

# Search for gravitational wave signals associated with gamma ray bursts

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**CNR** Roma

**UNIVERSITA'** La Sapienza, TorVergata, l'Aquila

# Summary

- What we know about GRB  
principal BATSE and Beppo-Sax results.

- The resonant cryogenic detectors  
EXPLORER and NAUTILUS.  
Present sensitivity.

- Data analysis  
under two hypotheses

- Experimental results

# Historical summary

- During the '60s , a series of satellites called Vela observed strange gamma ray signals.
- By 1973, Ray Klebesadel (LANL) notified the existence of GRBs and their outside solar system origin.
- During the next 20 years, many confirming results (IMP-6, OSO-7)
- In the decade '90s, on board of *Compton Gamma Ray Observatory*, BATSE has observed more then 2000 GRBs.
- In 1997, the Italian-Dutch *Beppo-Sax* satellite detected the first X-ray counterpart with an afterglow.
- Then, several counterparts, X, optical, radio have been observed.

# Sky distribution of 1637(1991-1996) GRBs of BATSE catalog

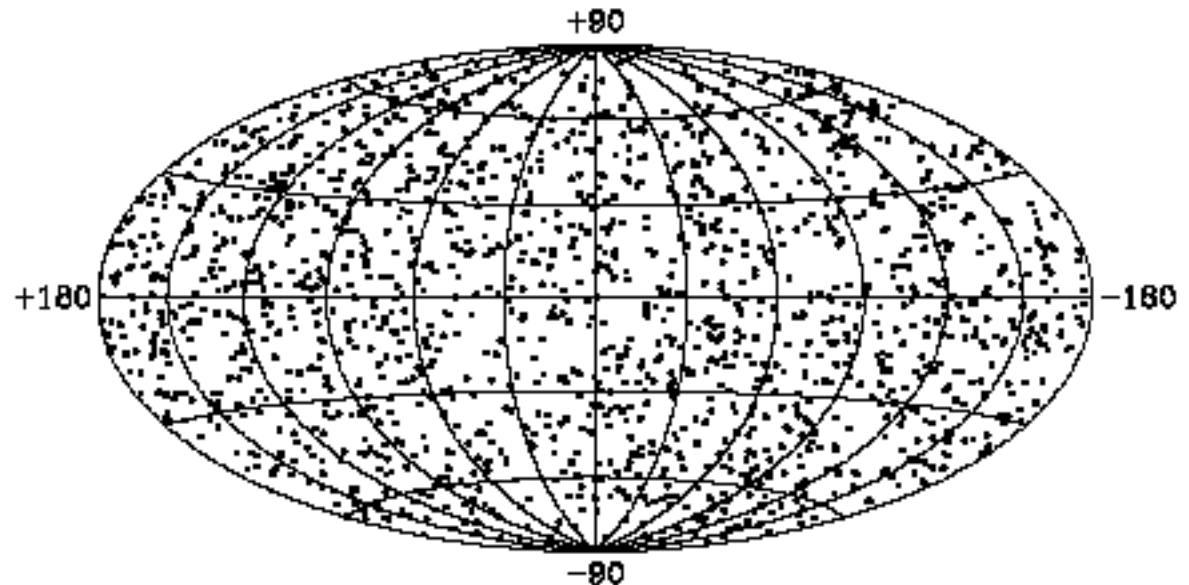
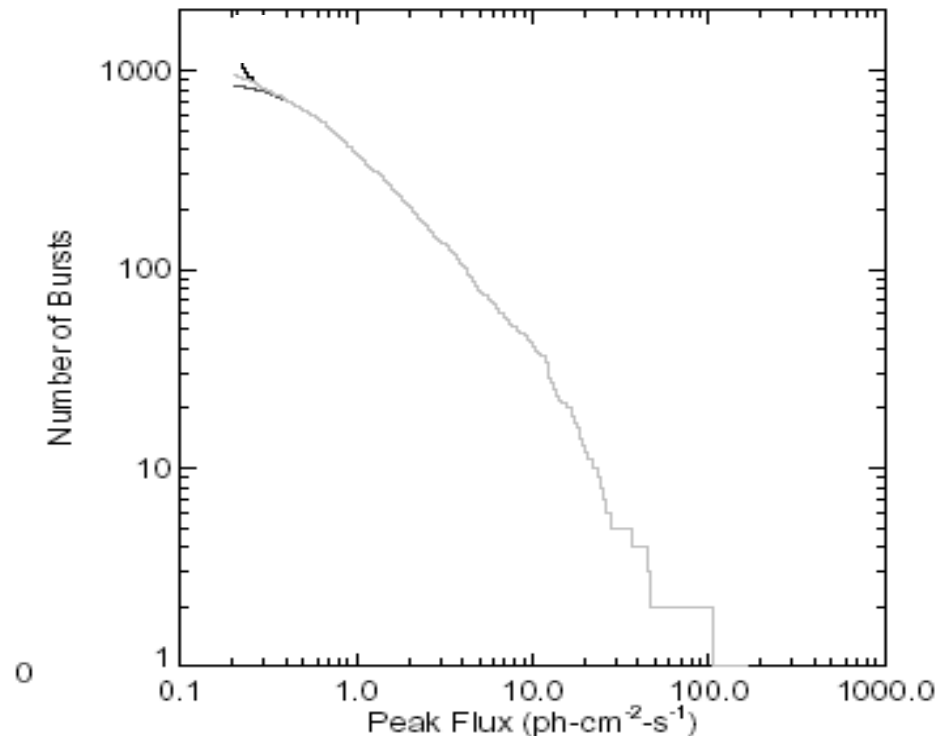


FIG. 5.— Sky distribution of the 1637 bursts in the 4Br catalog on an Aitoff-Hammer projection in Galactic coordinates. There is no correction for non-uniform sky coverage. Note that the full set of 4Br locations has been used, regardless of rigger energy range.

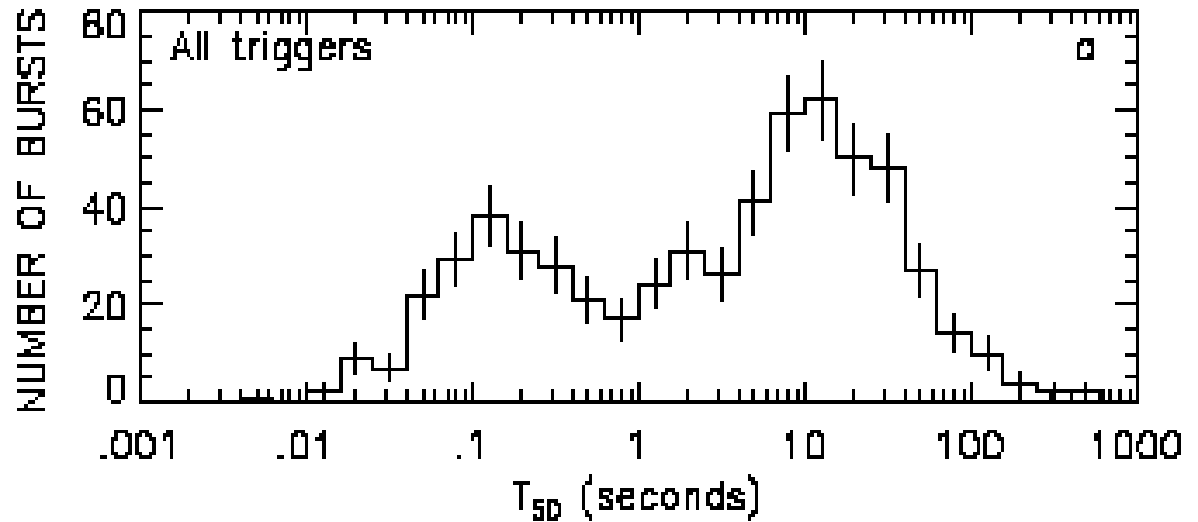
**=> Exclusion of local origin of GRBs**

# Integral log N - log F distribution



shows event lack in the low range of peak flux  
typical of a spherical finite distribution

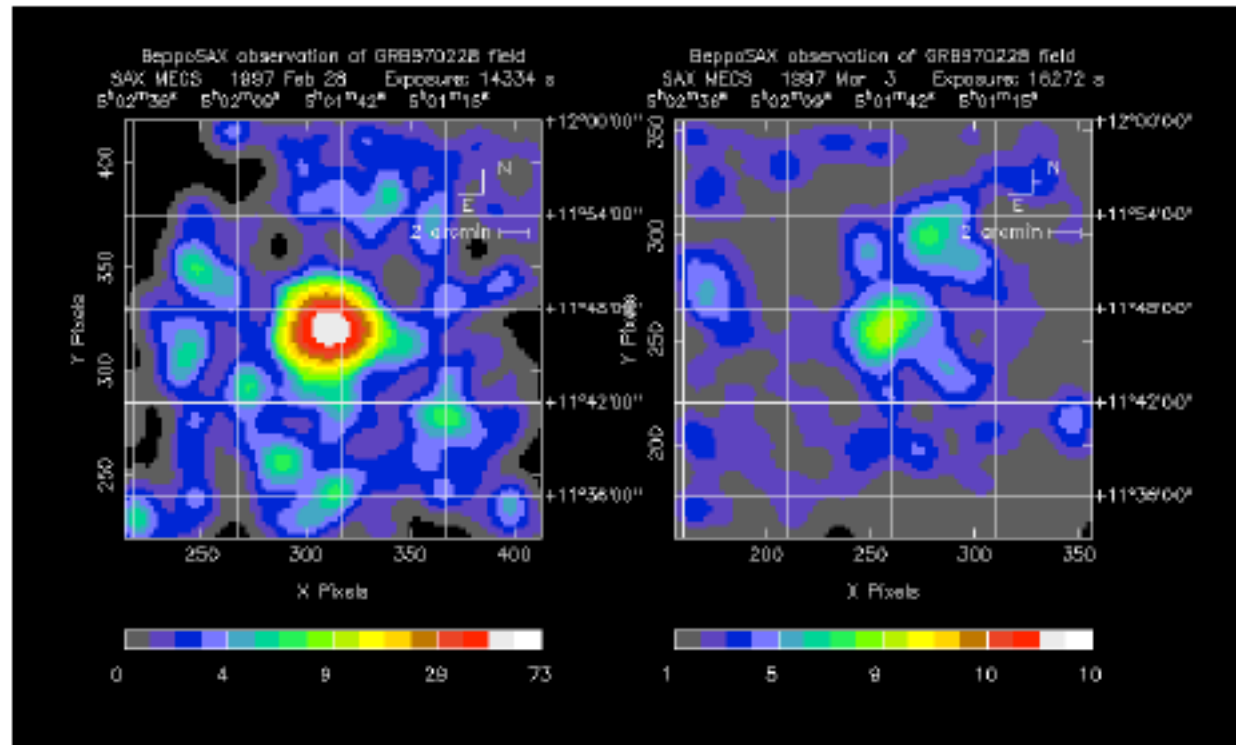
# Duration distribution



shows a bimodal statistic

# The Beppo-Sax pointing on 28 Feb 1997 reveals the first bright X-Ray counterpart

- The BeppoSAX pointing on Feb. 28 reveals a new, bright X-ray source within the 3 arcmin GRB error box at position  
1SAX J0501.7+1146  
The source flux is  $(2.8 \pm 0.4) \times 10^{-12}$  erg cm<sup>-2</sup> s<sup>-1</sup> in the MECS (2-10 keV) and  $(4.0 \pm 0.6) \times 10^{-12}$  erg cm<sup>-2</sup> s<sup>-1</sup> in the LECS (0.5-10 keV).



# Afterglow observation

During the last 5 years, more than **200** GRBs have been localized (within few hours to days) with

**WFC (Beppo-SAX)** (until June 2002)

**BATSE/RXTE** (until July 2001)

**HETE** (since February 2001)

**INTEGRAL** (since October 2002)

# Afterglow observations

**VARIABLE** wavelength

**VARIABLE** time delay

**VARIABLE** light curve

**VARIABLE** distance ( $z$  up to 4)

don't help to individuate a *typical GRB*

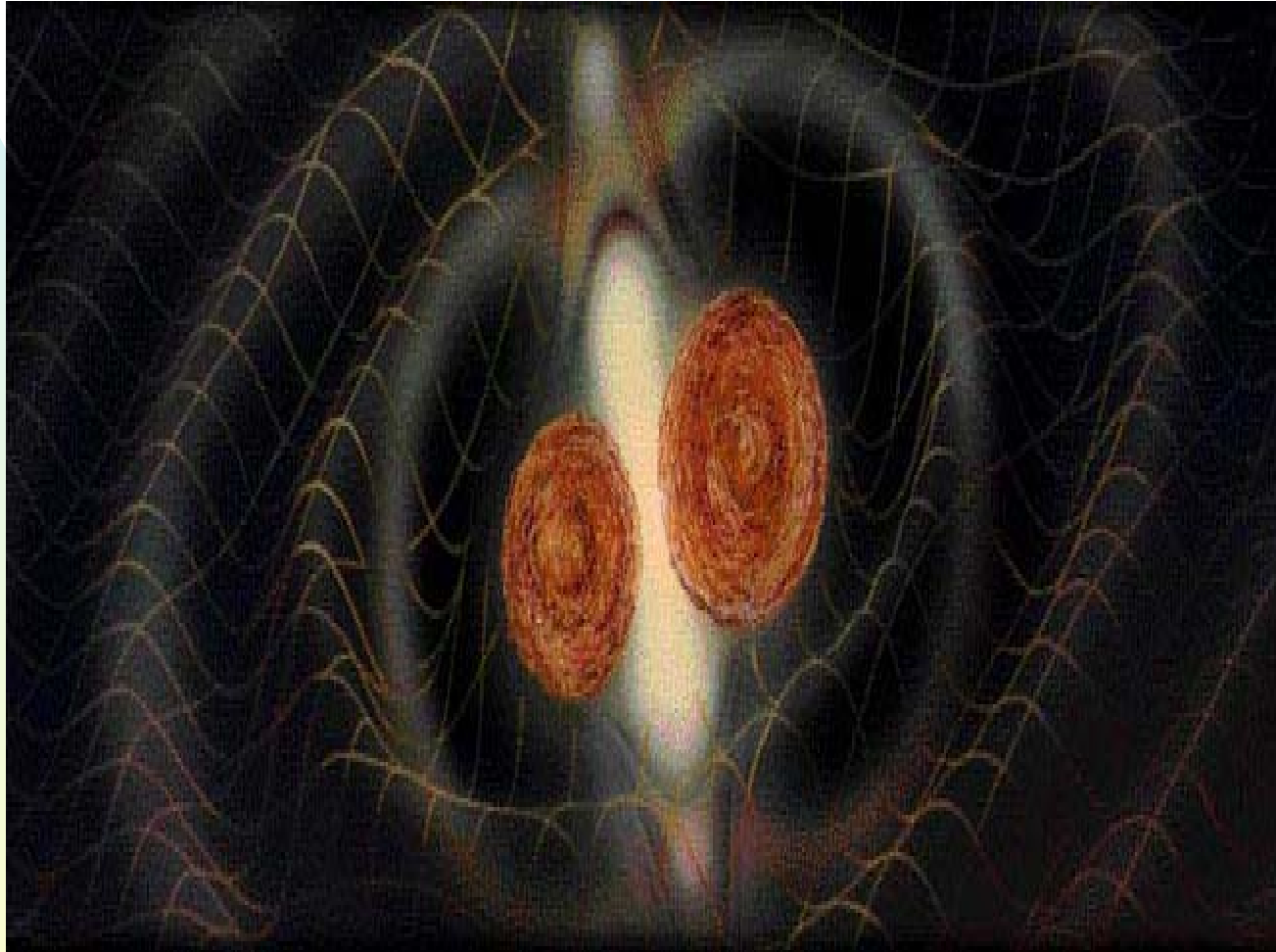
# Summarizing the experimental results (from BATSE and Beppo-Sax) of the last decade...

- Isotropic distribution
- Cosmological origin
- $10^{51} - 10^{53}$  erg (in a few seconds)
- Complex temporal behavior
- Bimodal statistic for the duration value
- EM counterparts in lower frequencies  
(phenomenological process)  
...the origin is compatible  
with the following hypotheses

• **GRBs** likely arise from shocks in a relativistic fireball that is triggered by rapid accretion on to a newly formed massive object.

• **Proposed GRB progenitors** include **binary neutron star mergers** (Eichler, Livio, Piran, Schramm, 1989) and **collapsar** - the collapse of a rotating star to a black hole-

# Gravitational Waves and GRBs may have the same sources



# Typical theoretical prediction for GW burst amplitude:

$$\Delta l/l = h = 3 \cdot 10^{-20} \frac{1 \text{ kHz}}{f(\text{kHz})} \frac{1 \text{ Mpc}}{R(\text{Mpc})} (M_{\text{GW}}/10^{-2} M_{\odot})^{1/2} (10^{-3} \text{ s}/\tau_{\text{GW}})^{1/2}$$

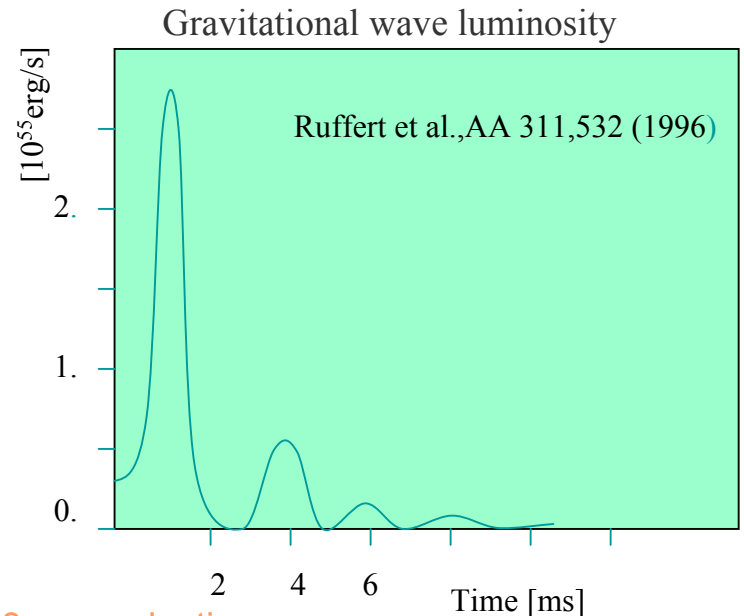
associated to a single GRB event:

@ 1 kHz

$\tau_{\text{GW}} = 1 \text{ ms}$

$\varepsilon_{\text{GW}} = 1\%$

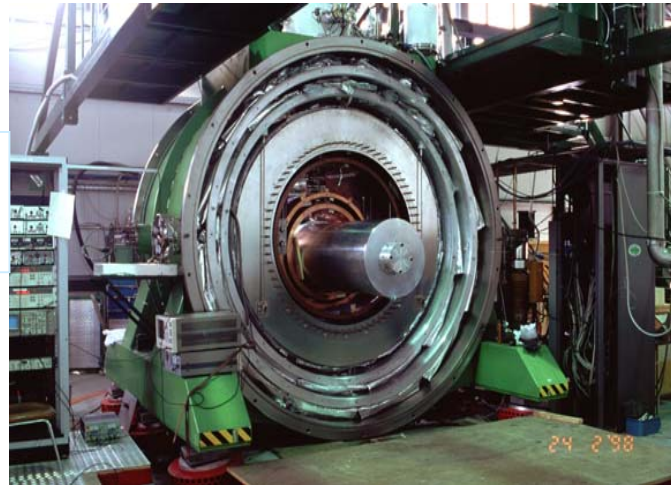
$$h \sim \frac{10^{-22} (M_{\text{GW}})^{1/2}}{R(\text{Gpc})}$$



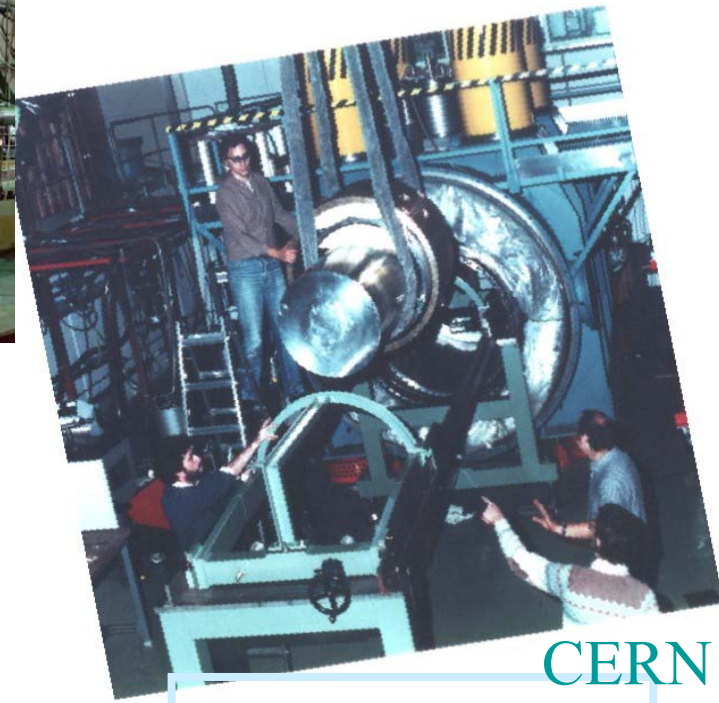
# ROG - The two cryogenic detectors -

## NAUTILUS

LNF-Frascati



bar length  $L = 3\text{m}$   
mass = 2300 Kg  
material Al5056  
resonance  $\sim 1\text{ KHz}$   
temperature = 0.1 K - 2 K



CERN

## EXPLORER

# MAIN FEATURES

## The mechanical oscillator

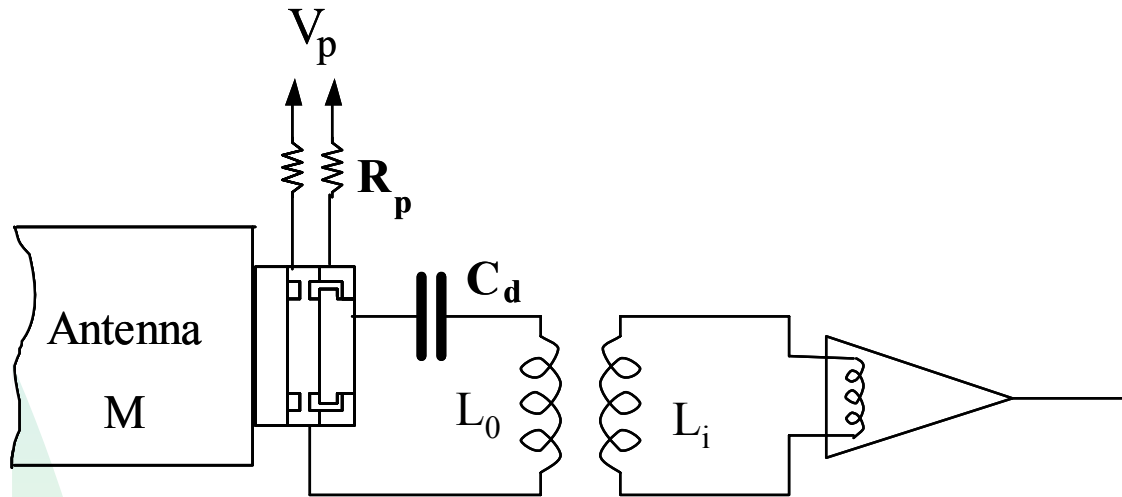
Mass  $M$

Speed of sound  $v_s$

Temperature  $T$

Quality factor  $Q$

Res. frequency  $f_r$



## The transducer

Efficiency  $\beta$

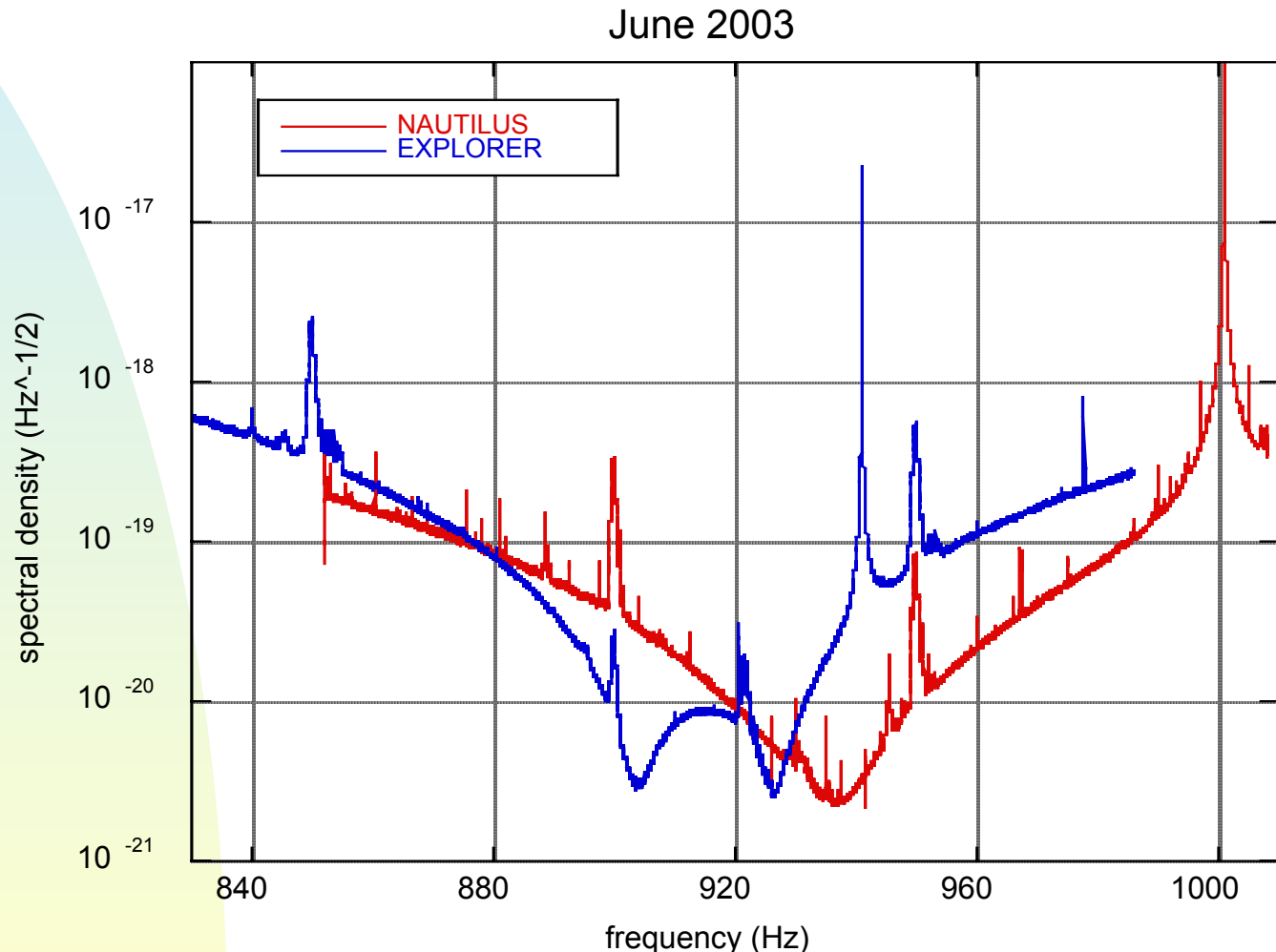
## The amplifier

Noise temperature  $T_n$

Minimum energy change detectable

$$\Delta E_{\min} = kT_{\text{eff}} \simeq kT/\beta Q + 2kT_n$$

# The present sensitivity of NAUTILUS EXPLORER



# Previous experimental studies

- SEARCH FOR TIME CORRELATION BETWEEN GRBs and DATA FROM THE GRAVITATIONAL WAVE ANTENNA EXPLORER.

**Coincidence technique.**

**No evidence in a time window of  $\pm 1$  s , at several delays.**

**(ROG Coll.)** Astron. Astrophys. Suppl. Ser. 138, 603 –604 (1999)

- MEASUREMENTS WITH THE RESONANT GRAVITATIONAL WAVE DETECTOR EXPLORER DURING THE GRB 980425

**No anomaly in the background of the GW data detector with the sensitivity of  $h \geq 10^{-18}$**

**(ROG Coll.)** Astron. Astrophys. Suppl. Ser. 138 605-606

- CORRELATION BETWEEN GRBs AND GWs.

**Using 120 GRBs, in a 10s time window, an U.L. of  $1.5 \cdot 10^{-18}$  was obtained.**

**(AURIGA Group)** Phys.Rev. D 63, 082002

# Cumulative techniques

have been proposed to detect a statistically significant association between GW signals and GRBs.

- L.S.Finn, S.D.Mohanty, J.D. Romano.  
Phys. Rev. D **60** , 121101 (1999).
- G. Modestino, G. Pizzella ,  
A&A., **364**, 419 (2000).
- M.T. Murphy, J.K. Webb, I.S. Heng  
MNRAS. **316** , 657 (2000).
- P. Bonifazi, G.V. Pallottino, A.V. Gusev,  
A.Kochetkova, Ak. Postnov, V. Rudenko,  
V.N. Vinogradov  
CNR-IFSI-2001-28
- G. Modestino and A. Moleti  
Phys. Rev. D **65**, 022005 (2002).

# Time delay between the two emissions

The typical amplitude of a GW burst, on Earth, associated to a single GRB, is:

$$h = \frac{10^{-22} M^{1/2}}{R(\text{Gpc})}$$

R = distance

M = amount of GW energy emitted ( $M_{\odot}$ )

**But there is no clear predictions about  $\Delta t = |t_{\text{GRB}} - t_{\text{GW}}|$**

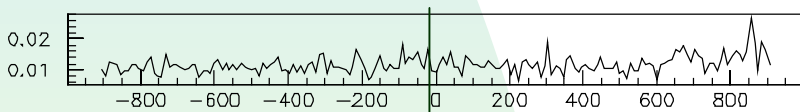
In our data analysis, we consider :

$\Delta t = 0$  as predicted by several models  
and also

variable  $\Delta t$

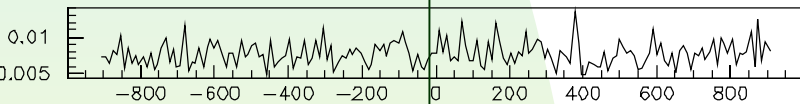
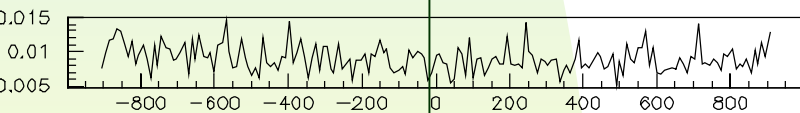
# Searching for a simultaneous GW signal

1) Combine the GW detector data  $E(t)$  with the same relative time with respect to the  $N$  GRB arrival time  $t_0$

 $E_1$ 

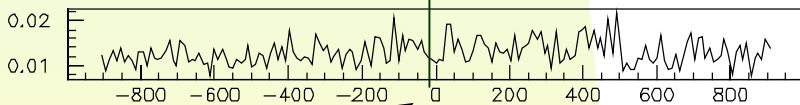
For the single data stretches

$$\sigma_i = \langle E_i \rangle$$

 $E_2$  $E_3$ 

2) Applying a cumulative algorithm:

$$\sigma = \sigma_i N^{-1/2}$$

 $E_n$ 

$t = t_{\text{GRB}}$

$\Delta t(\text{s})$

# Searching for a simultaneous GW signal

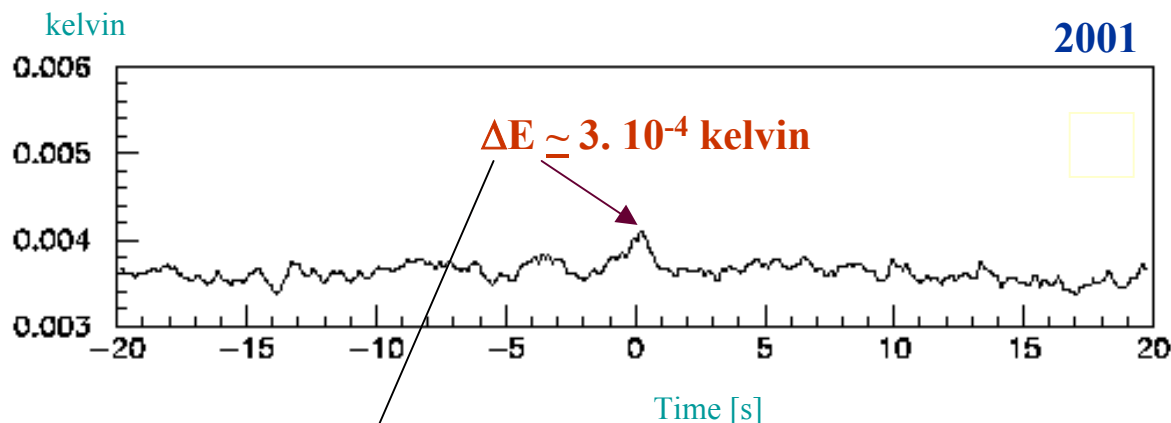
Experimental example:

## Cosmic-ray showers interacting with NAUTILUS



$$\langle E(t) \rangle = 3 \cdot 10^{-3} \text{K}$$

$$\sigma \sim 10^{-4} \text{K}$$



In agreement with the thermo-acoustic model

Astone et al. (ROG Coll.)  
PRD, 84, 14, 2000.

Astone et al. (ROG Coll.)  
Phy. Lett. B 499 16 (2001)

Astone et al. (ROG Coll.)  
Phys. Lett. B 540 179 (2002)

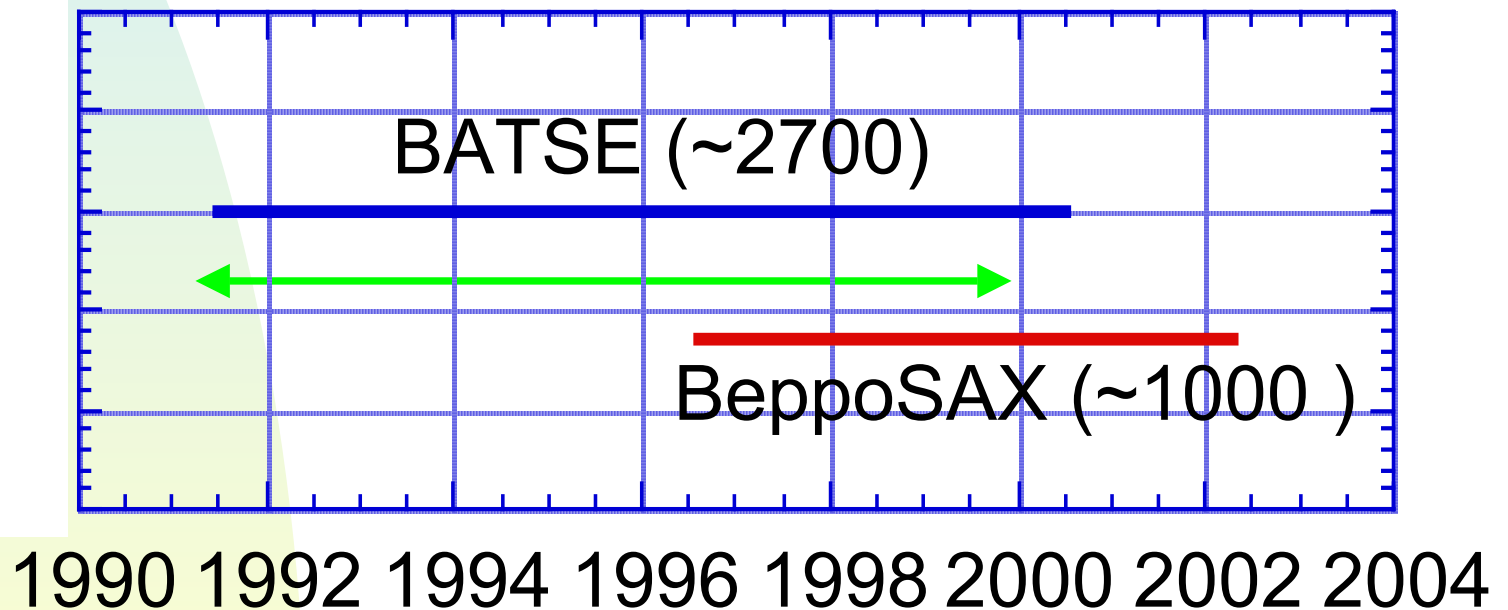
# Searching for simultaneous GW signal.

- 1991-1999
- GRB list = BATSE + Beppo-Sax
- GW detectors = EXPLORER + NAUTILUS
- GWB arrival time = GRB Peak Time  $\pm$  5 s
- GW data background over 30 minute periods with temperature noise  $t_n < 15 \cdot 10^{-3}$  kelvin (Peak Time  $\pm$  15 min)
- Cumulative median algorithm

# Searching for simultaneous GW signal.

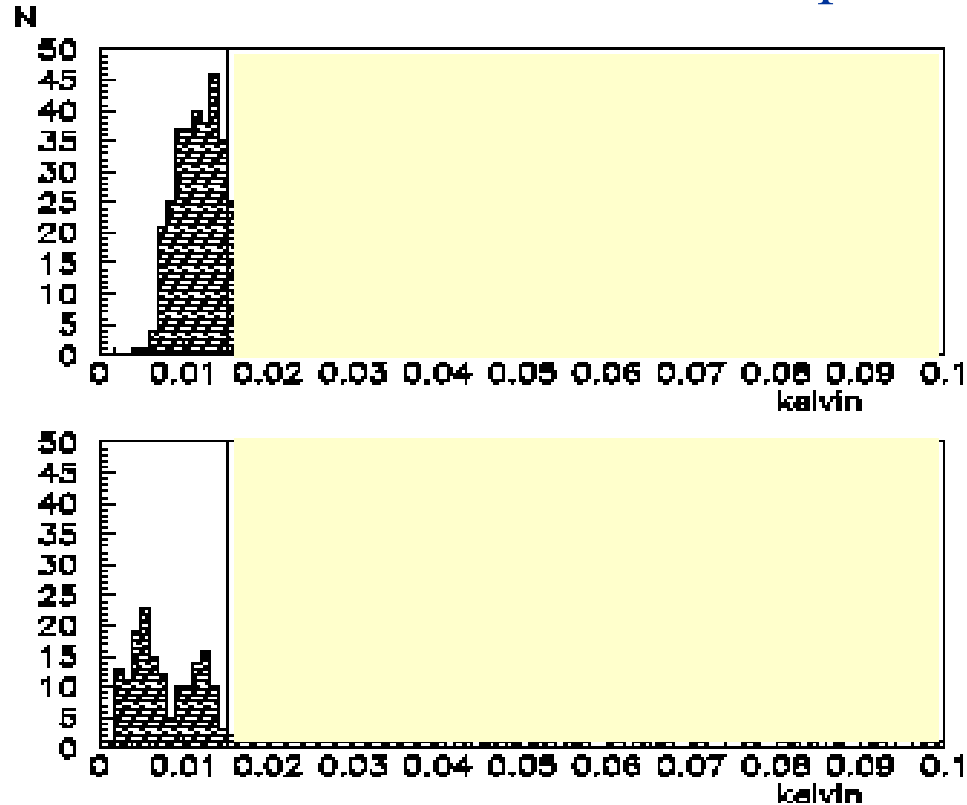
## GRBs Database

Trigger GRBs



# Data selection

Effective temperature  $T_e$  distribution computed in 1150 time intervals around each GRB peak time



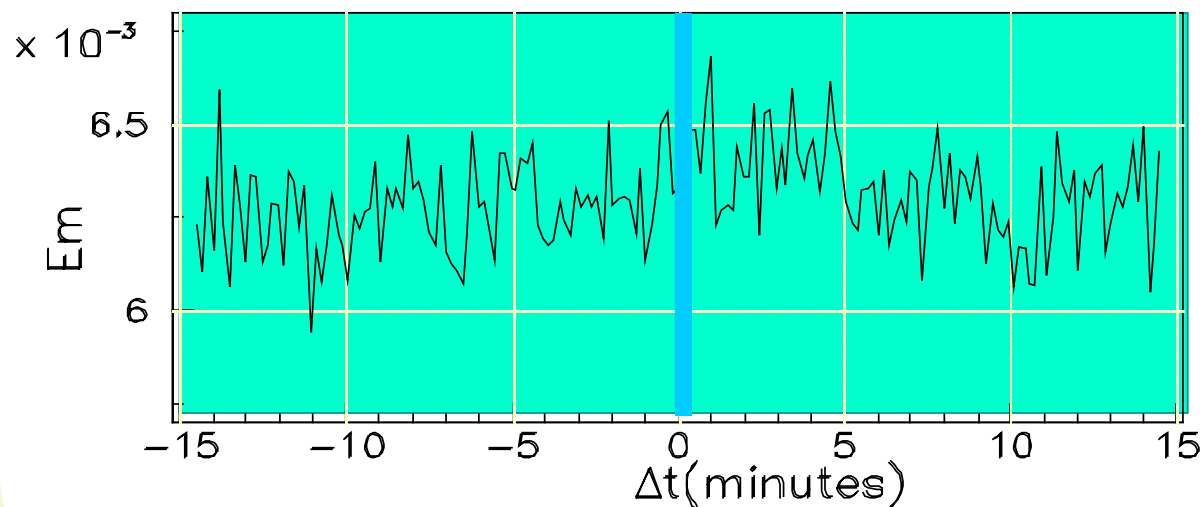
**$N=387$  data stretches with  $T_e \leq 15$  mK are selected**

# Searching for simultaneous GW signal.

- Combine **387** 30 min GW data stretches
- For each time delay, the median value  $E_m$  is extract

GW detector energy as a function of the GW-GRB delay

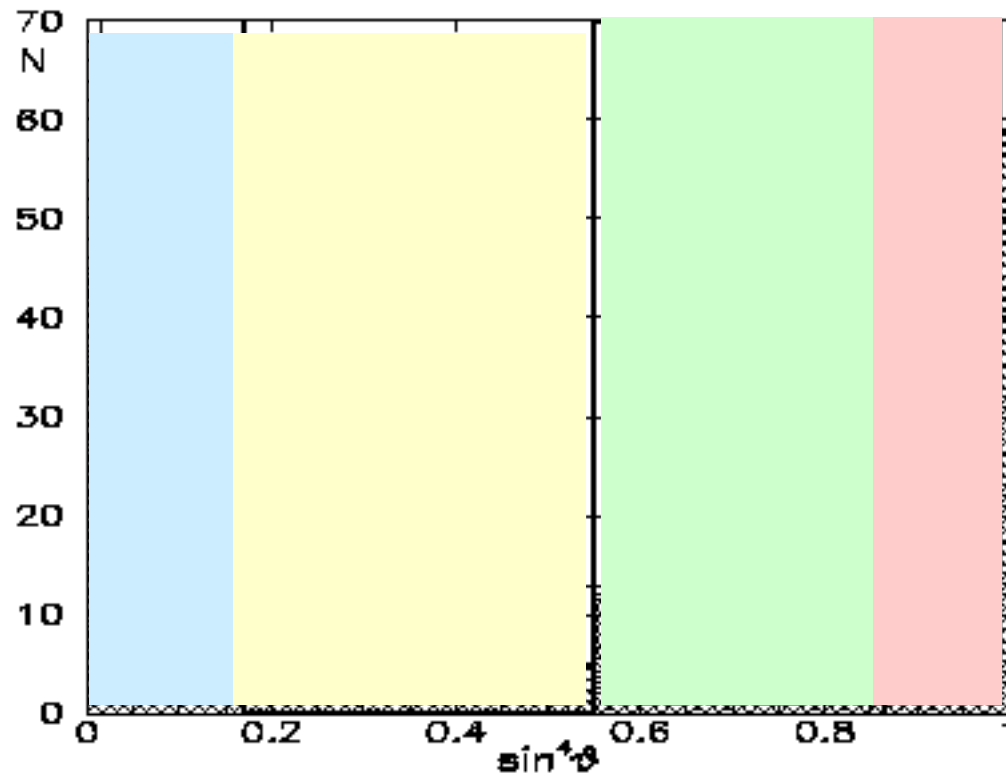
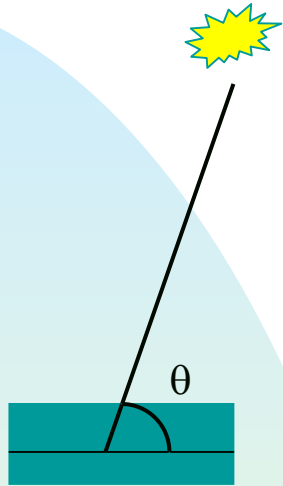
$$\langle E \rangle = 6.30 \text{ mK}$$
$$\sigma = 0.13 \text{ mK}$$



$$\underline{h} \leq 3 \cdot 10^{-19}$$

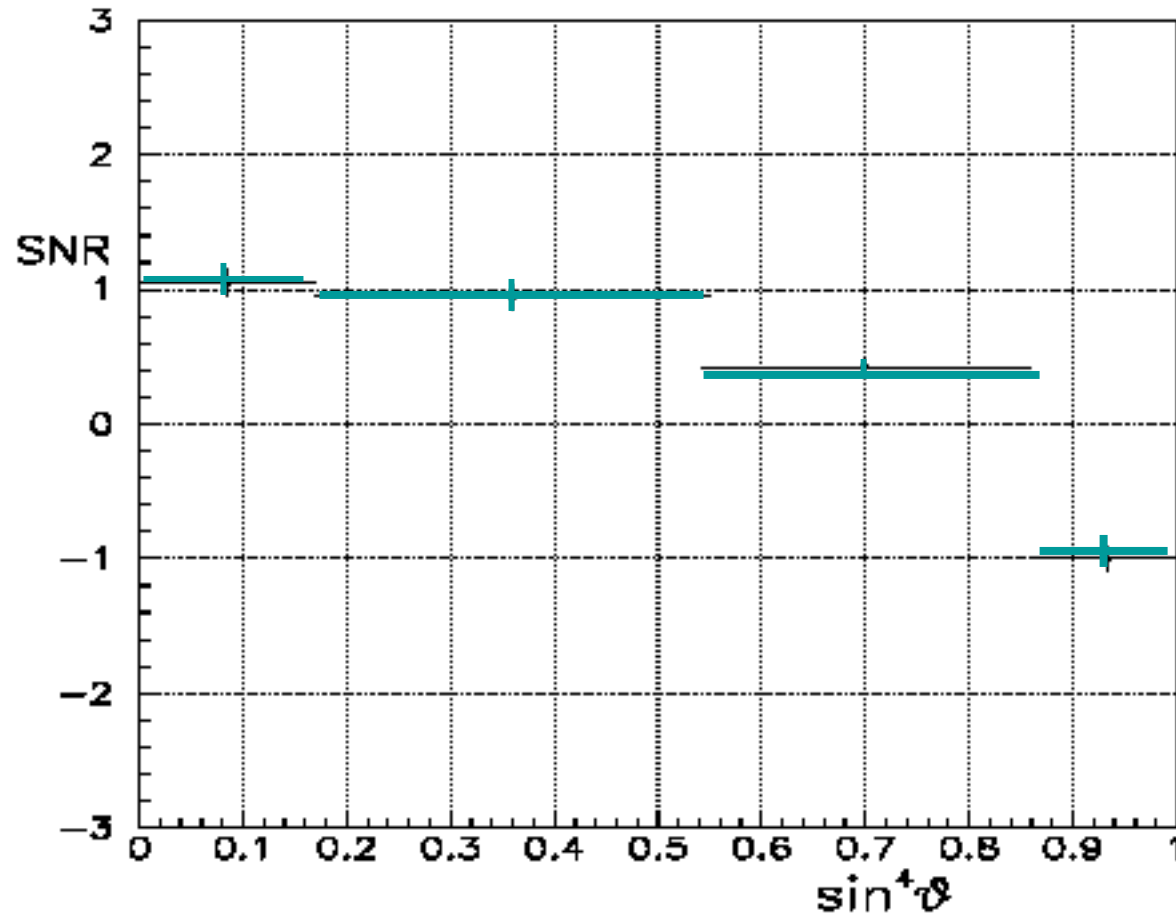
$$E(0) = 6.33 \text{ mK}$$

# Searching for a correlation with $\sin^4\theta$ .



$\sin^4\theta$  correspondingly to the 387 selected GRB arrival times and theoretical isotropic distribution

The 4 regions of increasing  $\sin^4\theta$ , separated by vertical lines, correspond to the data subsets separately analyzed.

Looking for a correlation with  $\sin^4\theta$ 

SNR of the excess at zero delay of the median value

# Searching for GW signals under variable delay hypothesis(\*)

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The basic idea of the analysis is the **simultaneity** of the signal on **two GW detectors**.

- Apply the usual data selection criteria evaluating the temperature noise in the time interval around the GRB time
- Select and cross-correlate data of the coincident intervals of the two GW detectors.
- Apply the usual cumulative algorithm to the cross-correlation function

(\*)Modestino, Moleti, PRD (2002)

Astone et al. (ROG Coll), PRD (2002).

# Cross-correlation analysis

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## Beppo-Sax Catalog 2001

- **EXPLORER (CERN)**
- ON from March to December
- $T = 2.6 \text{ K}$
- Duty Cycle = 91%
- Average sensitivity  
 **$h=4.5 \cdot 10^{-19}$**

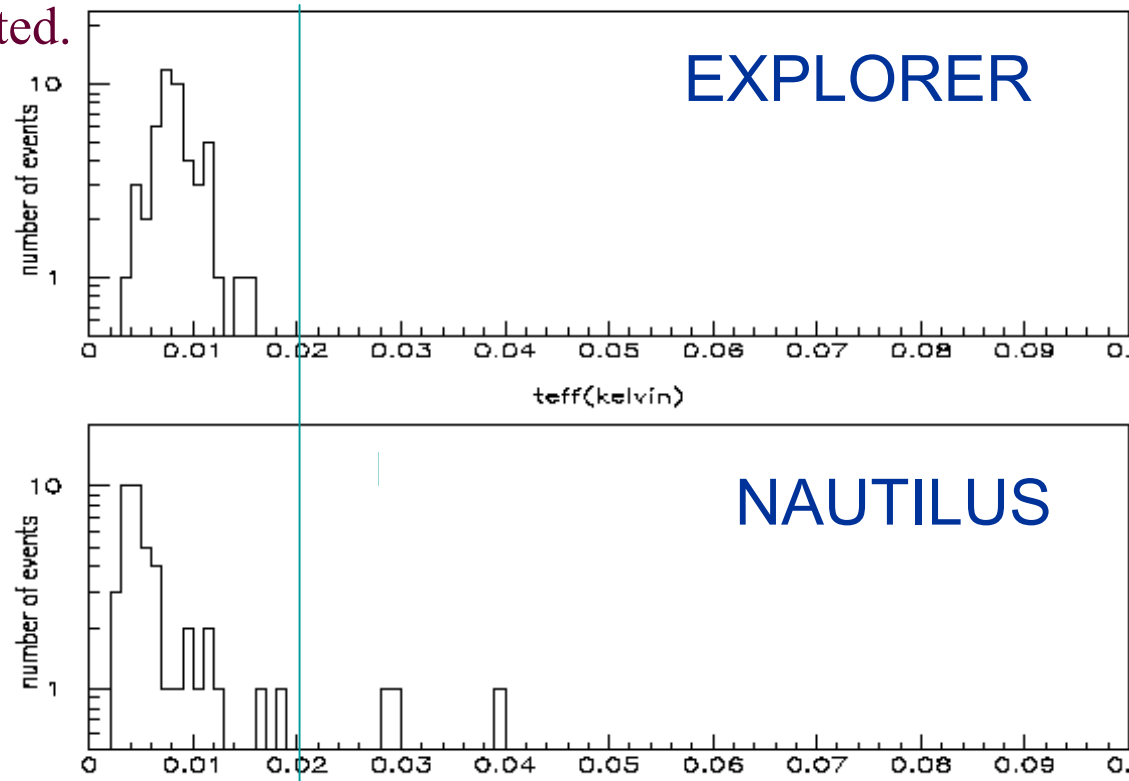
- **NAUTILUS (LNF)**
- ON from January to December
- $T = 1.5 \text{ K}$
- Duty Cycle = 80%
- Average sensitivity  
 **$h=5.7 \cdot 10^{-19}$**

# Cross-correlation analysis

$T_{\text{eff}}$  evaluated within a time window of  $\pm 400\text{s}$ , centered at  $t_{\text{GRB}}$

The data with  $T_{\text{eff}} \leq 20 \text{ mk}$  are selected.

**47 GRB** are analyzed

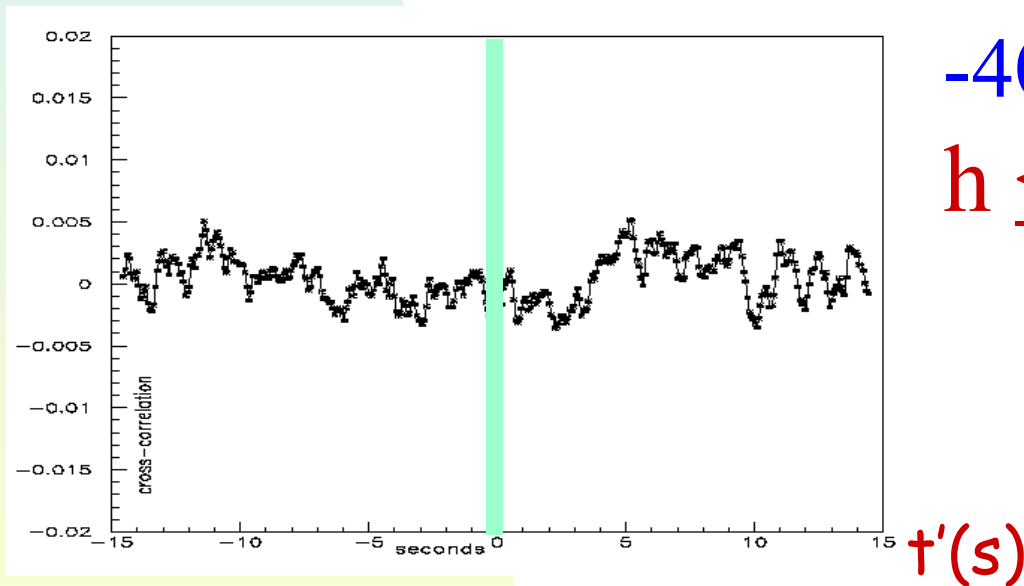


# Cross-correlation result

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## EXPLORER x NAUTILUS 2001

$R(t')$  cross-correlation function (averaged on the 47 GRBs) relative to the energy of the two GW detectors.



$$-400s \leq \Delta t' \leq +400s$$

$$h \leq 1.2 \cdot 10^{-18} \quad 95\%$$

# Conclusions

The recent GRB observations (and several theoretical predictions too) lead up to a common origin for GW bursts and GRBs.

The association between the two emissions can significantly improve the performances of the GW detectors with respect a random search

The last decade contains a very rich data archive for searching correlation between GW and GRB.

**We searched for correlation under both hypotheses of simultaneous emission and variable delay.**

**No significant correlation has been found**

$$h \leq 3 \cdot 10^{-19} \quad -5s \leq \Delta t \leq 5s$$

$$h \leq 1.2 \cdot 10^{-18} \quad -400s \leq \Delta t \leq 400s$$

The conditions are rapidly improving:

The next generation of GRB missions, the improving performances of the present GW detectors, the imminent runs of the GW interferometric detectors, will lead up to higher sensitivity in the measurement.

Pia Astone Danilo Babusci Massimo Bassan

Eugenio Coccia Carlo Cosmelli

Sabrina D'Antonio Viviana Fafone

Filippo Frontera Cristiano Guidorzi

Gianfranco Giordano Alessandro Marini

Yuri Minenkov Ivo Modena Arturo Moleti

Enrico Montanari GianVittorio Pallottino

Guido Pizzella Lina Quintieri Alessio Rocchi

Francesco Ronga Guido Torrioli

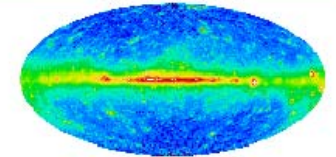
Roberto Terenzi Massimo Visco



# GLAST

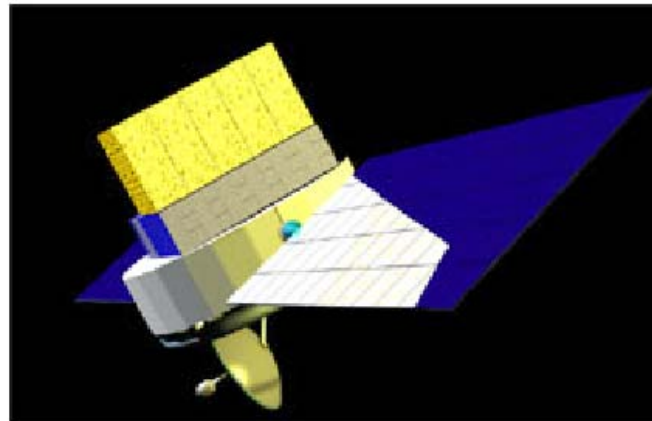
*The Gamma Ray Large Area Space Telescope*

## *The Mission*



## The

GLAST Mission is part of NASA's Office of Space and Science Strategic Plan, with launch anticipated in 2006. GLAST is a next generation high-energy gamma-ray observatory designed for making observations of celestial gamma-ray sources in the energy band extending from 10 MeV to more than 100 GeV. It follows in the footsteps of the **CGRO-EGRET** experiment, which was operational between 1991 and 1999.



# The AGILE contribution to GRBs studies

M. Tavani<sup>1,2</sup>, G. Barbiellini<sup>3</sup>, P. Caraveo<sup>1</sup>, V. Cocco<sup>4</sup>, E. Costa<sup>7</sup>, G. Di Cocco<sup>6</sup>, C. Labanti<sup>6</sup>, F. Longo<sup>1</sup>, S. Mereghetti<sup>1</sup>, A. Morselli<sup>4</sup>, A. Pellizzoni<sup>5</sup>, P. Picozza<sup>4</sup>, L. Piro<sup>7</sup>, M. Prest<sup>3</sup>, and S. Vercellone<sup>1</sup>

**Abstract.** AGILE is a gamma-ray mission planned to be operating as an Observatory during the period 2002-2005. Its baseline instrument is designed to detect gamma rays in the 30 MeV – 50 GeV band. AGILE's good sensitivity, very large field of view ( $\sim 1/5$  of the whole sky), and excellent timing capability ( $\sim 1$  ms deadtime) are ideal to study gamma-ray bursts (GRBs). AGILE is expected to detect  $\sim 10$  GRBs per year at energies above 100 MeV. The Super-AGILE option might be able to localize GRBs within a few arcminutes and provide additional information in the hard X-ray band. A rapid alert program is an essential part of the scientific goals of the AGILE Observatory.