS SEEN MAKE ANY SENSE?

- The “interesting coincidences” have an energy around 100 mK corresponding to a conventional burst amplitude $h \sim 2 \cdot 10^{-18}$
- The energy is equivalent to a conversion of $4 \cdot 10^{-3}$ solar masses in galactic center (8 kpc)
- New data are needed for further considerations

Stochastic Background

Crosscorrelation of EXPLORER and NAUTILUS data

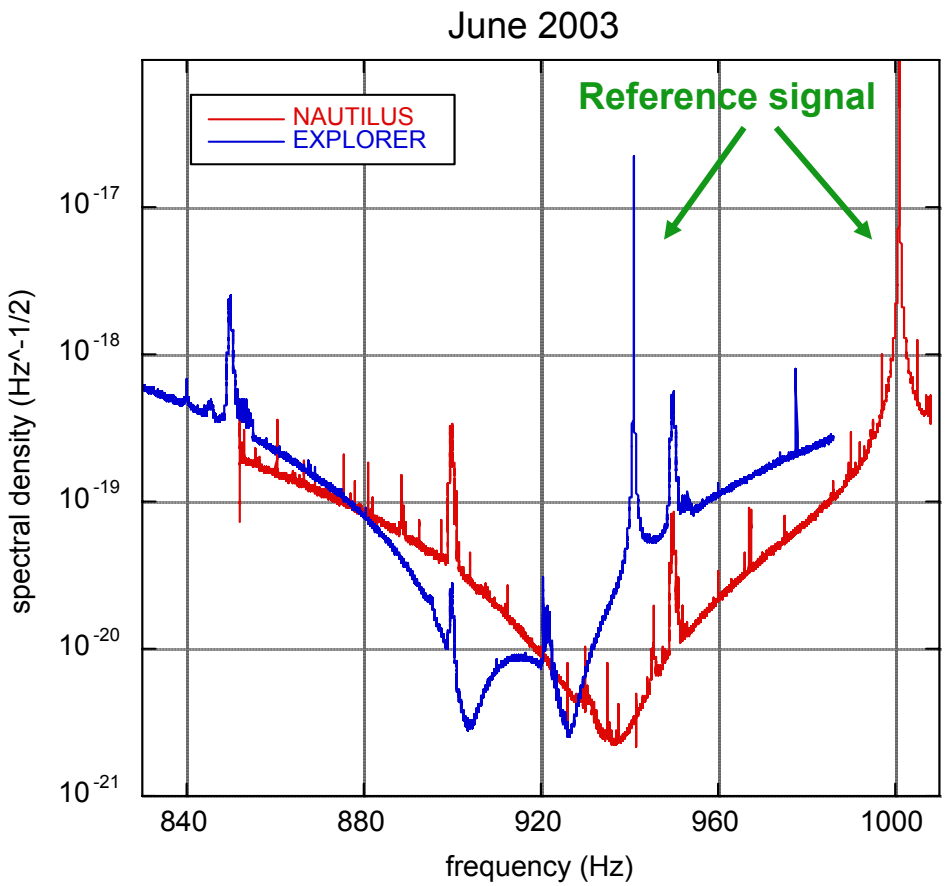
ROG Coll.: Astron. and Astrophys, 351, 811-814, (1999)

12 hours of data

$\Delta f = 0.1$ Hz

$S_{12} < 1 \times 10^{-44}$ Hz^{-1}

Ω_{GW} (920.2 Hz) < 60



Will optimize overlapping bandwidth by acting on the bias E field.

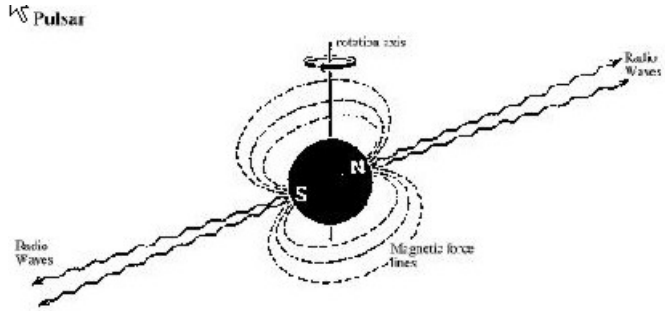
Potential common band is ~ 30 Hz = 300 x that exploited in `99.

If T_{obs} = 4 months $\Rightarrow \Omega_{GW} < 0.4$

Stochastic Background

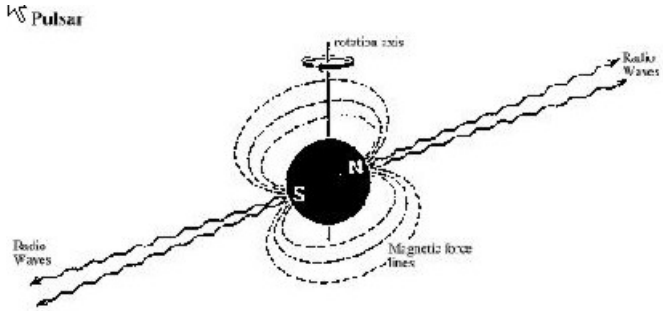
- **The cross-correlation of 6 months of NAUTILUS and AURIGA phase I, would put the limit $\Omega_{gw} \leq 0.1$ @ 935 Hz.**
- **Joint analyses with VIRGO - NAUTILUS and VIRGO - AURIGA II may put limits at the level $\Omega_{gw} \leq 3\text{-}5\ 10^{-3}$ (1y integration 10^{-22} $Hz^{-1/2}$ @900 Hz for VIRGO)**
- **LIGO I (10^{-22} $Hz^{-1/2}$ @ 1 kHz) and ALLEGRO ($2\ 10^{-21}$ $Hz^{-1/2}$): $\Omega_{gw} \leq 0.1$ (1y of data, analysed at periods of 2-3 months).**
- **LIGO II (10^{-23} $Hz^{-1/2}$ @ 1 kHz) and ALLEGRO (10^{-22} $Hz^{-1/2}$): $\Omega_{gw} \leq 6\ 10^{-4}$**

Continuous waves

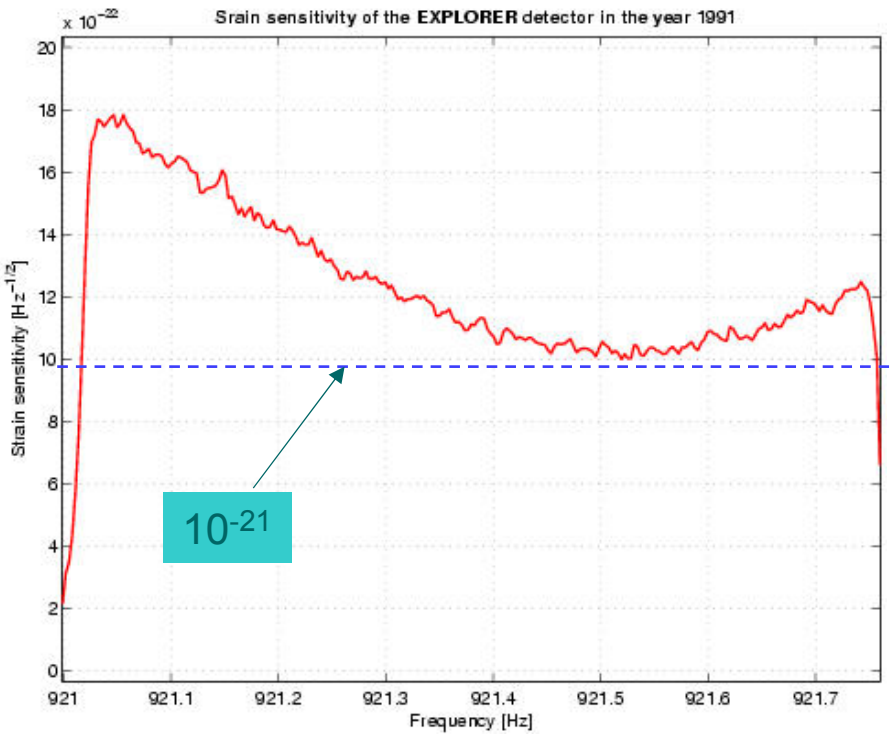


- ALLEGRO put upper limits (4 10^{-23} over 1 Hz band) on signals from the GC and 47Tucanae using one month of data
- Limit for signals in the GC, using 95 days of EXPLORER data $h_c=3x10^{-24}$, in the range 921.32 - 921.38 Hz (Astone et al. *PRD, 2002*)

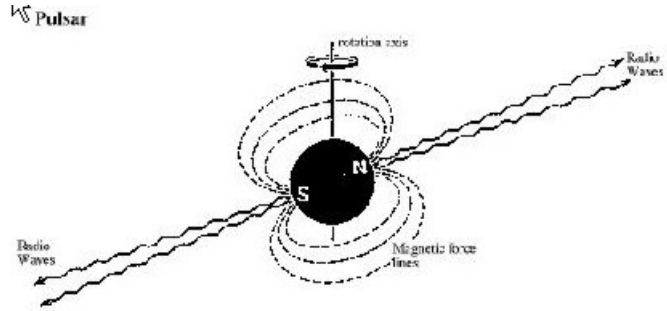
Continuous waves



Phase I: overall sky search over 2 days of EXPLORER 1991 data in collaboration with A. Krolak and collaborators put an upper limit of $h_c = 2 \cdot 10^{-23}$. (10^8 points, by choosing spin-down parameter and position randomly) (CQG, proc. GWDAW 2002)



Continuous waves



Phase II ended: collaboration with Krolak & C. and the Virgo Project Group in Rome. Two-day stretch of data disjoint from the two-day stretch analysed in the previous search.

Search done using the computers provided by the Virgo Project (March-May 2003). Number of candidates found: 29909.

Highest SNRS:

Northern Sky=8.15

Southern Sky=7.83

(99% confidence threshold is 8.3, none of the candidates exceeded this thrs.)

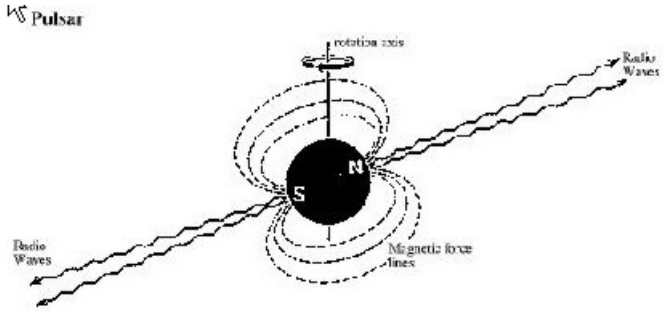
Comparison of candidates found in the two searches is now in progress.

The results of the search will be compared with those of an analysis done using the hierarchical search procedure, developed by the Virgo group of Rome, in collaboration with the ROG group (this work is now in progress). The aim is to analyze at least 1 year of data of EXPLORER and NAUTILUS.

Phase III: 2 more days of EXPLORER data is in progress.

www.astro.uni.torun.pl/~kb/all-sky and www.roma1.infn.it/rog

Continuous waves



Agreement between ROG and Max Planck in Golm for the coherent analysis (search of pulsars) of data selected from 1 year of data of Nautilus 2001.

The data base of FFTs (17193 FFTs, 28 minutes each, in the format used by GEO/LIGO in their analysis) has been produced and is now in the cluster in Golm.

The procedures to veto the data is under studying.

Searches pointing at Globular Clusters, Galactic Plane..are in schedule.

Effect of cosmic rays

$h = 3 \times 10^{-22}\ Hz^{-1/2}$

$h_{pulse} = \Delta L/L = 4 \times 10^{-19}$

$\Delta E = 2\ mK = 0.3\ \mu eV$

Nautilus is equipped with 7 layers (3 above the cryostat - area 36m^2/each - and 4 below -area 16.5 m^2/each) **of Streamer tubes.**

The cosmic ray effect on the bar is measured by an offline correlation, driven by the arrival time of the cosmic rays, between the observed multiplicity in the ST detector (saturation for M≥10^3 particles/m^2) and the data of the antenna, sampled each 4.54 ms and processed by a filter matched to δ signals

Effect of cosmic rays on a resonant detector

Grüneisen coefficient

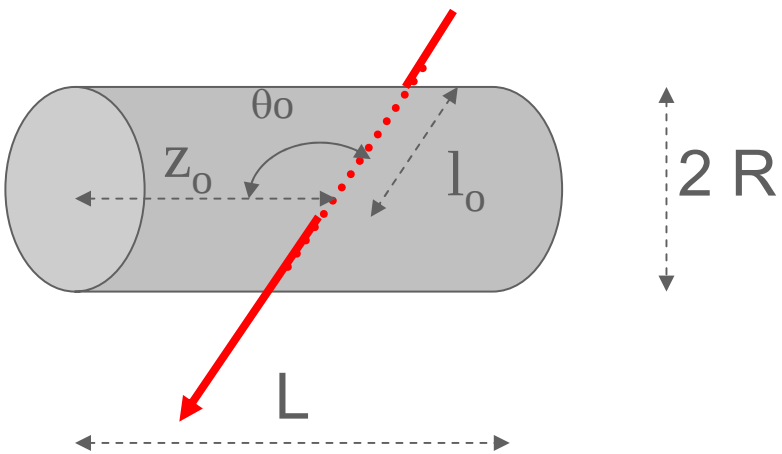
Energy lost

$$E = \frac{4}{9\pi}\frac{\gamma^2}{\rho L v^2}\left(\frac{dW}{dx}\right)^2\left(\sin\left(\frac{\pi z_o}{L}\right)\frac{\sin(\pi l_o \cos(\theta_o)/2L)}{\pi R\cos(\theta_o)/L}\right)^2 = 7.64\,x10^{-9}W^2\ f\ \left[\frac{K}{GeV^2}\right]$$

density

sound velocity

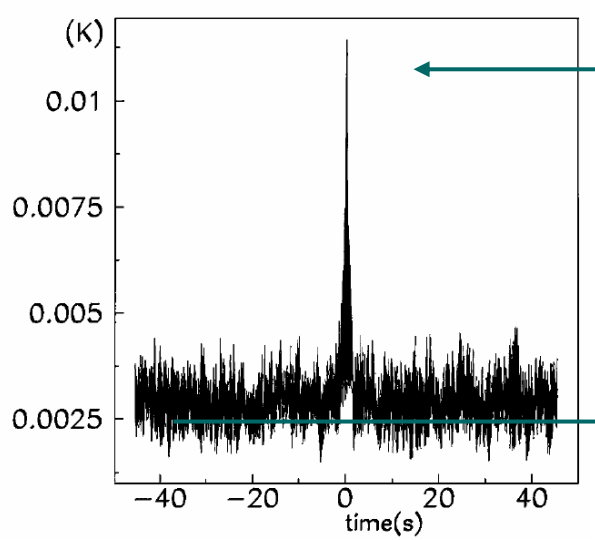
Calculation for Nautilus



The longitudinal mode of vibration of the antenna is excited by the thermal expansion due to the energy lost by the particles

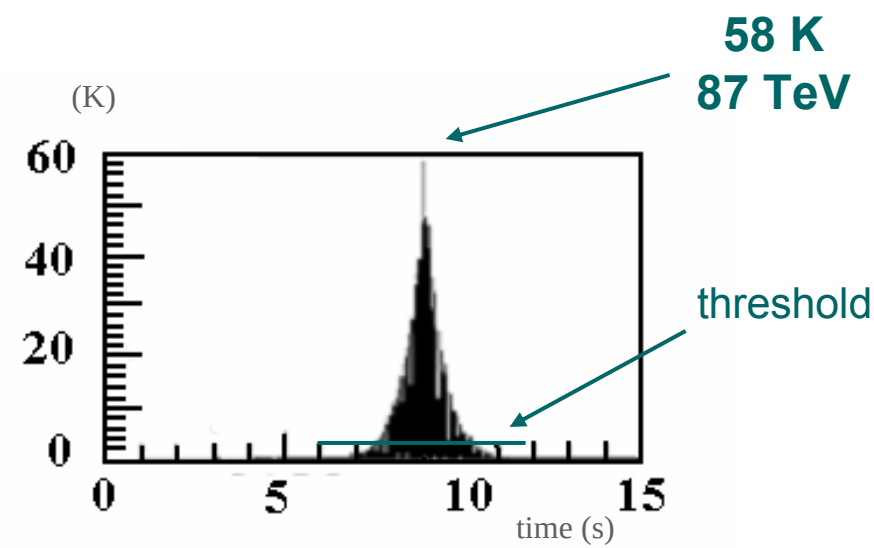
The first analysis confirmed the calculation made by several authors.

P.Astone et al.: *"Cosmic rays observed by the Resonant Gravitational wave detector Nautilus"* Physical Review Letter, **84**, (2000)14-17



Detection of very large unexpected events.

P.Astone et al.: *"Energetic Cosmic Rays observed by the resonant gravitational wave detector NAUTILUS"* , Phys. Letters B 499, Feb 2001 16-22



RESULTS WITH NAUTILUS BAR NOT SUPERCONDUCTING

Period	NAUTILUS temperature (K)	Duration (hours)	nc	n	Rate(ev/day)
Sept-Dec 1998	0.14	2002	12	0.47	
Feb-July 2000	0.14	707	9	0.42	
total		2709	21	0.89	0.178
Aug -Dec 2000	1.1	118	0	0.03	
Mar-Sept 2001	1.5	2003	1	0.54	
total		2121	1	0.45	0.006

Superconductivity is presently considered as the origin of the anomalous events

P.Astone et al.: *"Effect of cosmic rays on the resonant g.w. detector Nautilus at temperature T=1.5K"* Physics Letters B 540 179-184 (2002)).

Effect of cosmic rays

RAP

Rivelazione Acustica di Particelle