PRESENT AND FUTURE OF RESONANT DETECTORS

MASSIMO BASSAN
Università "Tor Vergata" and INFN - Roma2
ROG and MINIGRAIL Collaborations

ABSTRACT
some elementary considerations on:

- BAR DETECTORS: WHY ?
- Bar Detectors: how do they work ?
- SENSITIVITY and BANDWIDTH: WHERE WE STAND and where can we go ?
  - Handles to improve present performances
- Some data from our detectors…
- New detectors for the future: MINIGRAIL and DUAL

RESONANT DETECTORS, WHY ?

Bars with respect to Interferometers :

- Technology :
  different principles and instrumentation

- Complementary Frequency Band
  HF signals allow to study unique features
  of compact objects

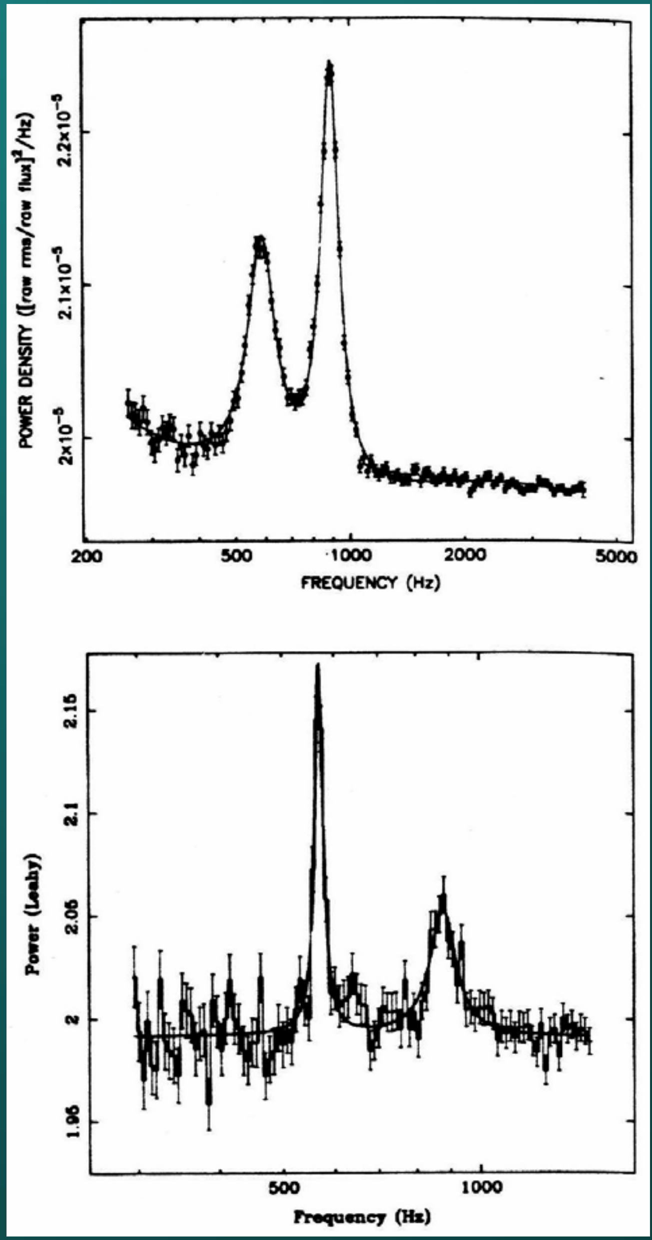
- Symmetry properties
  discriminating the signal quadrupole character

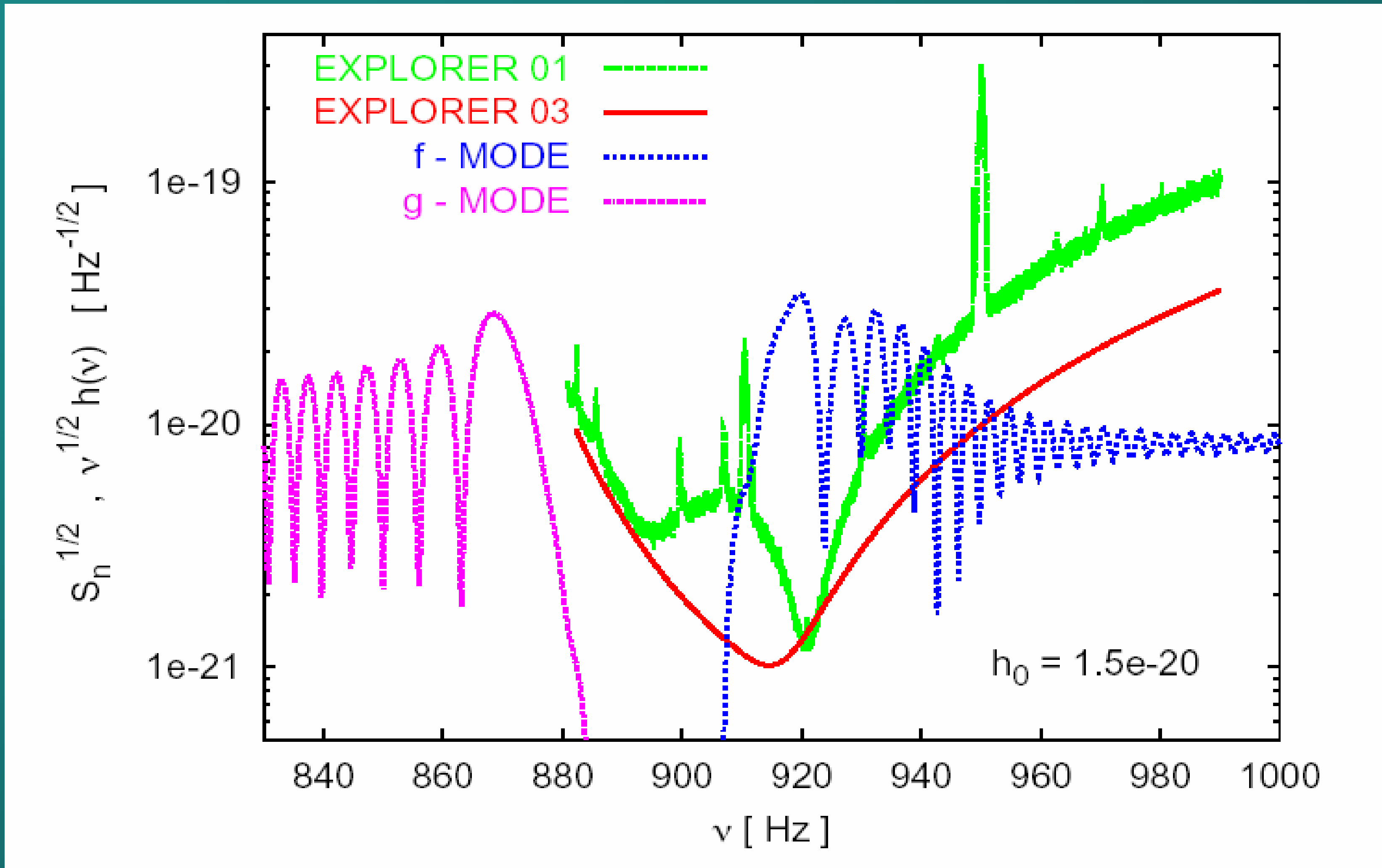
- Detectors presently in reliable operation

Quasi-Periodic Oscillations

- NS and BH XRBs sometimes exhibit QPOs
- Frequencies are high (kHz QPOs), so the oscillations occur deep in the potential well
- Relativistic effects are likely to be important

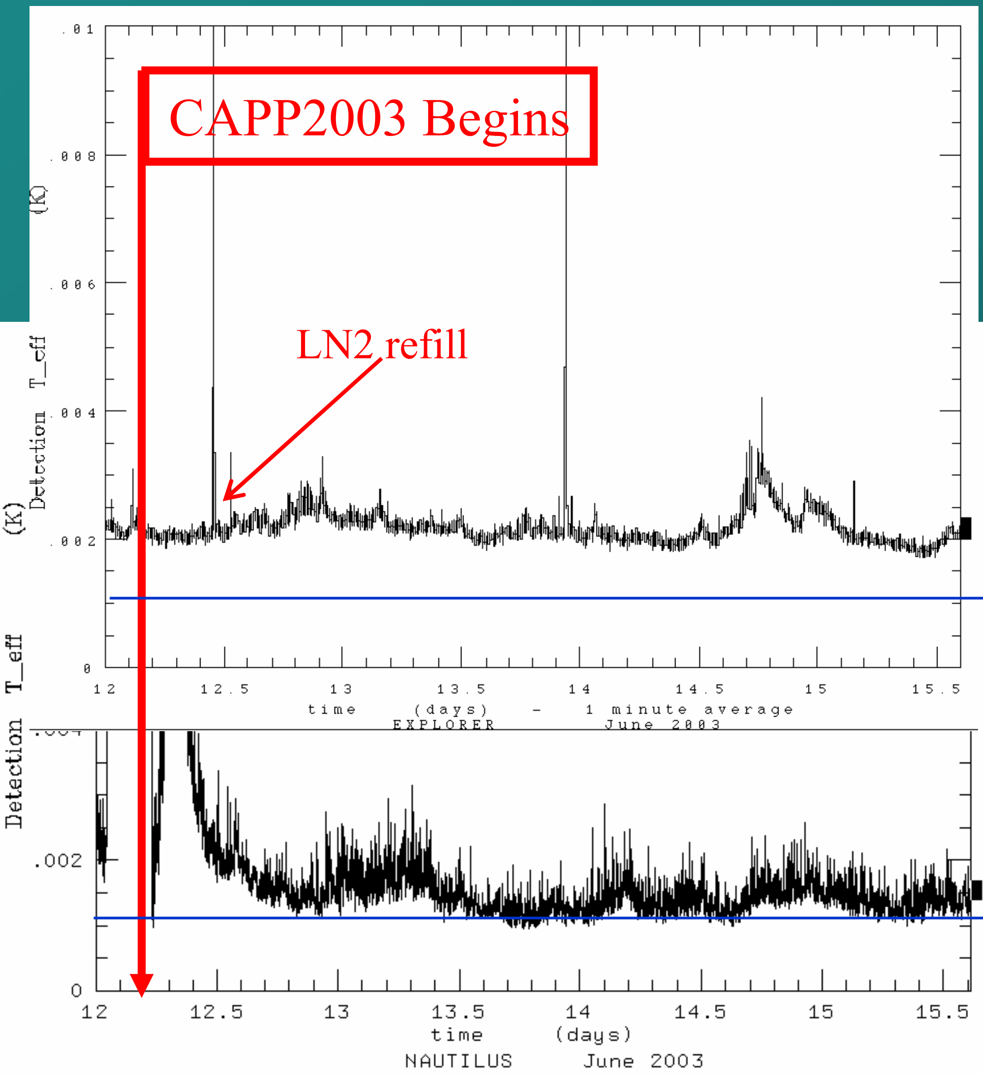
From dr. Narayan's talk





V. Ferrari et al. (2002)

RELIABLE OPERATION :
last 4 days of data in Explorer and Nautilus



Each data point in either plot is a 1minute average of the data filtered at ~200 Hz

Burst energy sensitivity:
1 mK =85 neV
in a 2300 kg resonator !

RESONANT DETECTORS:

Yesterday: J. Weber

Tomorrow

The detectors of the Roma-Frascati group: EXPLORER and NAUTILUS

Today

Bar Al 5056 M = 2270 kg
L = 2.97 m Ø = 0.6 m
ν_A= 915 Hz @ T = 2.5 K
Cosmic ray veto (recently completed)

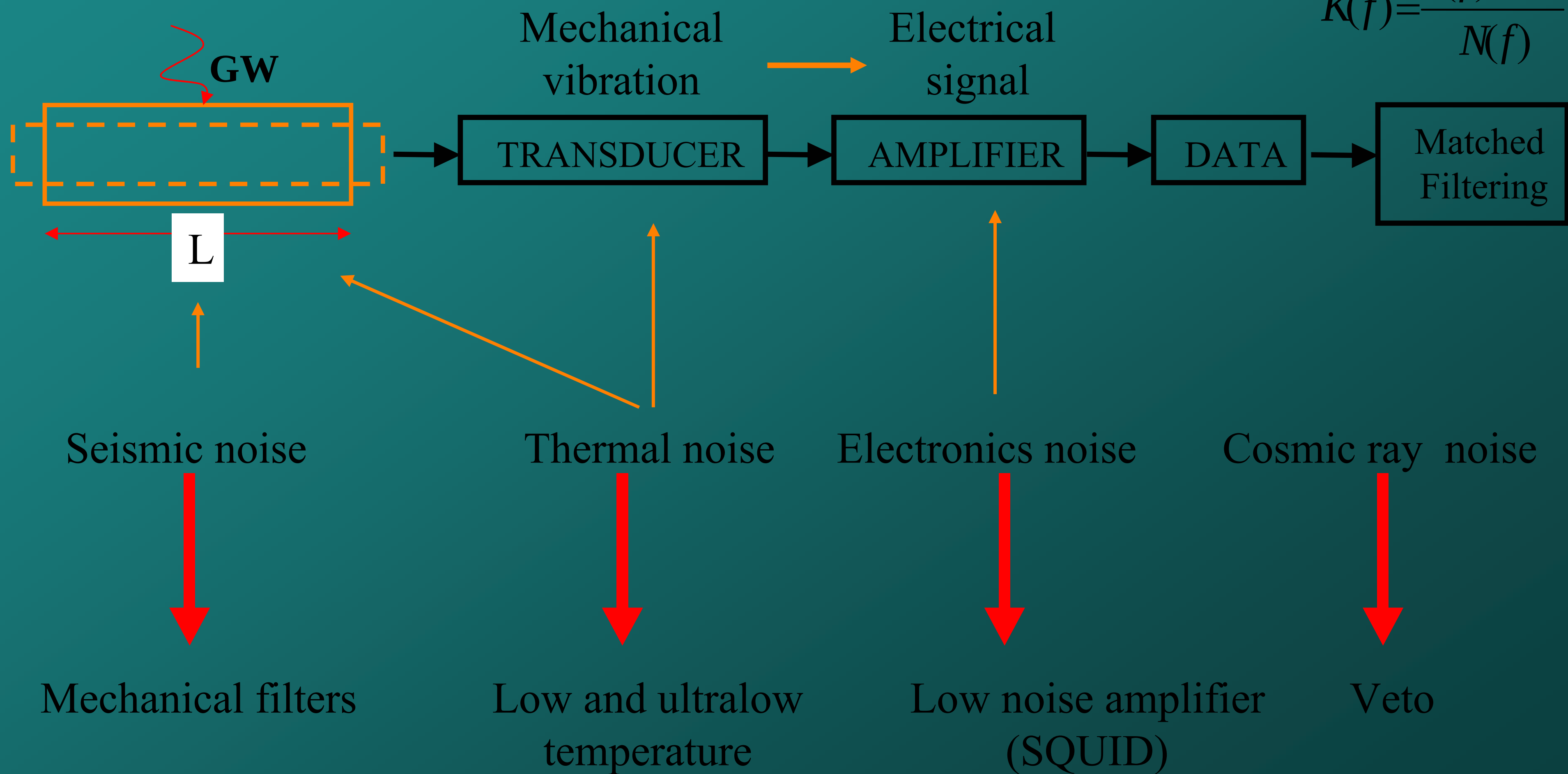
ν_A= 935 Hz (recently tuned)
Al 5056 bar M = 2270 kg
L = 2.92 m Ø = 0.6 m
Cooled by a dilution fridge T=130 mK
Cosmic ray telescope veto

GRAVITATIONAL WAVE DETECTORS

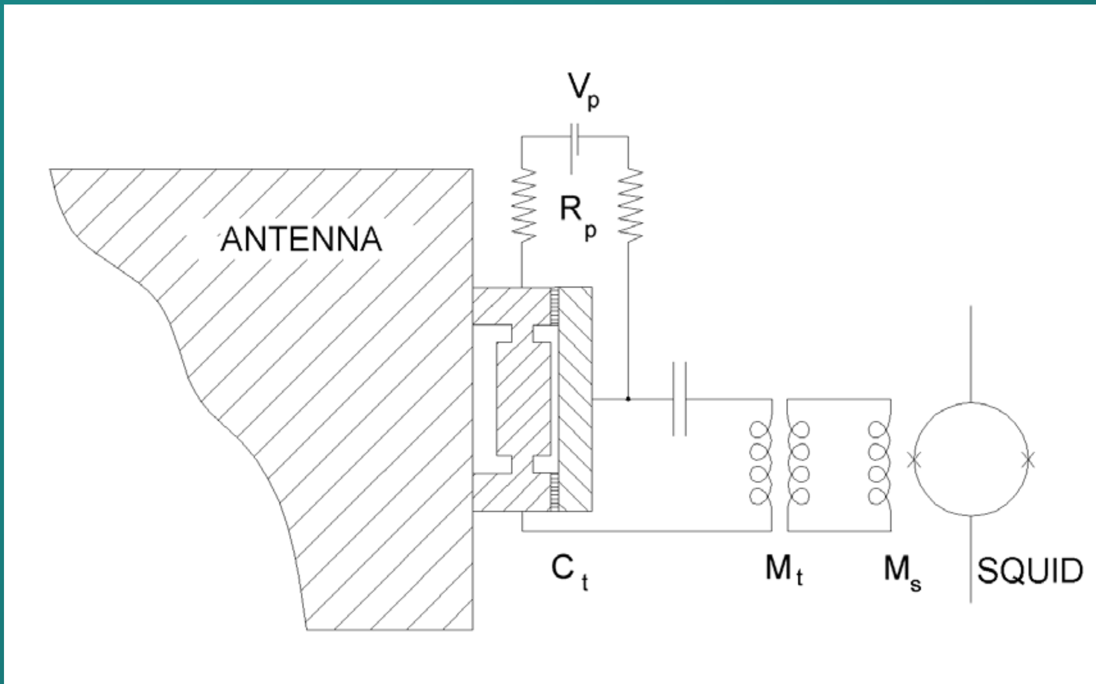
The GW excites the longitudinal mode of vibration of a massive (~2 ton) cylinder

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

$$K(f) = \frac{S(f)e^{-i2\pi f t_0}}{N(f)}$$

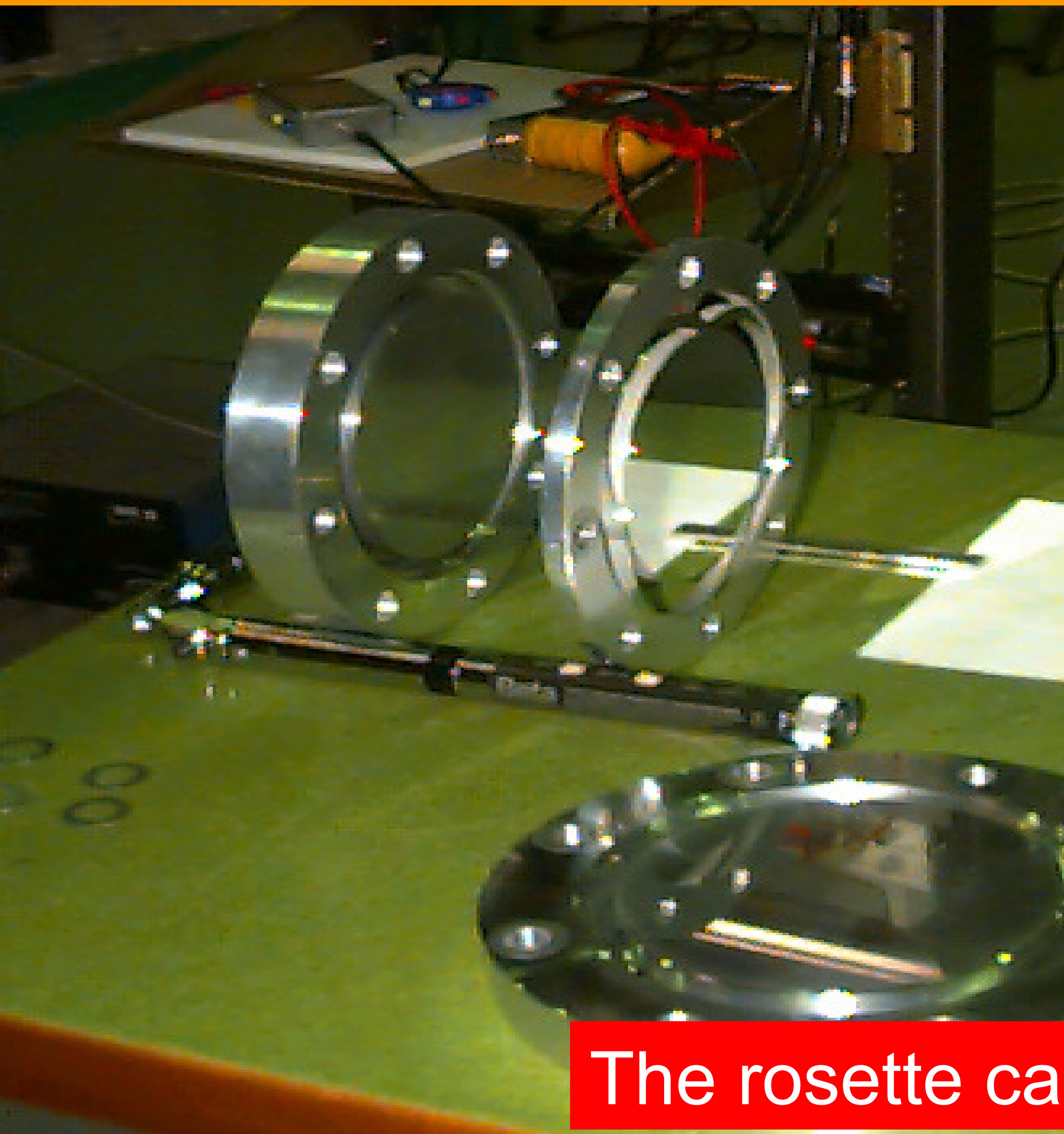


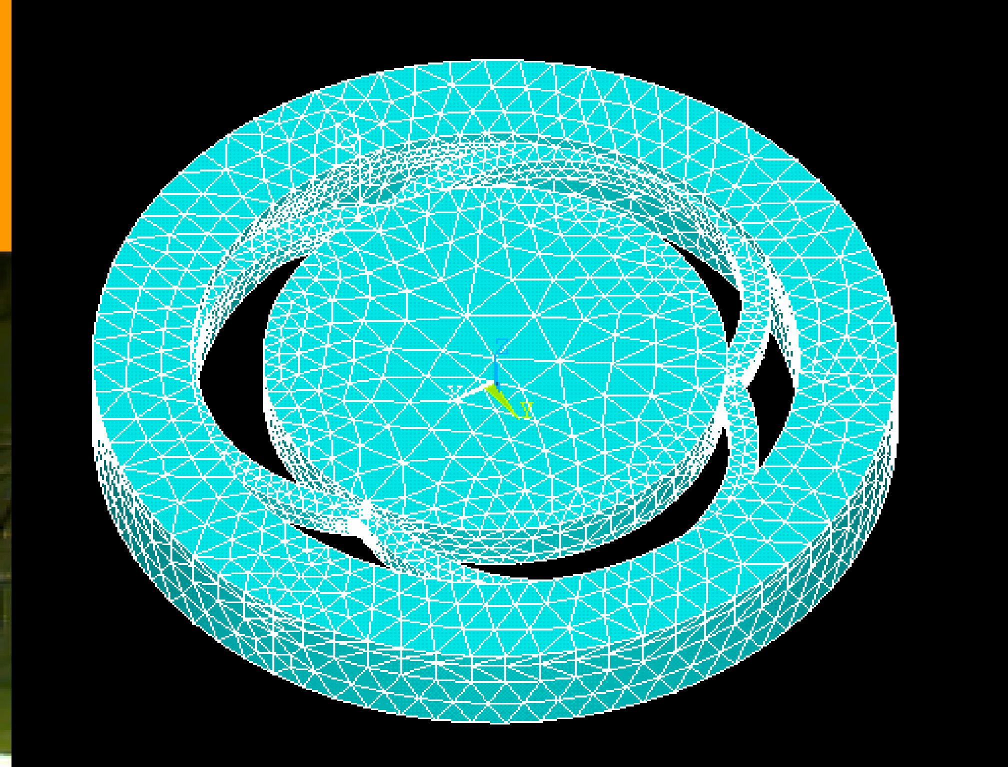
The readout of Explorer, Nautilus and Auriga



- small gap (10μm) capacitive pick up, d.c. biased with $E \sim 10^7$ V/m
- Superconducting matching transformer(Lp =2 H, Ls =2 μH)
- High sensitivity d.c. SQUID (JJ technology) $\phi_{min} = 2\ \mu\phi_o /\sqrt{Hz}$

PRECISION MECHANICS:

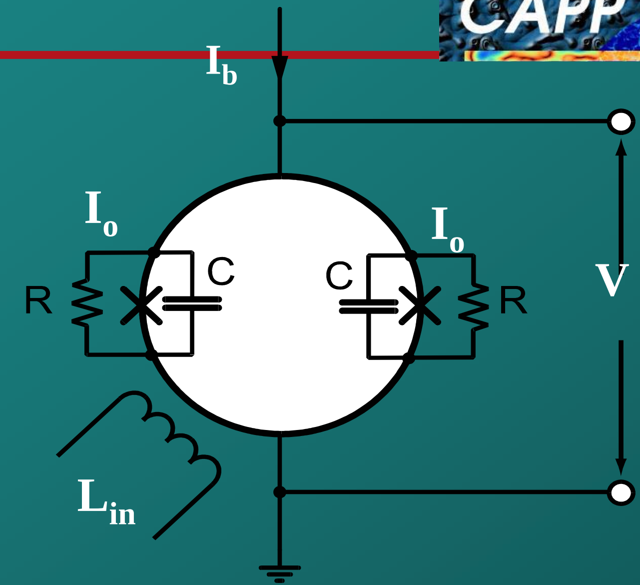




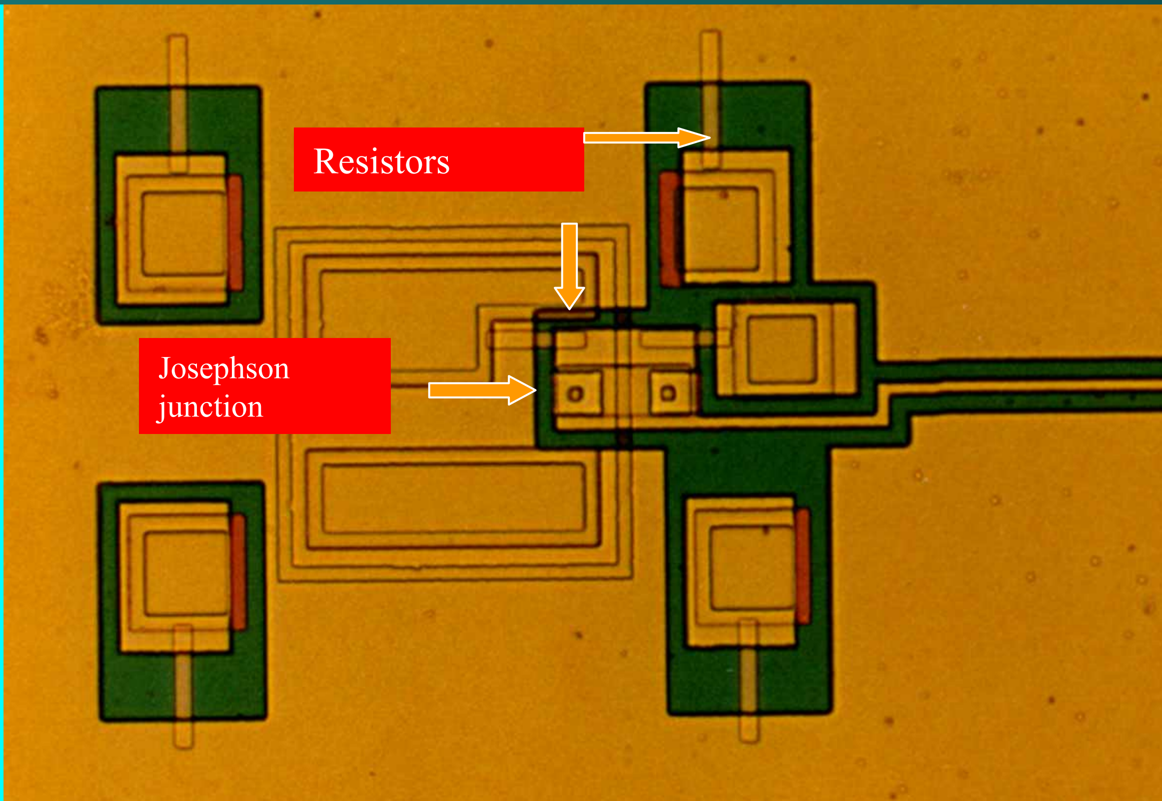
The rosette capacitive transducer; gap=9μm

Quantum at work

dc-SQUID



- superconducting loop with inductance L
- 2 Josephson junctions:critical current I_o, shunt resistance R, capacitance C,
- Input inductance L_{in}, coupling α



$S_h(f)$ = Spectrum of a g.w. excitation that would appear equal to the noise in the antenna (SNR=1)

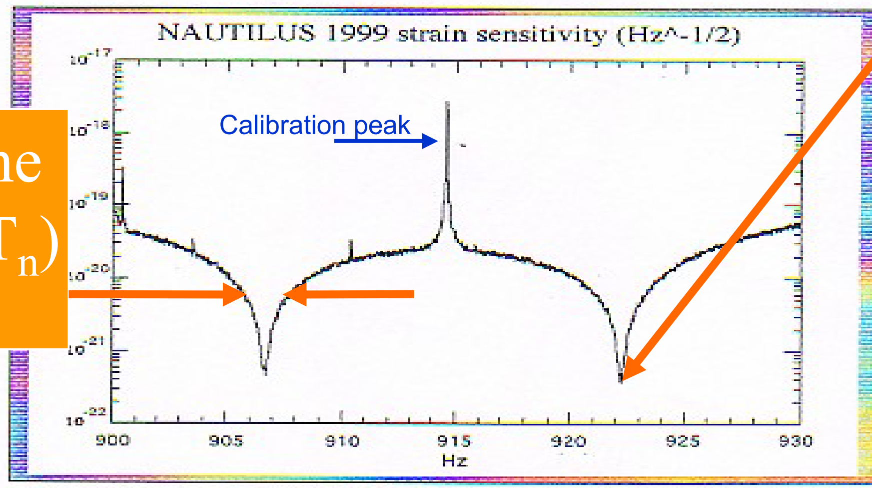
The peak sensitivity depends on T/MQ

$$\tilde{h}_{min} \approx \left(\frac{T}{MQ}\right)^{1/2} \quad [1/\sqrt{Hz}]$$

T Thermodynamic Tem[perature]
M Mass
Q Quality Factor

$$\Delta f \approx \left(\frac{\beta}{T_n}\right)^{1/2} \quad [Hz]$$

ß Capacitive transducer efficiency
T_n Electronic temperature noise



The bandwidth depends on the transducer (β) and amplifier (T_n)

We need to broaden AND deepen the dips in this curve:

=> More peak sensitivity

=> AND more bandwidth

WIDENING THE BAND IN EXPLORER

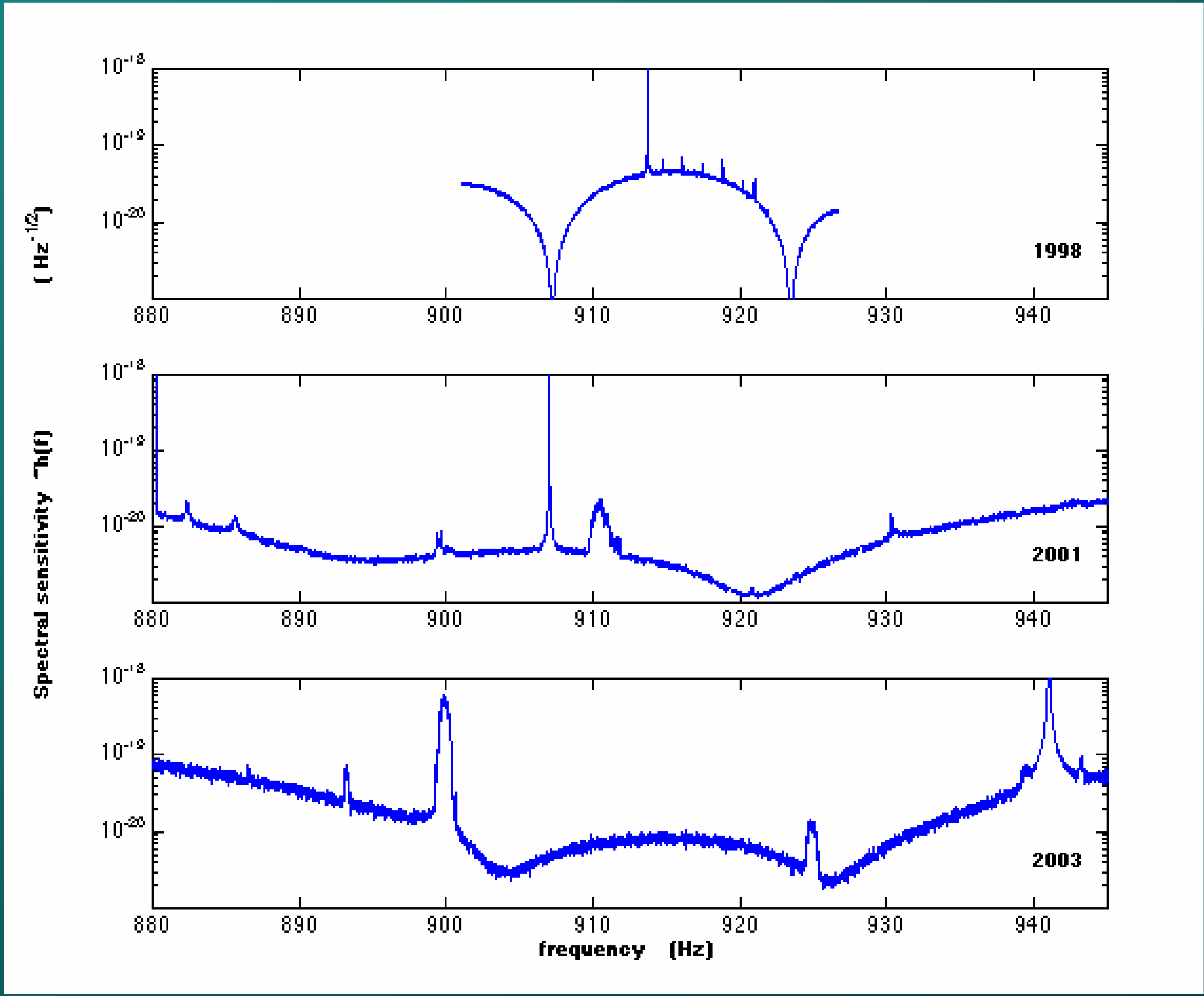
EXPLORER has been on the air since May 2000 with:

-new, 10 μm gap transducer

-New, high coupling SQUID

The noise temperature is < 3 mK for 84% of the time.

Bandwidth: the detector has a sensitivity better than 10^{-20} $Hz^{-1/2}$ on a band larger than 40 Hz



REAL DATA, A QUICK REVIEW

- Search for relic background of g.w.
- Search for periodic sources (and SN1987a remnant)
- Search for burst:
  - The IGEC upper limit
  - 2001 data from Explorer and Nautilus
- ~~Detection of cosmic rays in Nautilus~~

SEARCH FOR STOCHASTIC BACKGROUND I

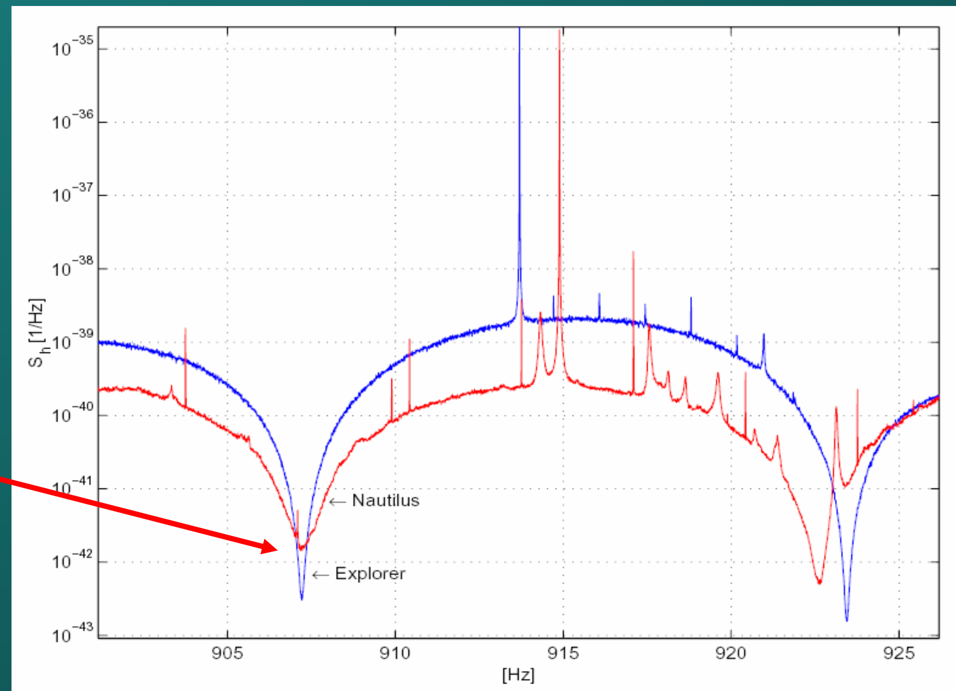
- Crosscorrelation of EXPLORER and NAUTILUS data

12 hours of data

$\Delta f = 0.1$ Hz

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

$$\Omega_{GW}(920.2) < 60$$



$$S_{12}(f;\Delta f) = \frac{1}{\Delta f}\int_{f-\frac{\Delta f}{2}}^{f+\frac{\Delta f}{2}} H_{1h}(f')H_{2h}^{*}(f')df'$$

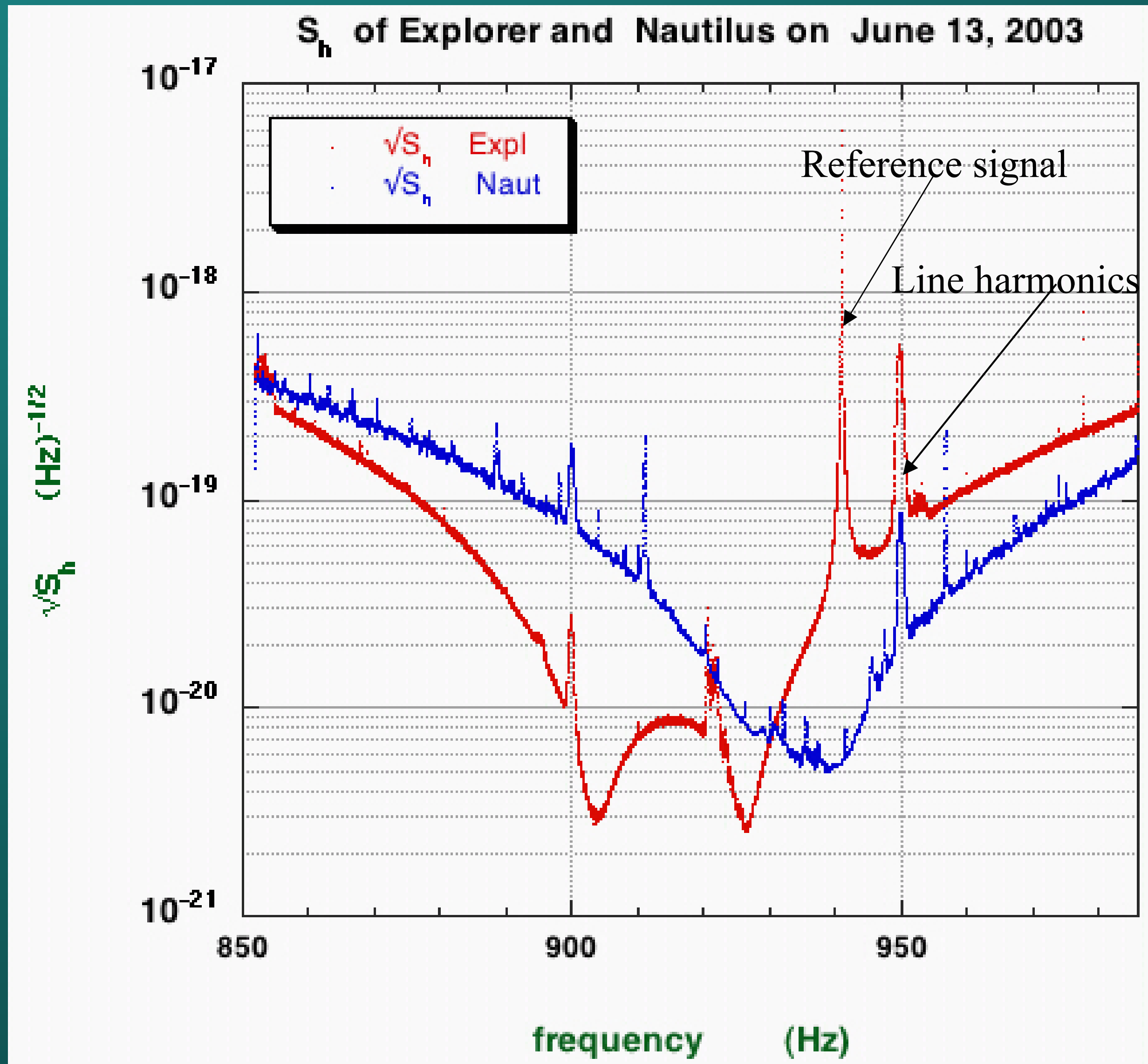
$$\Omega_{gw}(f) = \frac{S_h(f)f^3 4\pi^2}{3H_0^2}$$

"Crosscorrelation measurement of stochastic gravitational waves with two resonant gravitational wave detectors",
Astron. and Astrophys, 351, 811-814, (1999).)

NEXT SEARCH, ON 2003 DATA:

- Will optimize overlaping bandwidth by acting on the bias E field

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



SEARCH FOR STOCHASTIC BACKGROUND III

- Limits of $\Omega_{gw} < 1$ achievable cross-correlating data from a bar-bar couple or from a bar-interferometer couple:

- The cross-correlation of 4 months of NAUTILUS and AURIGA data, at the sensitivity expected in the next run, would put the limit at $\Omega_{gw} \leq 0.1$

- Joint analyses with VIRGO, NAUTILUS and AURIGA may put limits at the level $\Omega_{gw} \leq 3\text{-}5\ 10^{-3}$ (1y integration time, NAUTILUS upgraded and AURIGA phase 2, and VIRGO at 10^{-22} $Hz^{-1/2}$ @900 Hz

SEARCH FOR BURST SIGNALS

- The search for burst signals with a single detector is meaningless. It is almost impossible to distinguish the candidate events from the back-ground of noise. The “coincidence analysis” between the event candidates of different detectors strongly decrease the false alarm probability.

$$\lambda = N \frac{(\Delta t)^{N-1}}{T_{obs}^{N}} \prod_{i=1}^{N} n_i$$

Number of events

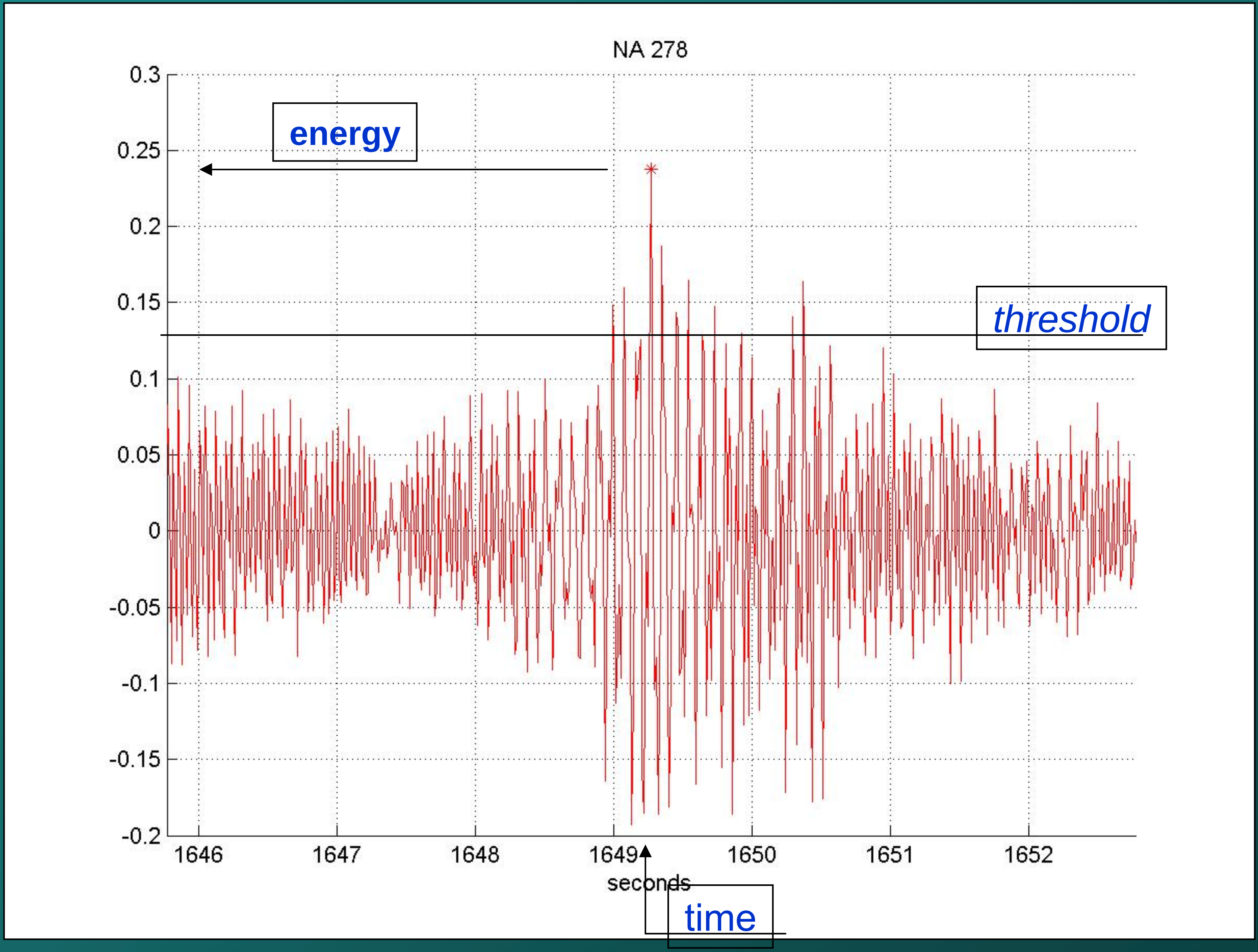
Rate of accidental coincidences

Number of detectors

Common observation time

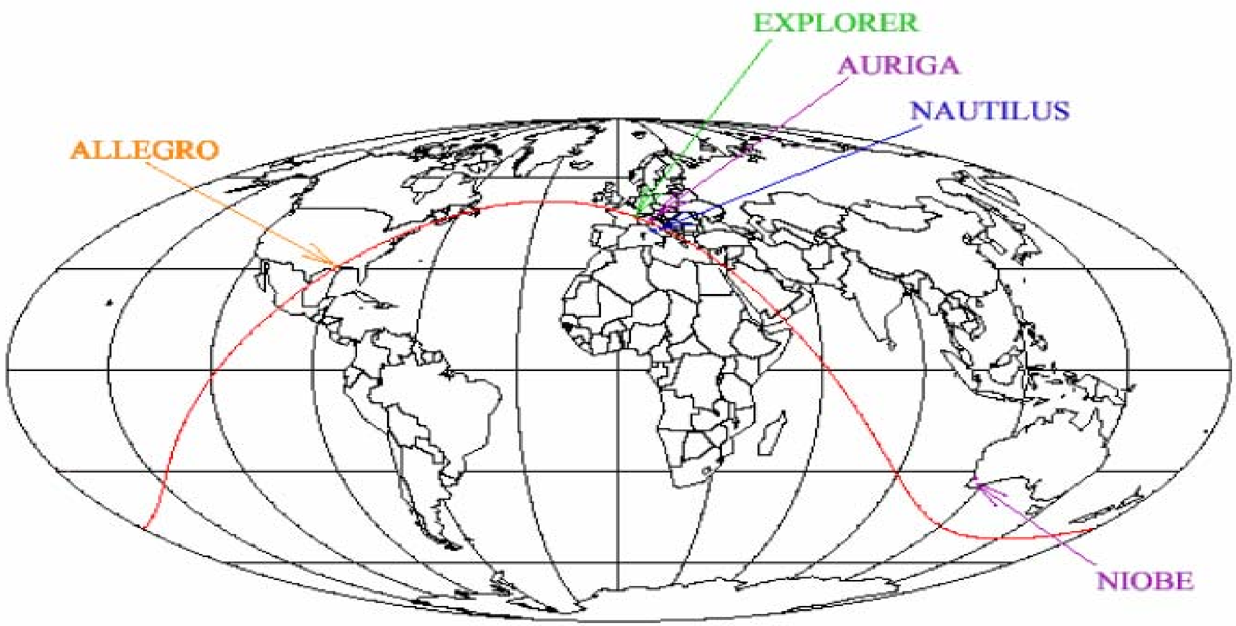
Coincidence window

What is an *event* ?



IGEC

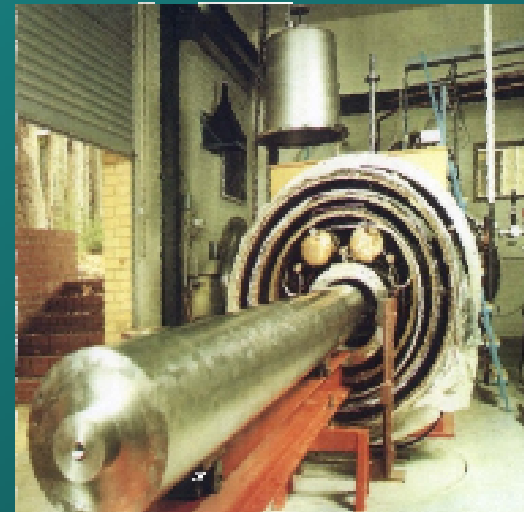
International Gravitational Event Collaboration



- Collaboration for data exchange between the five resonant detector operating world wide

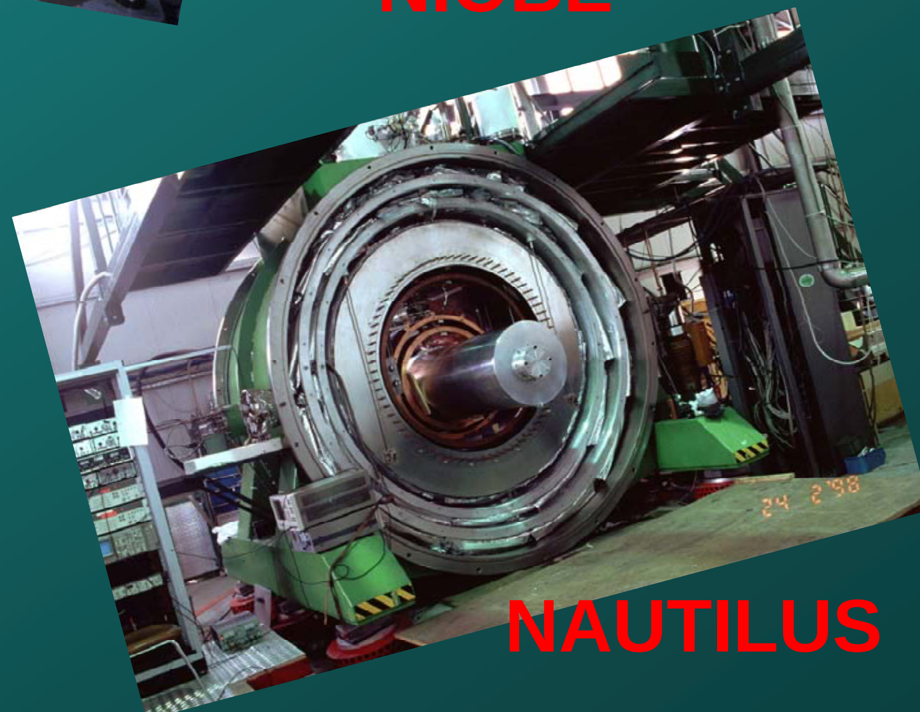
ALLEGRO

AURIGA



NIOBE

EXPLORER



NAUTILUS

Physics News Update

The AIP Bulletin of Physics News

Subscribe to Physics News Update

Archives

2000 1999 1998 1997
1996 1995 1994 1993
1992 1991 1990

Latest Physics News Graphics | Latest Physics News Update

Number 514 (Story 1), 29 November 2000 by Phillip F. Schewe and Ben Stein

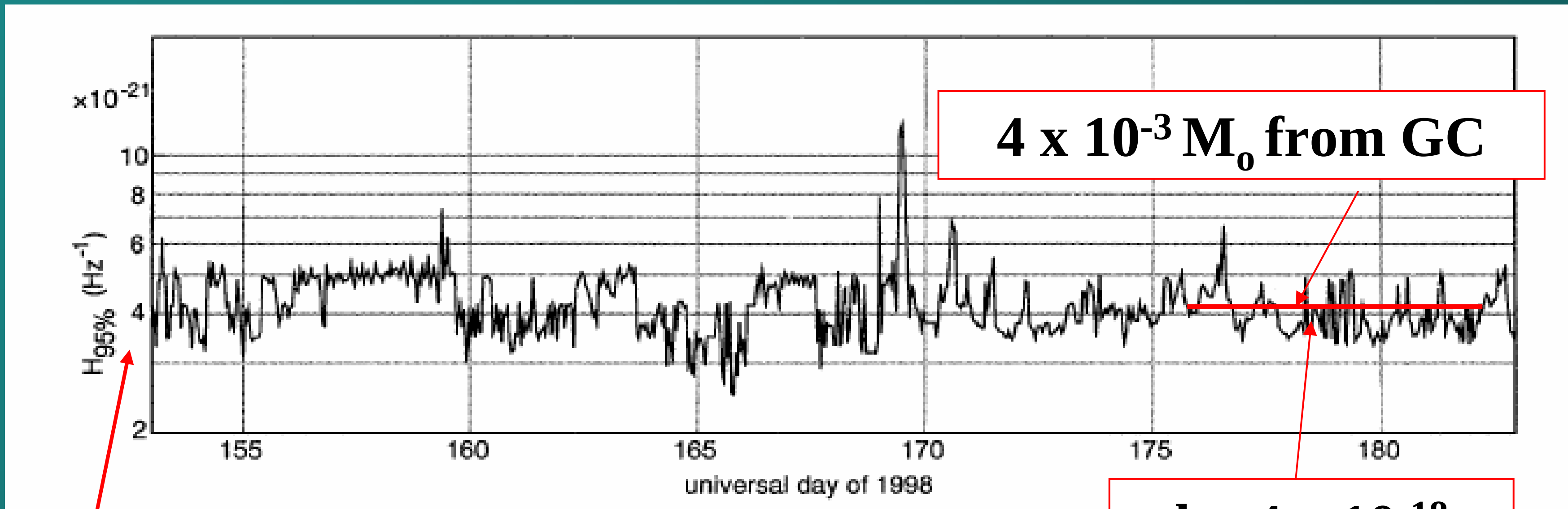
New Upper Limit on Gravity Wave Events in Our Galaxy

The International Gravitational Event Collaboration (IGEC) is the first ever network of cryogenic resonant-cylinder gravity wave detectors. It consists of five widely spaced detectors: one in the US (Baton Rouge), two in Italy (Legnaro and Frascati), one in Switzerland (at CERN), and one in Australia (Perth).

Searching for passing gravity waves is a delicate art since it involves sensing deformations much smaller than the size of an atomic nucleus in huge detectors meters or kilometers in size. In the resonant detector approach this means watching for longitudinal vibrations in chilled automobile-sized metal cylinders. In the interferometer approach (used at LIGO; see, for example, Update 442) the deformation is the change in the separation of distant mirrors attached to test masses. Gravity waves strong enough to be detected will most likely come from events such as the coalescence of black holes or neutron stars, and these are rare. IGEC reports now that in its first operational period it has observed no gravity waves. From this they calculate an upper limit of the order of one per year in the rate at which such gravity wave events occur in our galaxy.

GEC is not only striving to have the sensitivity to record gravity waves from events out to distances of 100 million light years but is also hoping to be able to locate the source of the waves in the sky.

UPPER LIMIT IGEC



$4 \times 10^{-3}\ M_o$ from GC

$h = 4 \times 10^{-18}$

- Upper limit with 95% confidence on the amplitude of a single GW burst with optimum parameters

EXPLORER-NAUTILUS EVENTS OF 2001

DATA-EVENT SELECTION :

- All events in coincidence within ±5 s with seismometer signals were vetoed (-8%)
- All events corresponding to hourly averaged T_{eff}> 10 mK and T_{eff} >7mK in the 10 minutes before the event were eliminated
- Only events belonging to working periods with duration longer then 12 hours are considered

=> 1490 hrs of coinc. Operation

COINCIDENCE SELECTION :

- whitin a time coincidence (adaptive) ~ 0.4 s

=> 43 coincident events

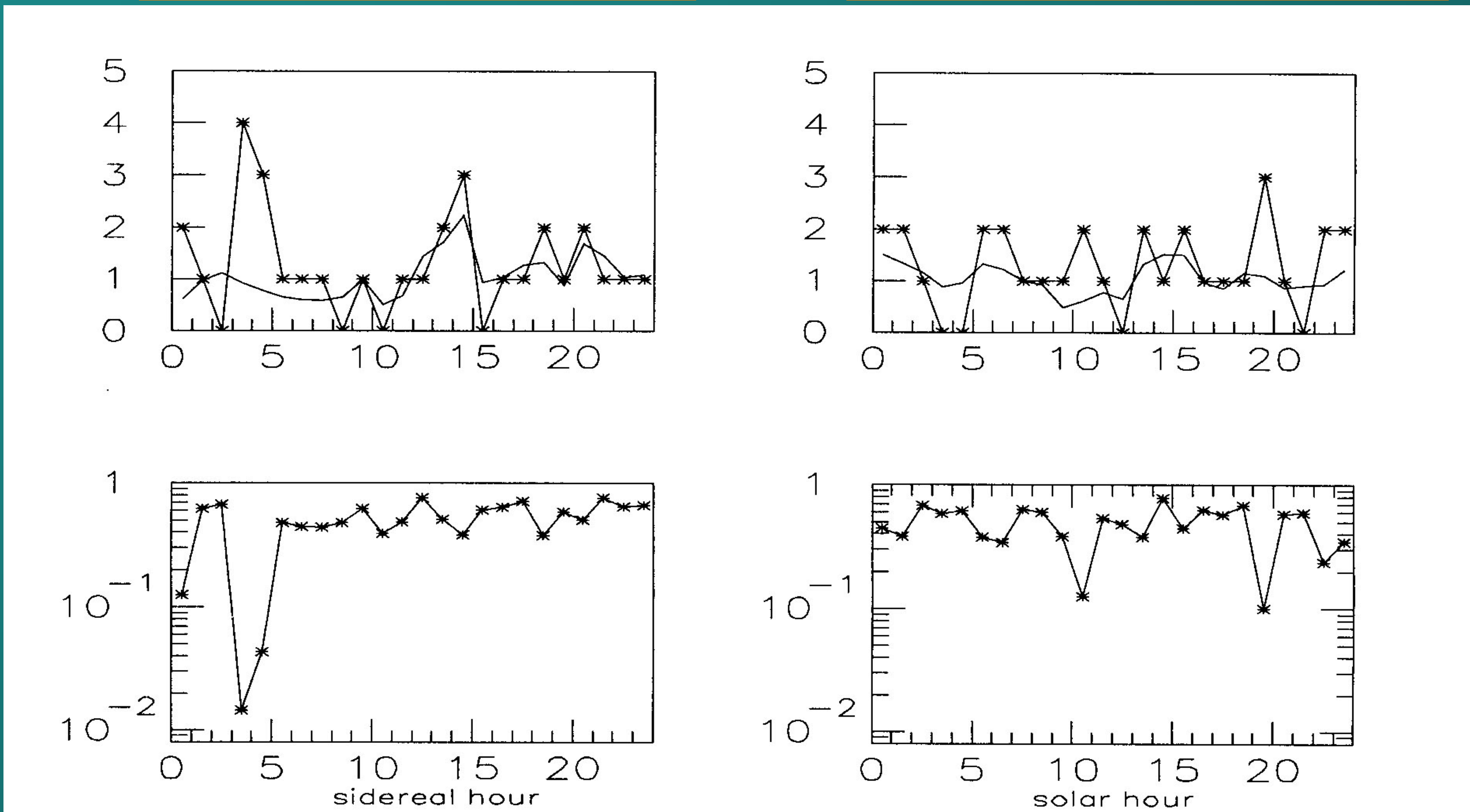
- with event energies “compatible with a common cause” (± 1σ)

=> 31 coincident events

RESULTS OF THE ANALYSIS

Sidereal time

Solar time



Events

Probabilities

*= coincidences ________ = accidentals

Energy correlation (no energy filter)

- Events of the sidereal peak (hours 3-5) strongly correlated
- Probability for Gaussian distribution $<10^{-3}$

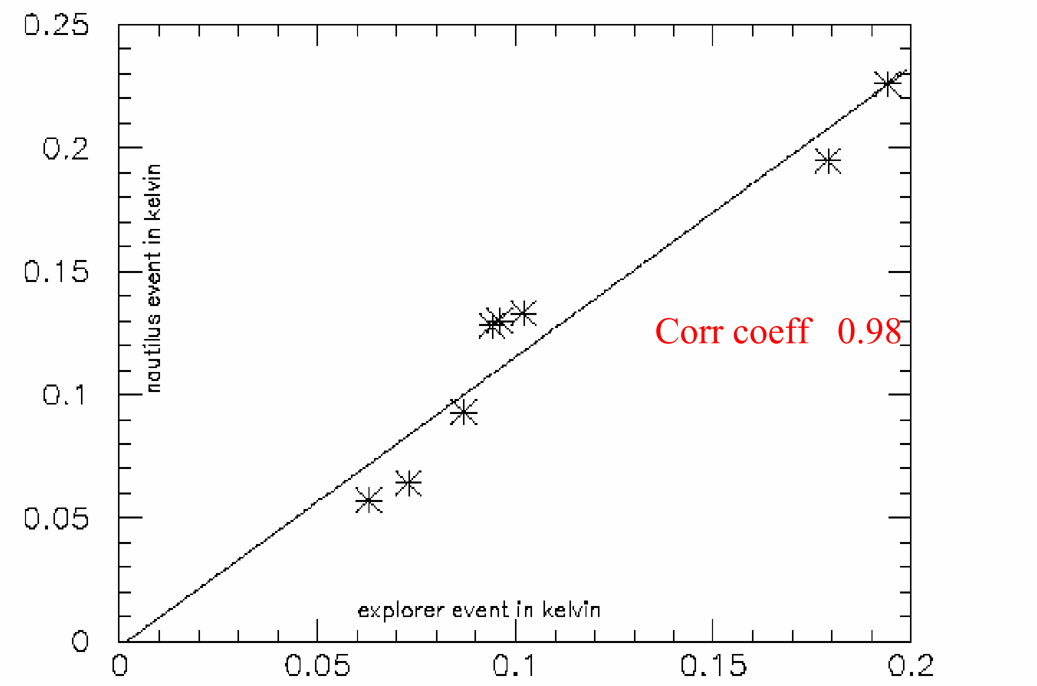
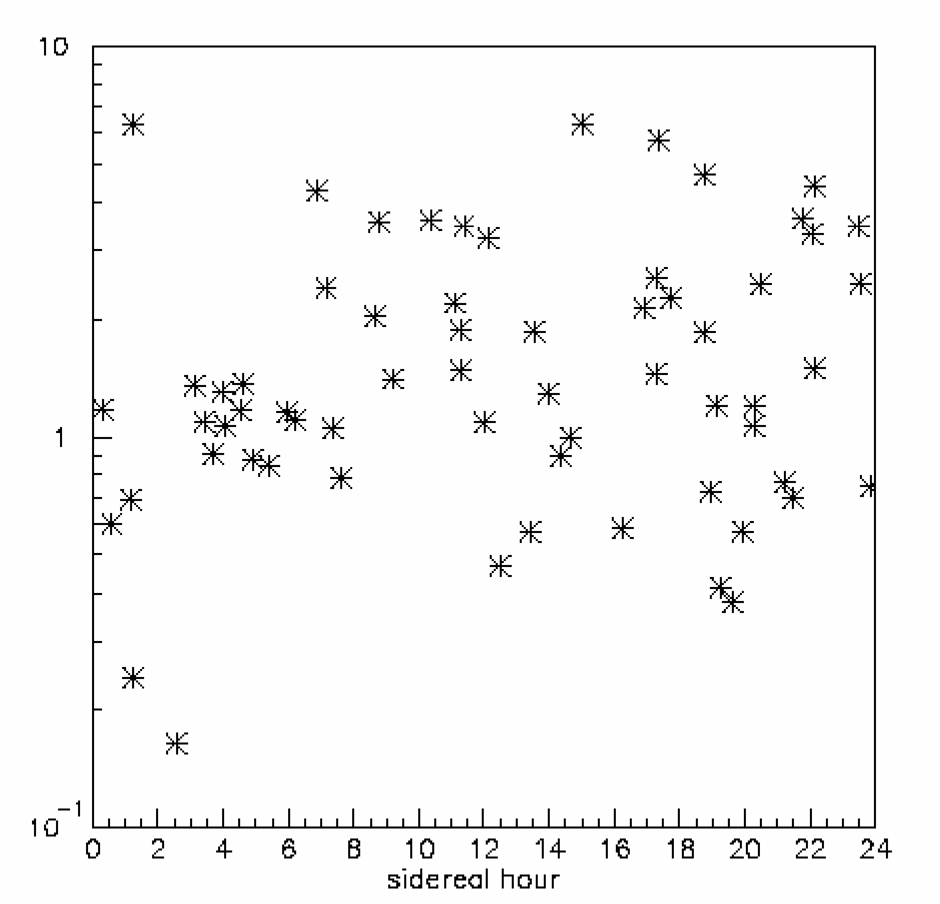


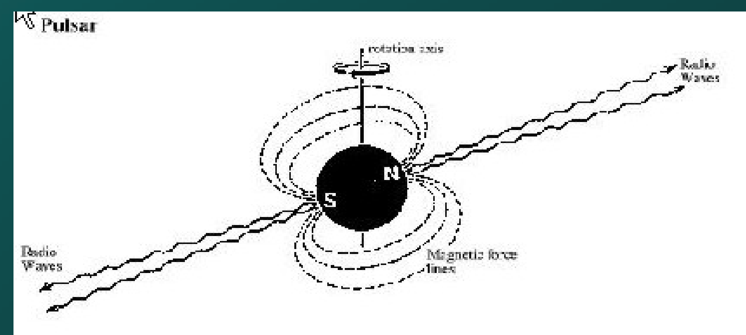
Fig. 8: Correlation between the event energies of NAUTILUS with those of EXPLORER for the eight coincidences occurred in the sidereal hour interval 3 to 5, in time periods $\geq$ 1 *hour*. The correlation coefficient is 0.96. No energy filter was applied.



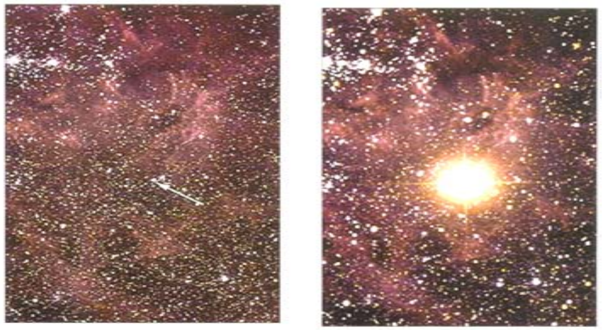
SEARCH FOR CONTINUOUS WAVES I

- 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 $h_c=3\times10^{-24}$ *(Astone et al. PRD 65, 022201, 2002)*
- Overall sky search over 2 days of data is now running: limit at the level of $h_c=3\times10^{-23}$ (1 million points, by choosing spin-down parameter and position randomly) *(Astone, Borkowsky, Jaranowsky, Krolak, PRD, 65,042003, 2002)*
- Collaboration with VIRGO-Rome group. Application of the strategy for the pulsar search to the EXPLORER and NAUTILUS data

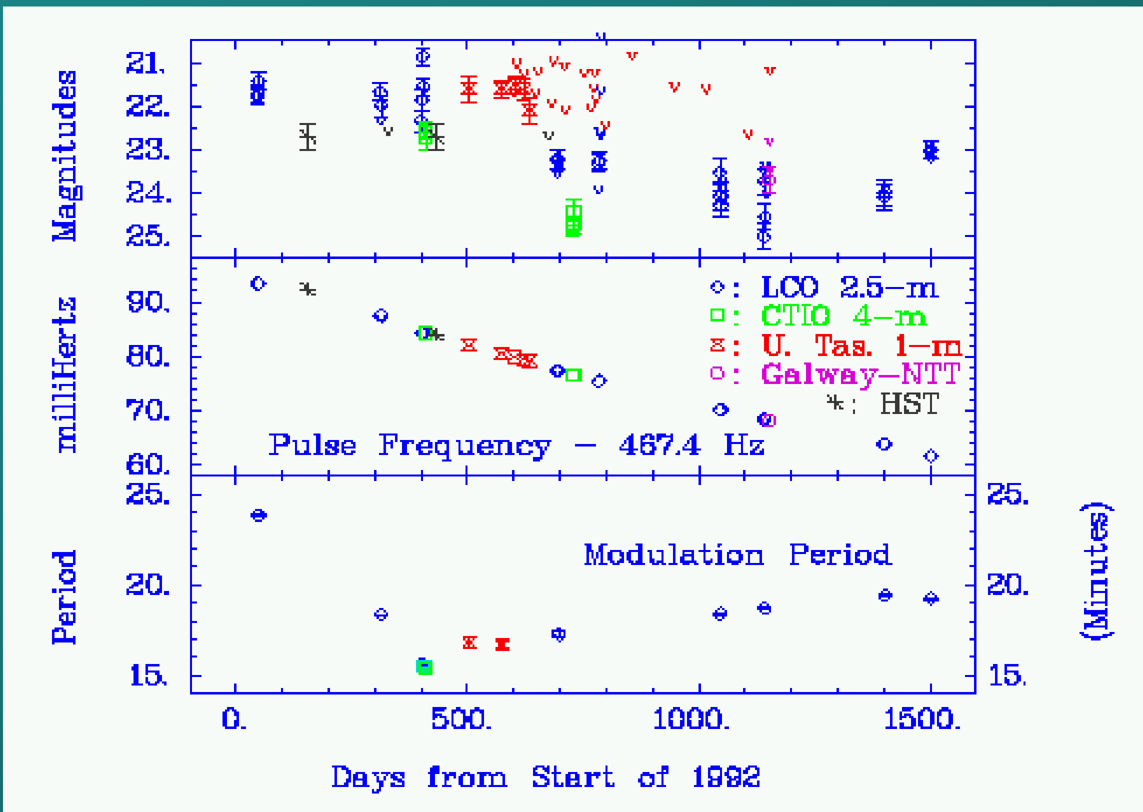
$$SNR = \frac{\overline{h} \cdot t_{obs}}{2\, S_h(\overline{\nu})}$$



Hunting SN1987a


Supernova 1987a

Evidence for a <u>triaxial</u> faint pulsar associated with SN1987a has been found in data taken from 5 detectors in the optical/near-infrared bands in the years 1992-1996 (Middleditch *et al.*, New Astronomy, 5, 243, **2000**).



$$P = 2.14\, ms;$$

$$\dot{P} \approx 2 \cdot 10^{-10} \text{ Hz/s};$$

$$P_{mod} \approx 10^{3}\, s$$

$$\Rightarrow f_{GW} = 935.0\, Hz$$

$$\Rightarrow h_{max} \approx 4.7 \times 10^{-26}$$

- So, we chopped the bar of Nautilus to resonate @ 935 Hz

Bursts

IGEC, Phys. Rev. Lett. ***85,*** *5046 (2000)*
Class. Quant. Grav. ***18****, 43 (2001)*
Class. Quant. Grav. 19, 5449 (2002)

Continuous signals

Phys. Rev. D ***65,*** *022001(2002)*
Phys. Rev. D, ***65****,042003 (2002)*

Stochastic Background

Astron. Astrophys. ***351****, 811 (1999)*

more

Search for correlation with GRB's
Astron. Astrophys. ***138****, 603 (1999)*
Phys. Rev. D (in press); astro-ph/0206431

Gravitational near field
Eur. J. Phys. C ***5****, 651 (1998)*

Effect of cosmic rays
Phys. Rev. Lett. ***84*** *, 14 (2000)*
Phys. Lett. B ***499****, 16 (2001),*
Phys. Lett. B (2002).

…Therefore, to improve sensitivity:

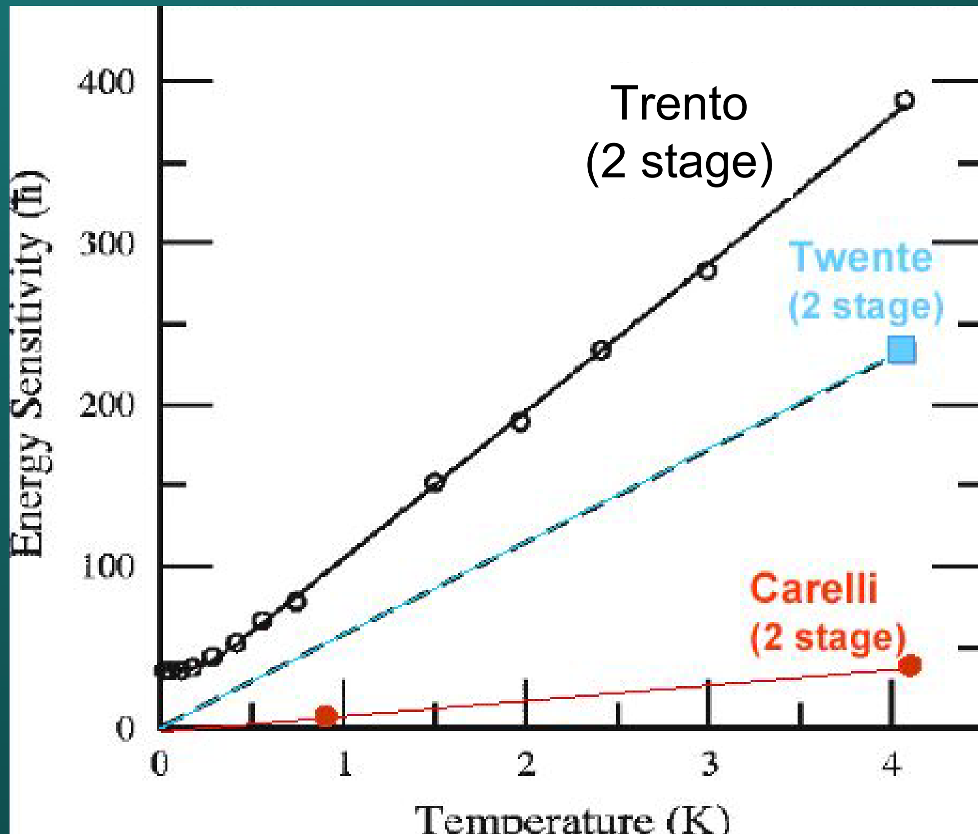
- We need to improve the peak spectral sensitivity $\tilde{h}(f_a)$
  - Increase M : large and/or multimode detectors
  - Reduce T/Q : ultracryogenics. New materials
- We also need to increase the bandwidth Δf
  - Increase β : transducer w/ tighter coupling
  - Reduce T_n : better amplifier (double SQUIDs)

IMPROVING T_n : Better Amplifiers

A SQUID is so good an amplifier that noise from the second stage is usually dominant.
The only suitable second stage is another d.c. SQUID.

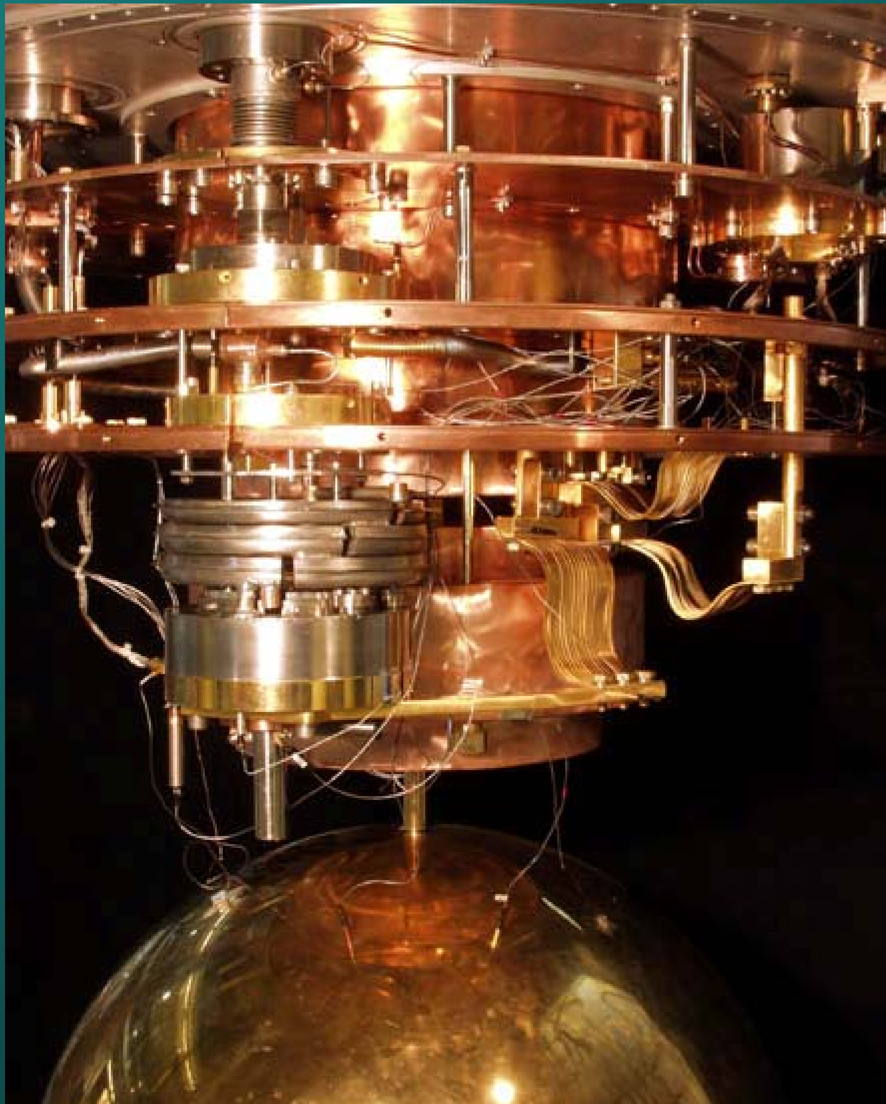
However the two devices tend to disturb each other !!!

Several efforts underway to produce a reliable amplifier for antenna Readouts



IMPROVING T/Q : (I)

- New, powerful Dilution Refrigerators
- MINIGRAIL was cooled (Jan 2003) to 80 mK
- Cooling below 30 mK appears possible
- T_{min} probably limited by ortho-para H conversion.

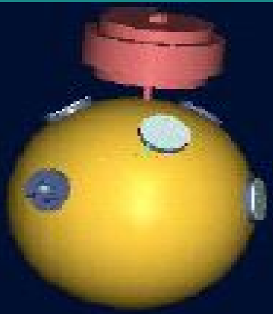


IMPROVING THE ANTENNA CROSS SECTION (II): SPHERES

- Need a larger mass (larger cross section, or lower thermal noise). This can be achieved with
  - One single huge resonator
  - Distributing the mass over many small detectors

- Besides, the resonator mass can be better exploited by monitoring all the modes that are sensitive to g.w.

  => use the 5 quadrupole modes of a sphere.



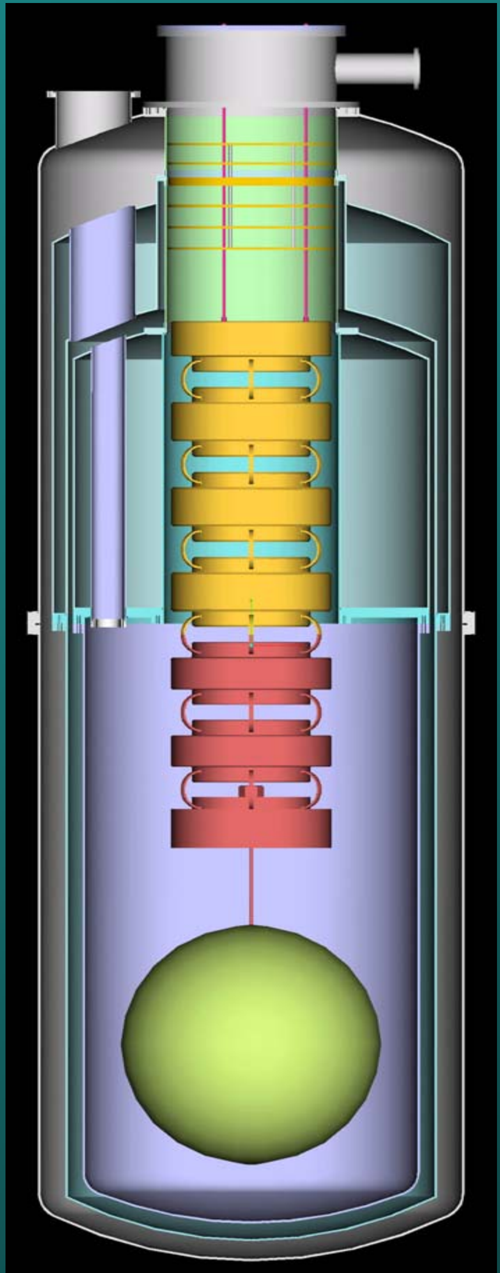
Large cross section

$$\sigma_n \propto M v^2$$

- Due to larger mass → 17 x
- Due to omni-directionality → 4 x

- Total → 70 x

Exploiting the resonant-mass detector technique: the spherical detector



MINIGRAIL
Leiden (Netherlands)

MARIO SHENBERG
Sao Paulo (Brasil)

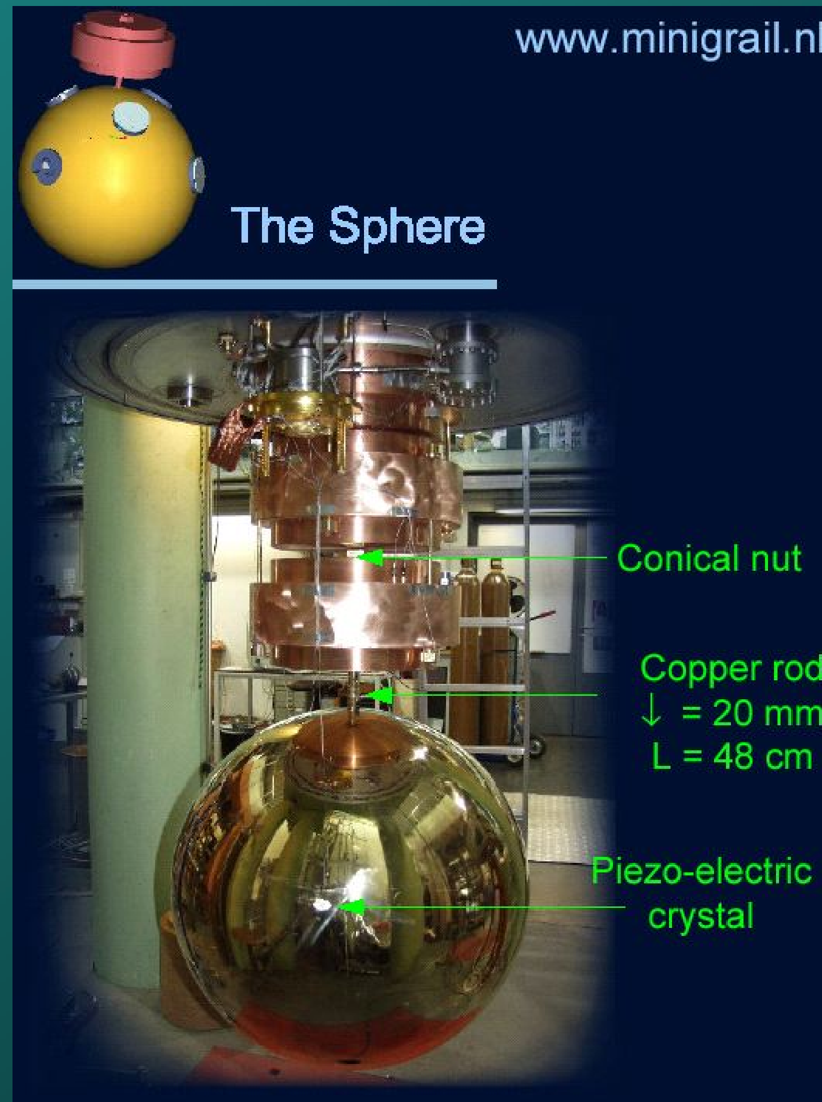
SFERA
Frascati (Italy)

CuAl(6%) sphere
Dia= 65 cm
Frequency = 3 kHz
Mass = 1 ton

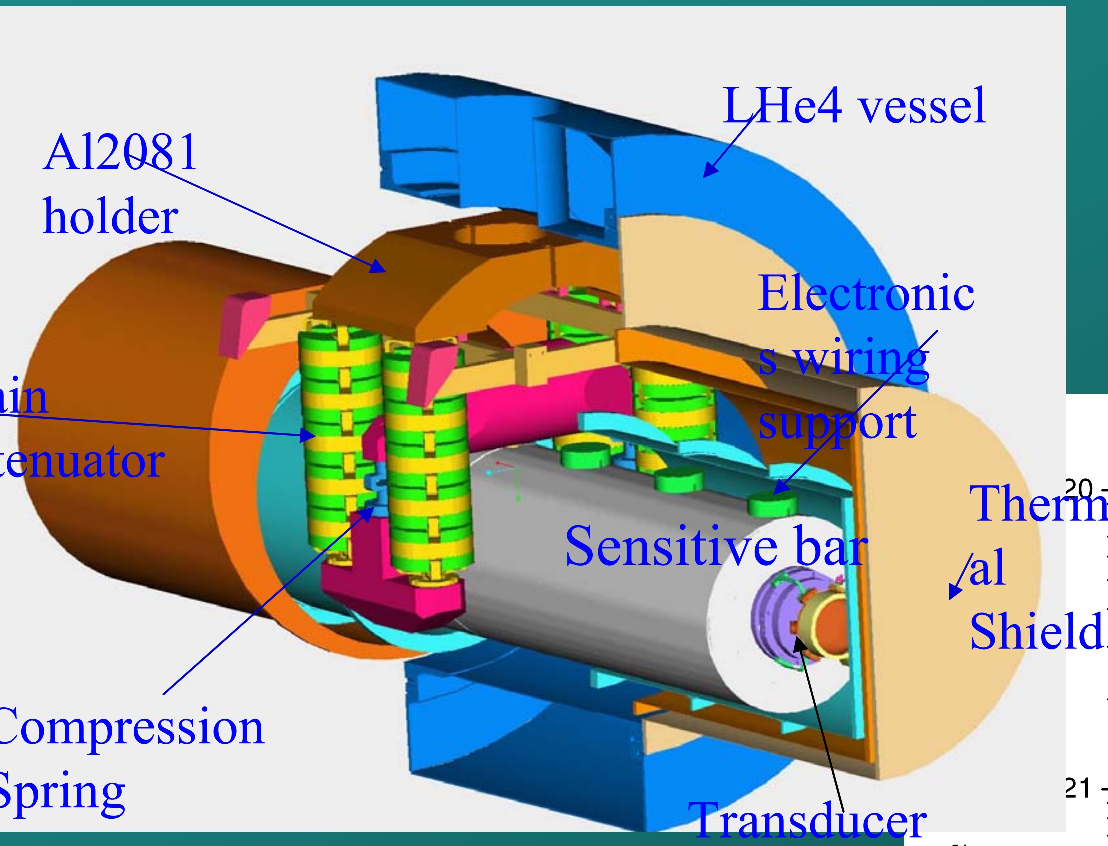
We might eventually have an array of small spherical resonators !

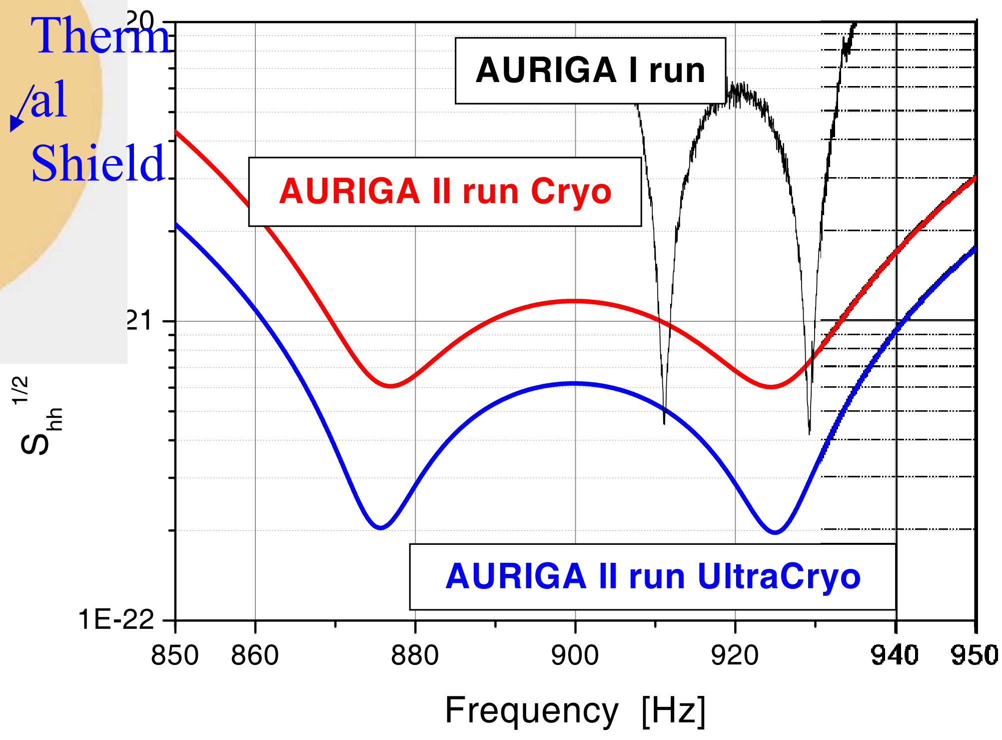
TIGA, PRL 1993
Hollow sphere, PRD 1998
Dual sphere, PRL 2001

SPHERES AROUND THE WORLD



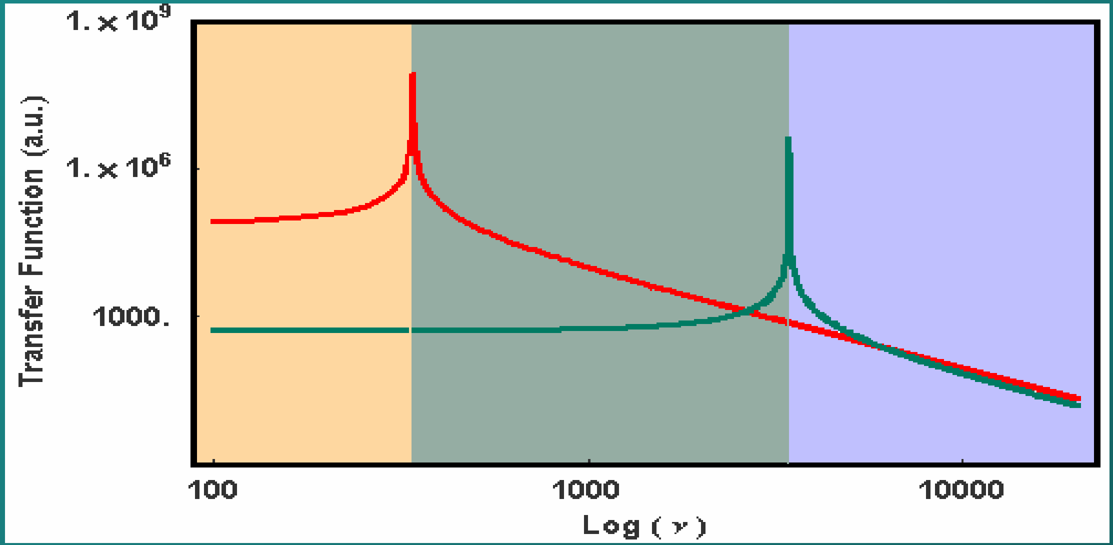
NEXT RUN OF AURIGA (fall 2003..)

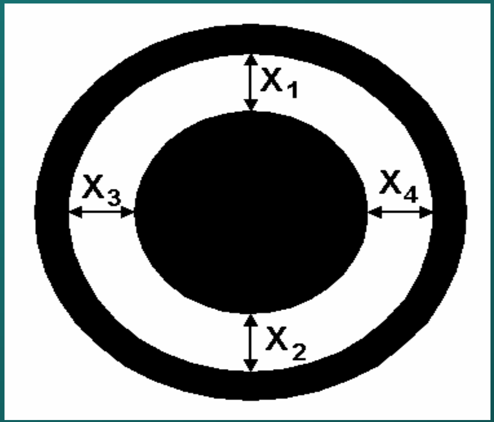


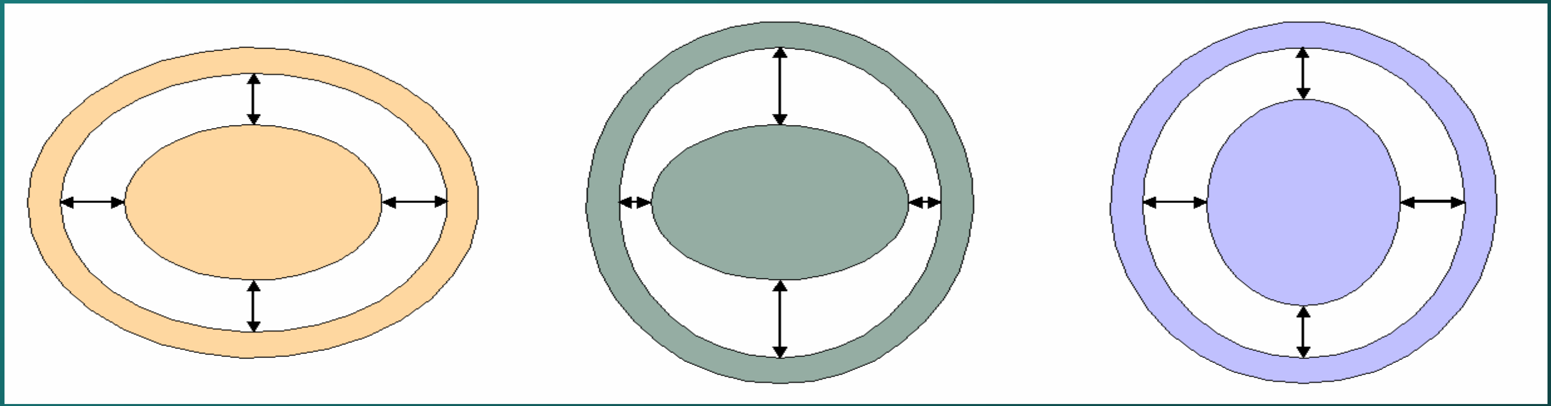


Dual Resonator concept:

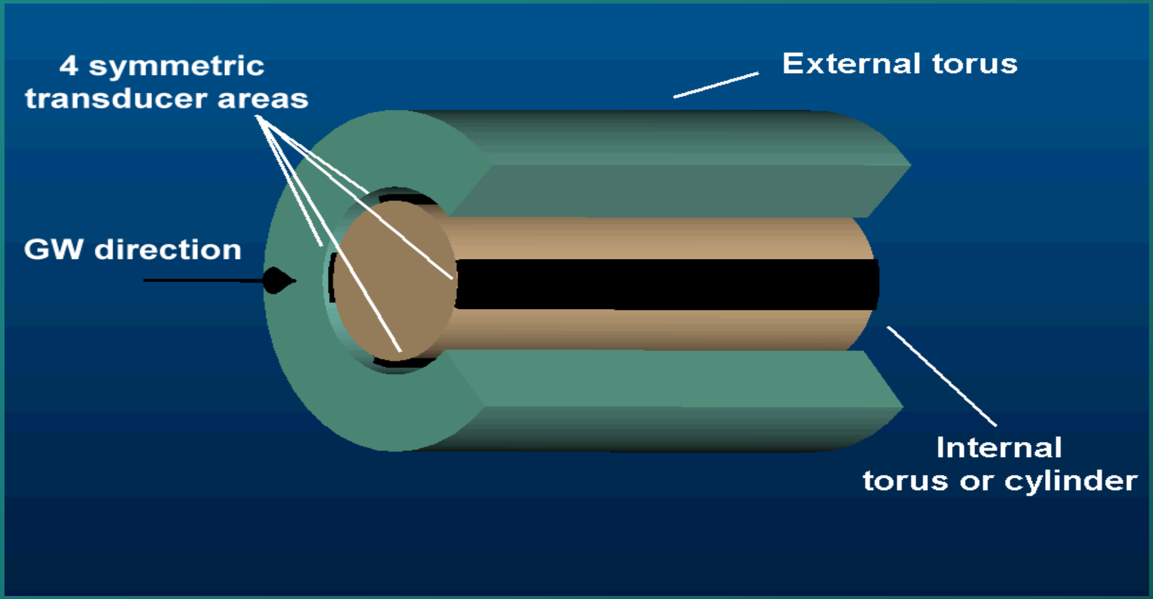
distance measurement between two concentric bodies = h measurement







We apply the same detection principle to a toroidal detector



This geometry can be equipped with a capacitive or inductive transducer with SQUID read-out:

- Wide area transducers (not affected by the thermal noise produced by short-wavelength normal modes)
- Natural implementation of mode-selective detection

THE FUTURE (in the age of interferometers)

- There is still ample room for improvements in sensitivity
- LIGO preliminary data shows IFOs might take longer to operate than expected : bars are still the only sentinels
- A coincident detection by two totally different instruments will be a stronger evidence
- Cross correlation IFO-Bar for stoch. bkgnd will be crucial (D $<\lambda/2\pi$)
- New, upcoming multimode resonators will exploit the technology with a sensitivity boost + omnidirectionality