Search for gravitational wave signals associated with gamma ray bursts

Giuseppina Modestino
INFN - LNF

ROG Collaboration

INFN Laboratori Nazionali di Frascati, Roma1, Roma2
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.

Principal results of the '90s

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

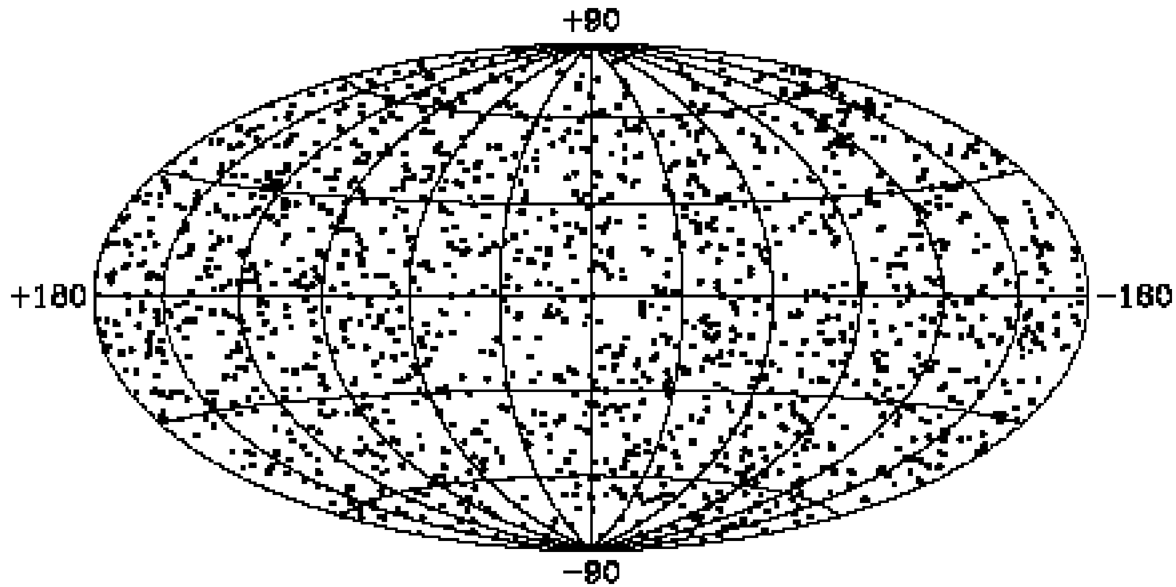
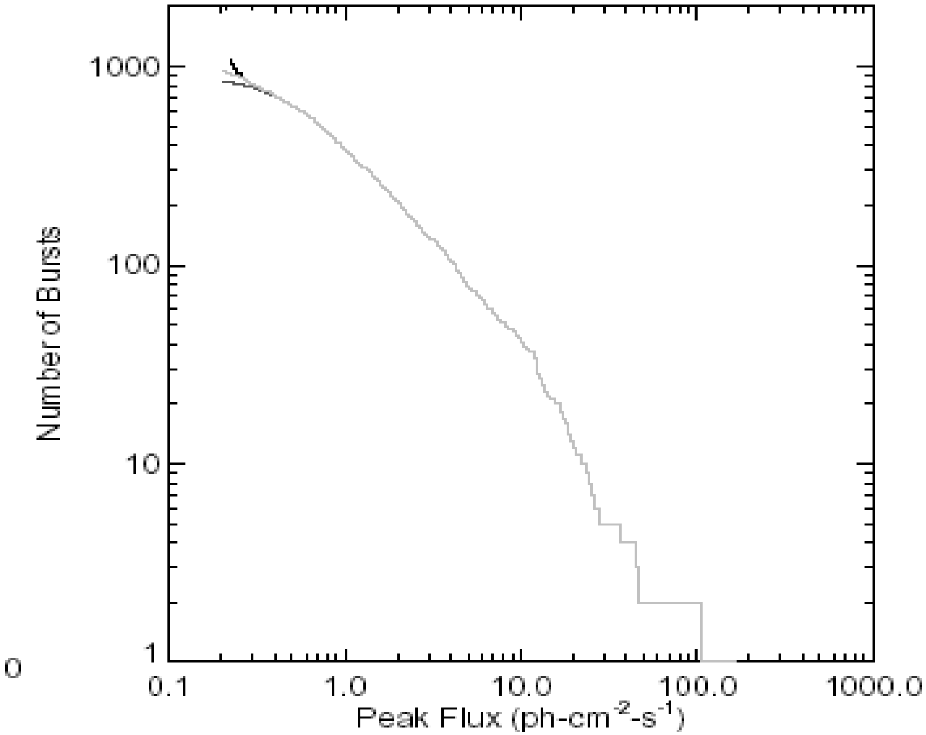


FIG. 5.— Sky distribution of the 1637 bursts in the 4Br catalog on an Aitoff-Hammer projection in Galactic coordinates. There is no correction for non-uniform sky coverage. Note that the full set of 4Br locations has been used, regardless of trigger energy range.

=> Exclusion of local origin of GRBs

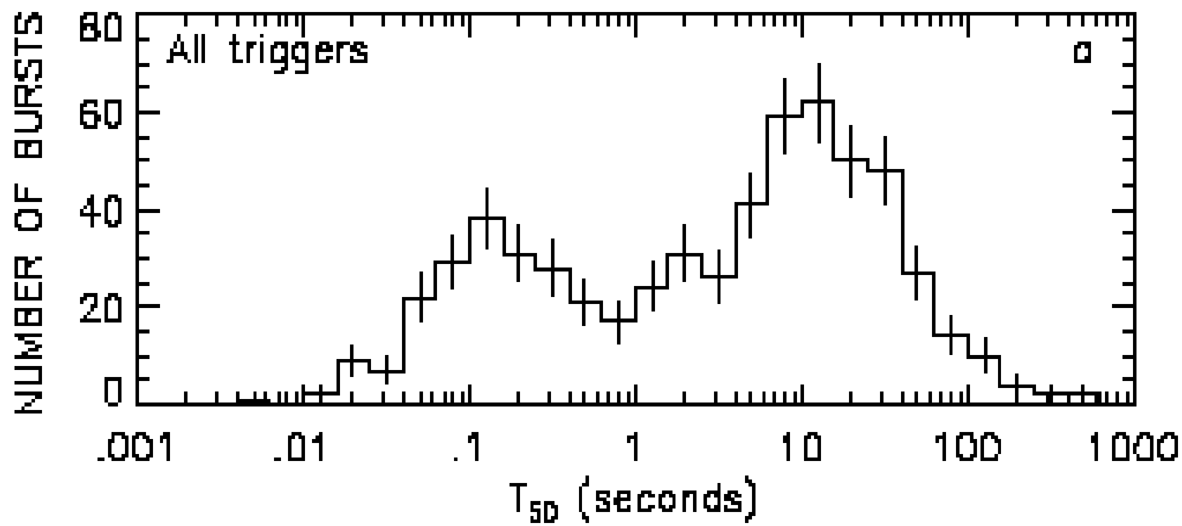
Principal results of the ‘90s

Integral log N - log F distribution



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

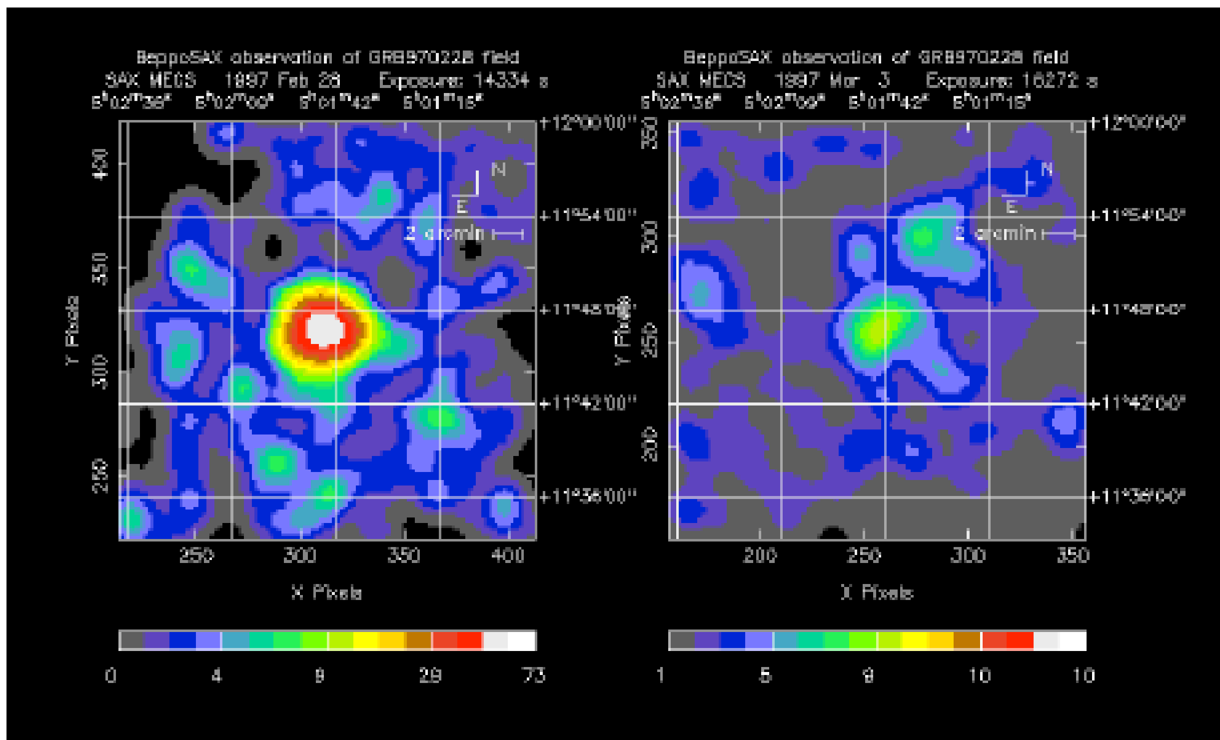
Duration distribution



shows a bimodal statistic

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

- 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 +/- 0.4) x 10E-12 erg cmE-2 sE-1 in the MECS (2-10 keV) and (4.0 +/- 0.6) x 10E-12 erg cmE-2 sE-1 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

Principal results of the '90s

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

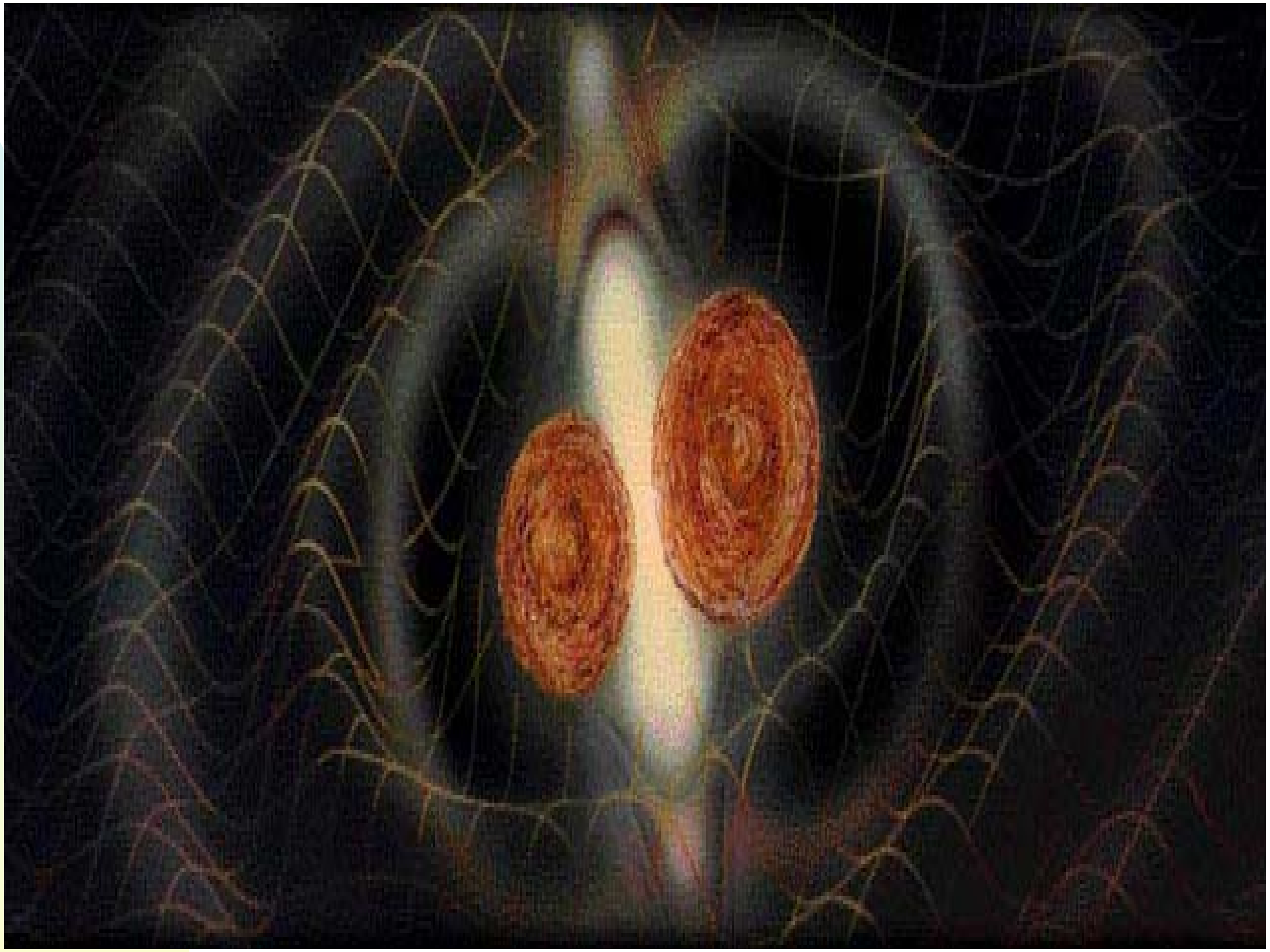
- Isotropic distribution
- Cosmological origin
- 10^{51} - 10^{53} erg (in a few seconds)
- Complex temporal behavior
- Bimodal statistic for the duration value
- EM counterparts in lower frequencies (phenomenological process)

...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:

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

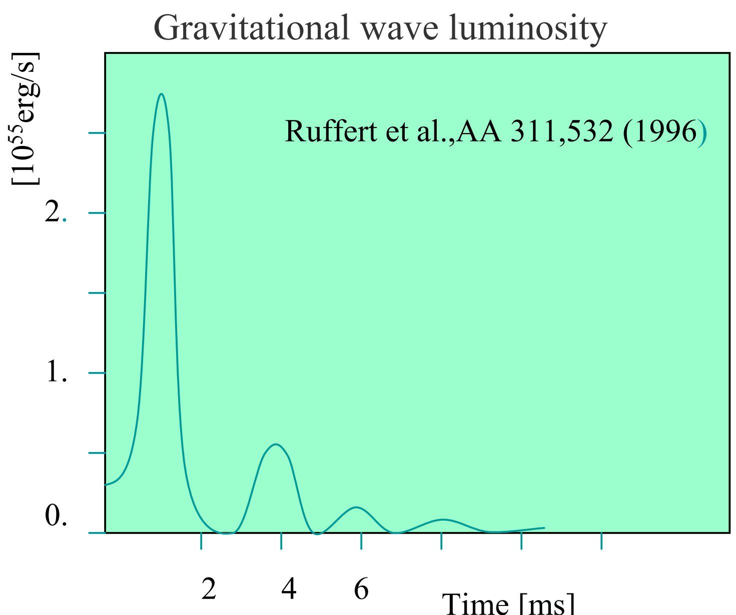
associated to a single GRB event:

@ 1 kHz

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

$\varepsilon_{GW} = 1\%$

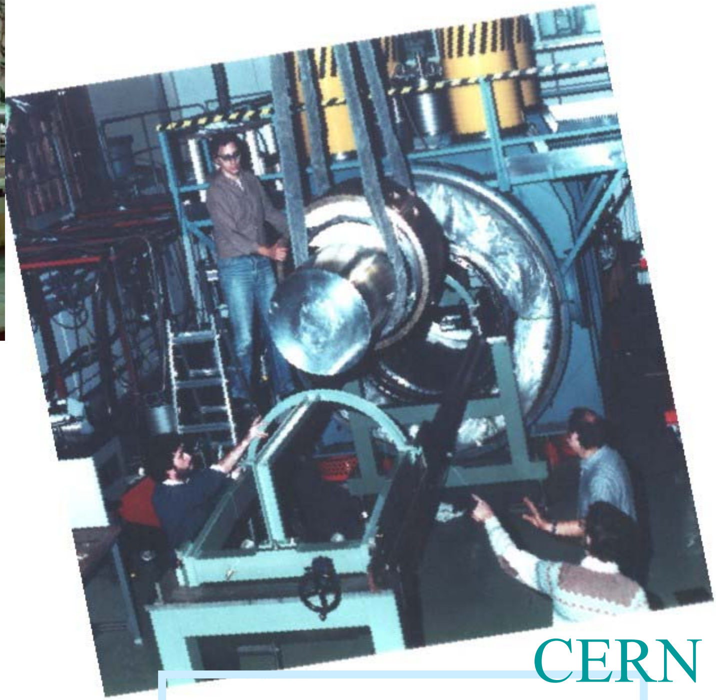
$$h \sim \frac{10^{-22}\ (M_{GW})^{1/2}}{R(\text{Gpc})}$$



ROG - The two cryogenic detectors -

NAUTILUS

LNF-Frascati

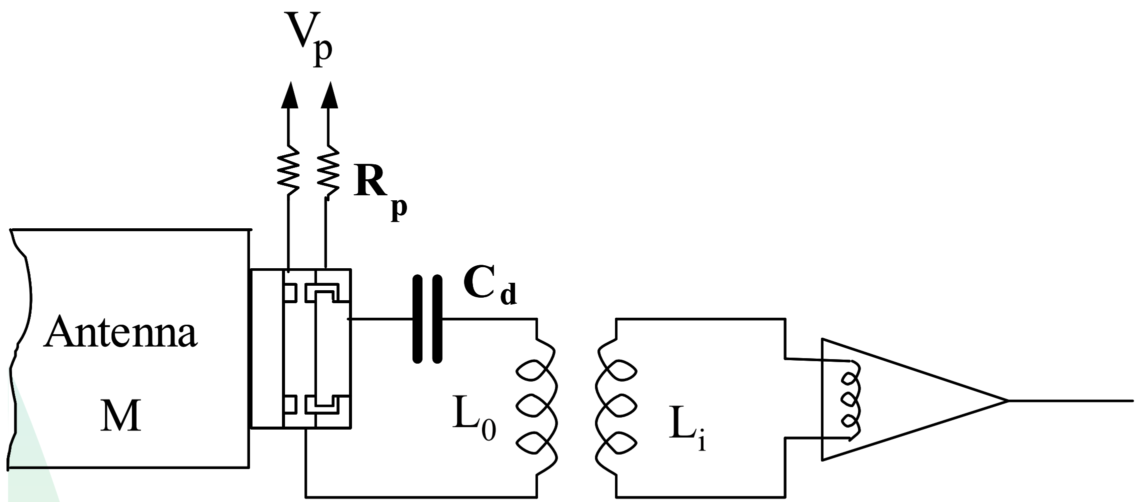


CERN

EXPLORER

bar length L = 3m
mass = 2300 Kg
material Al5056
resonance ~1 KHz
temperature = 0.1 K - 2 K

MAIN FEATURES



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

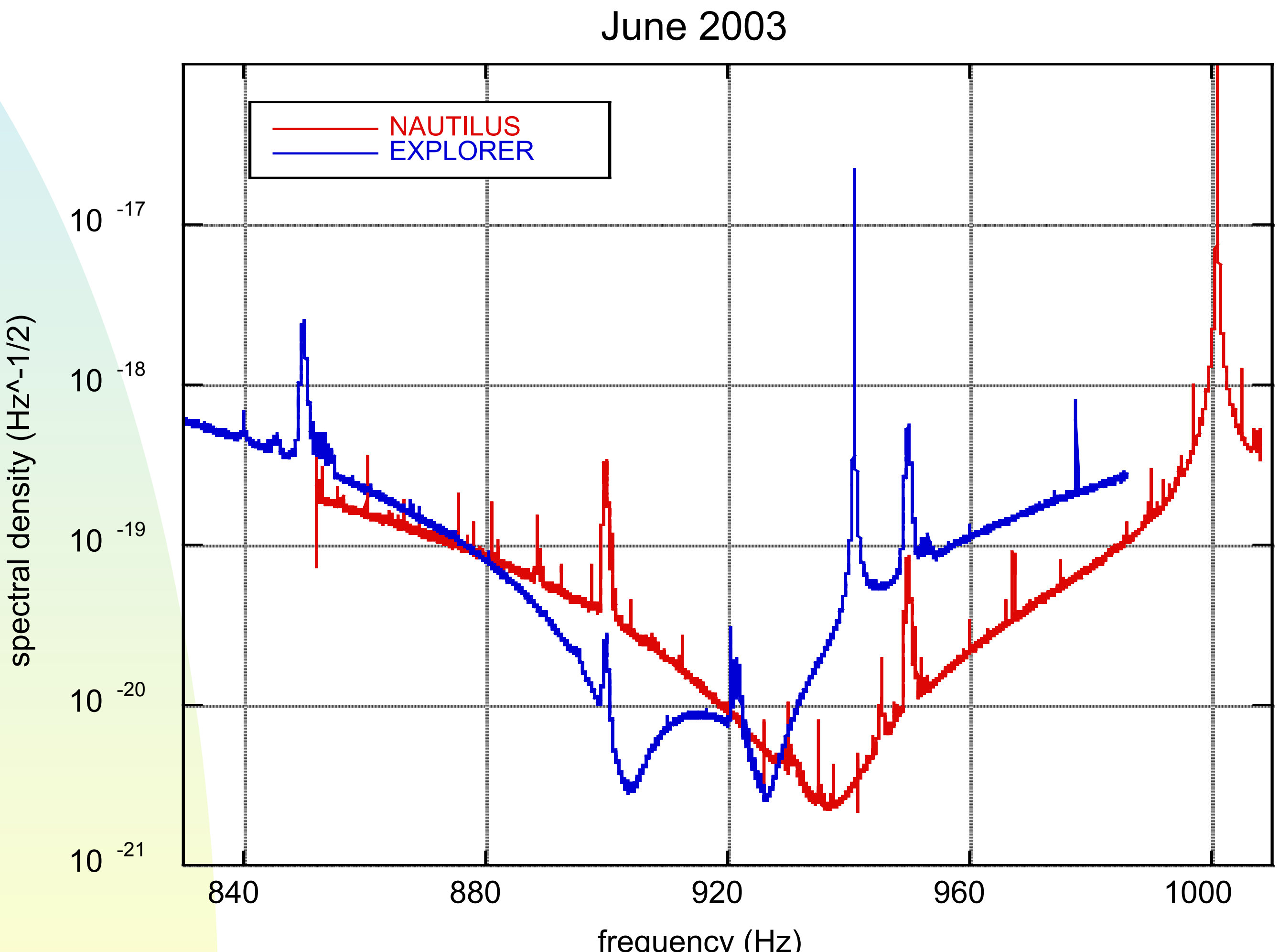
The amplifier

Noise temperature $\mathbf{T_n}$

Minimum energy change detectable

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

The present sensitivity of NAUTILUS EXPLORER



Previous experimental studies

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

Coincidence technique.

No evidence in a time window of ± 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>=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 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:

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

R = distance
M = amount of GW energy emitted (Mo)

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

In our data analysis, we consider :

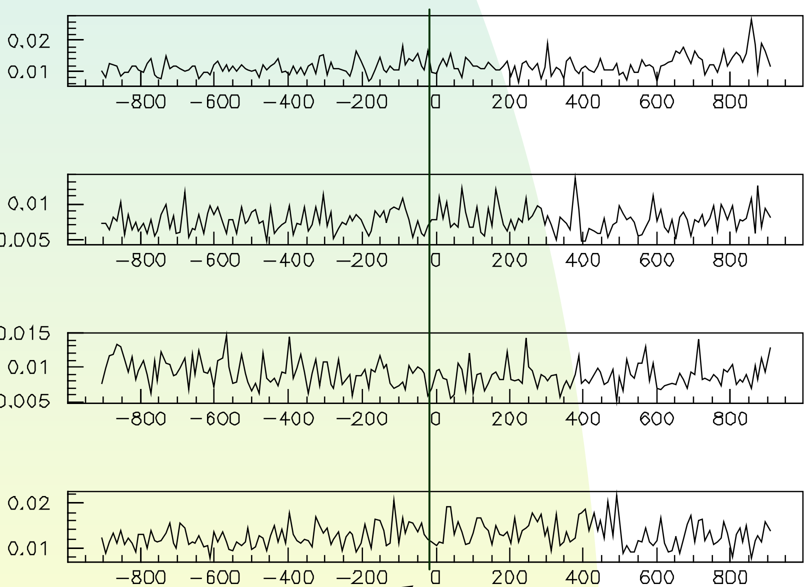
$\Delta t = 0$ as predicted by several models

and also

variable Δt

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

E_2

E_3

E_n

$t=t_{GRB}$

$\Delta t(s)$

For the single data stretches

$\sigma_i = \langle Ei \rangle$

2)Applying a cumulative algorithm:

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

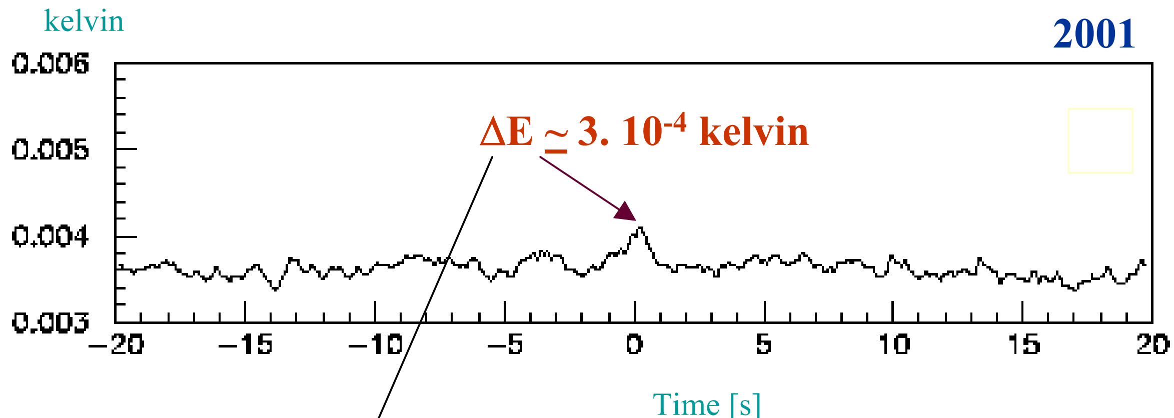
Searching for a simultaneous GW signal

Experimental example:

Cosmic-ray showers interacting with NAUTILUS

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

$\sigma \sim 10^{-4}$ 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 ± 5 s
- GW data background over 30 minute periods with temperature noise $t_n < 15 \quad 10^{-3}$ kelvin (Peak Time ± 15 min)
- Cumulative median algorithm

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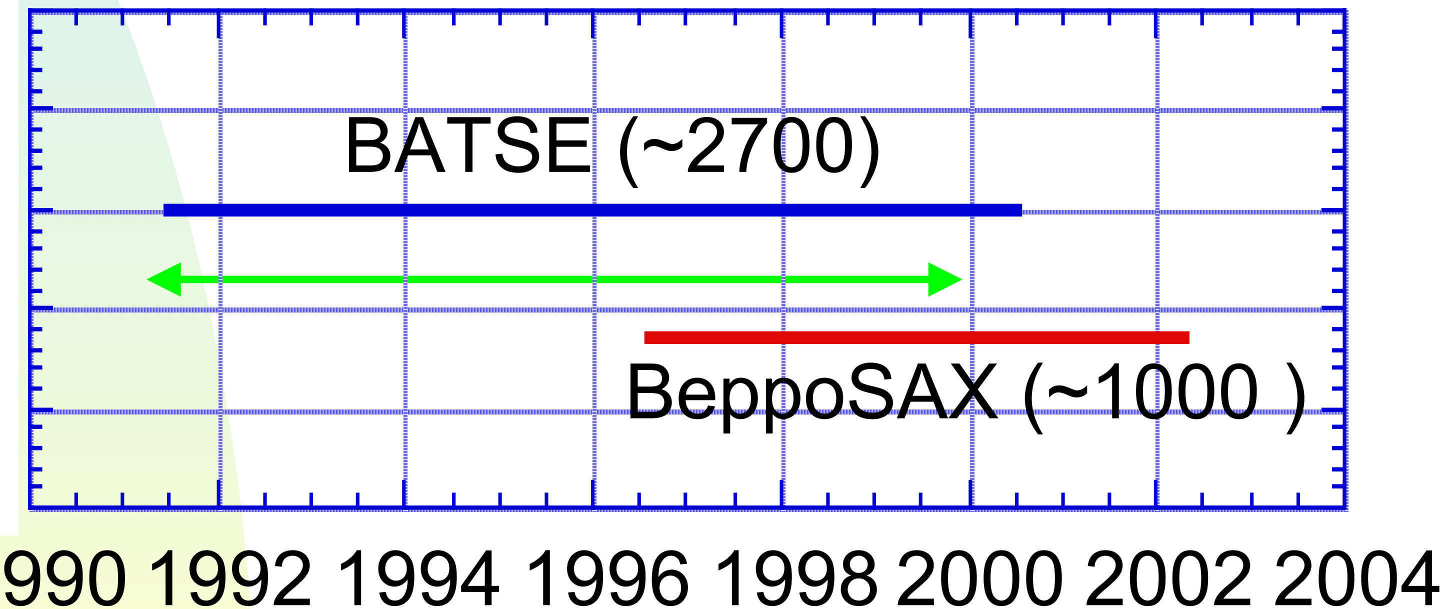
Searching for simultaneous GW signal.

GRBs Database

Trigger GRBs



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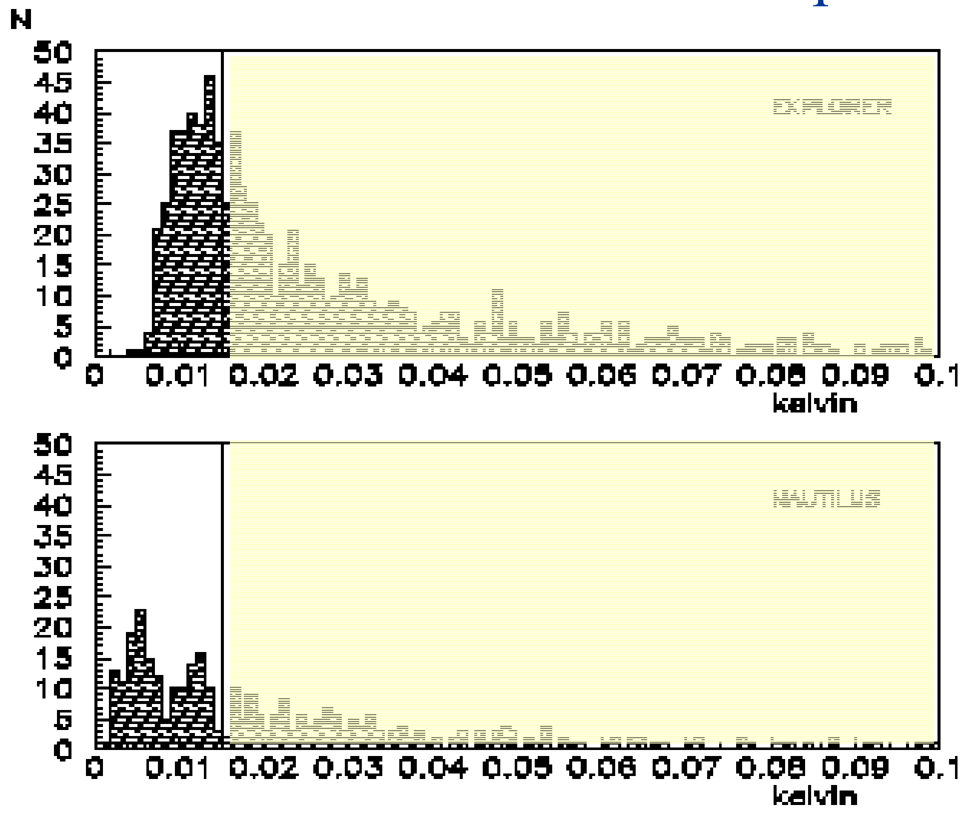
Data selection

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



N=387 data stretches with Te ≤ 15 mK are selected

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Subm. to PRD

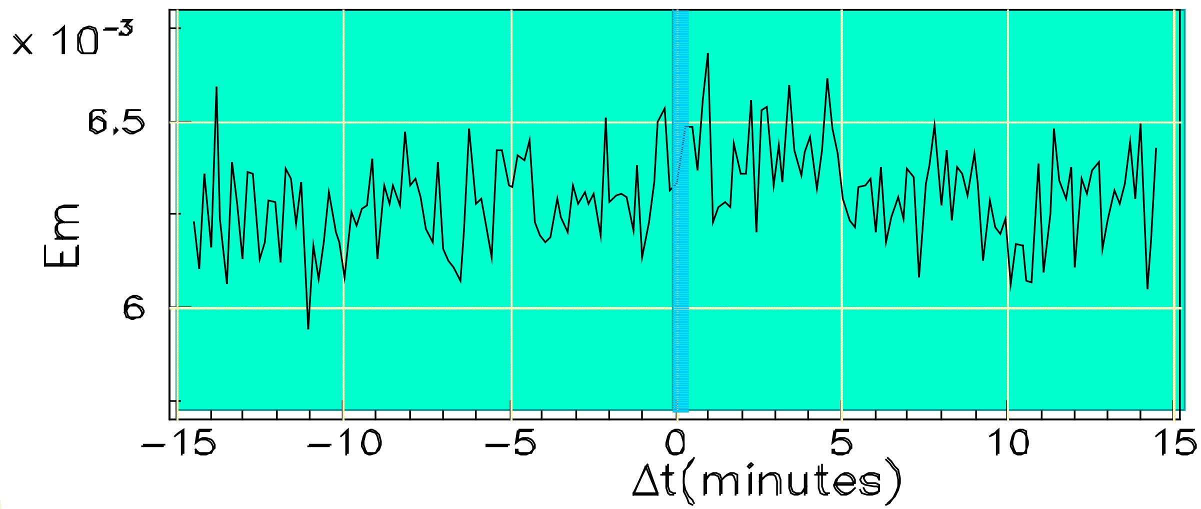
Searching for simultaneous GW signal.

- Combine 387 30 min GW data stretches
- For each time delay, the median value Em is exctract

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

$\langle E \rangle = 6.30$ mK

$\sigma = 0.13$ mK



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

E(0) = 6.33 mk

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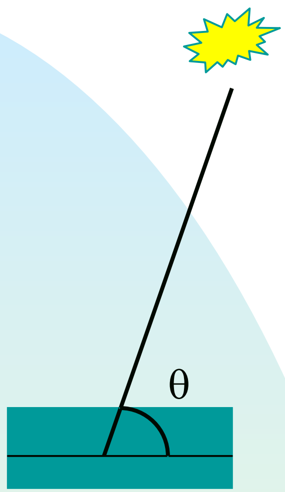
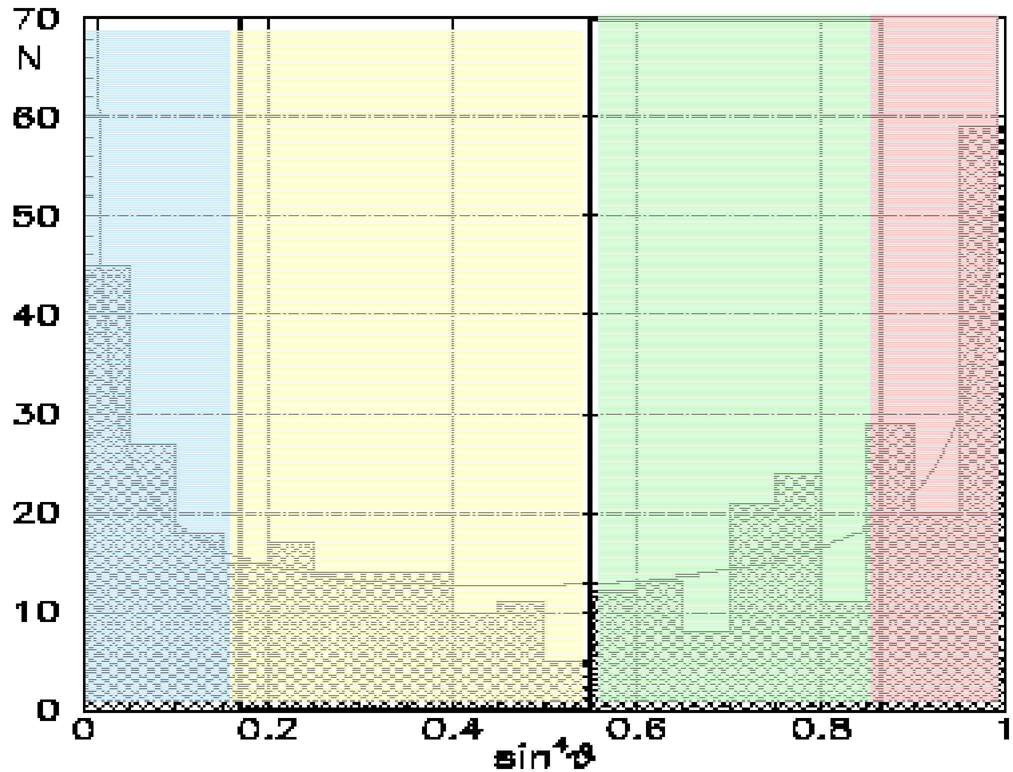
Subm to PRD

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



$\Sigma \sim \sin^2\theta$



$\sin^4\theta$ 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.

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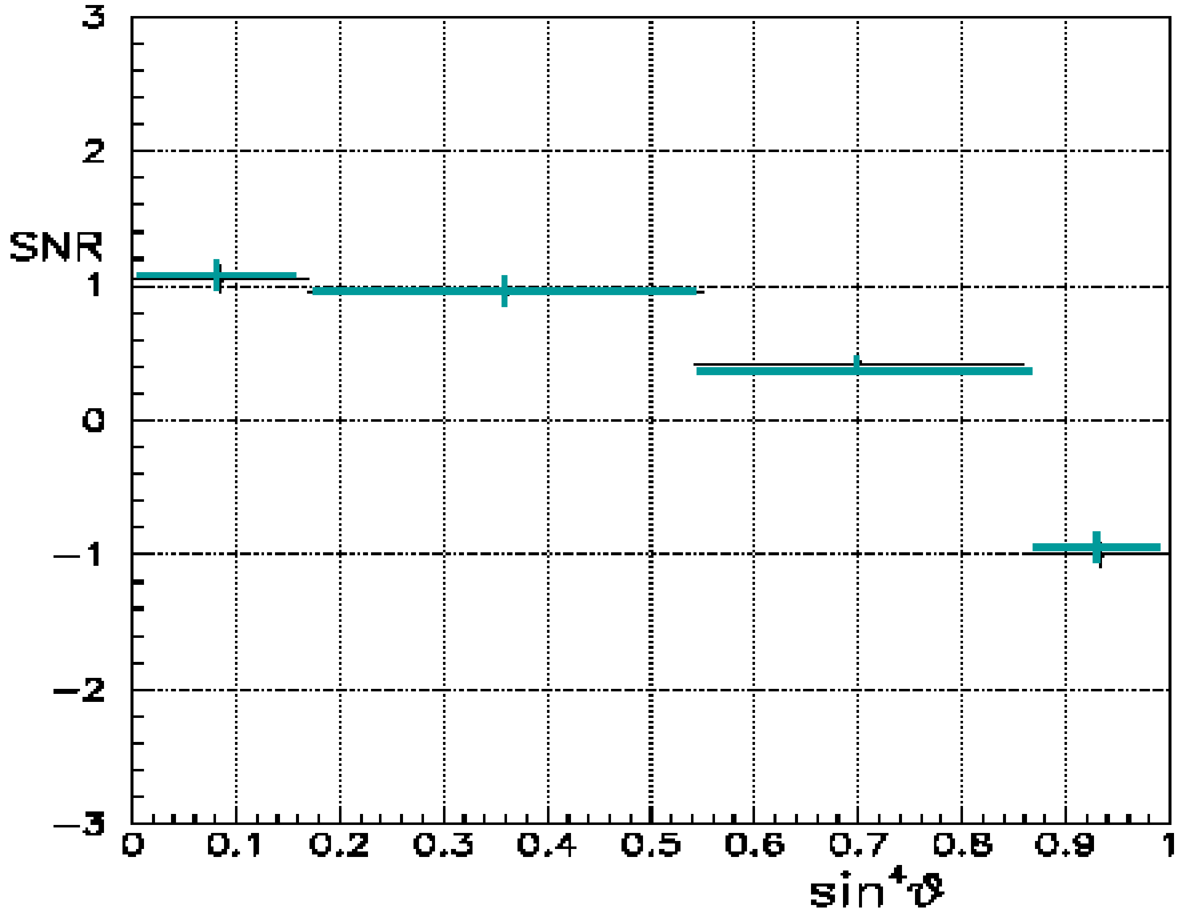
Looking for a correlation with $\sin^4\theta$



SNR of the excess at zero delay of the median value

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Subm. to PRD

Searching for GW signals under variable delay hypothesis(*)

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

- Apply the usual data selection criteria evuluating 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

Beppo-Sax Catalog 2001

- **EXPLORER (CERN)**
- ON from March to December
- T = 2.6 K
- Duty Cycle = 91%
- Average sensitivity

h=4.5 10-19

- **NAUTILUS (LNF)**
- ON from January to December
- T = 1.5 K
- Duty Cycle = 80%
- Average sensitivity

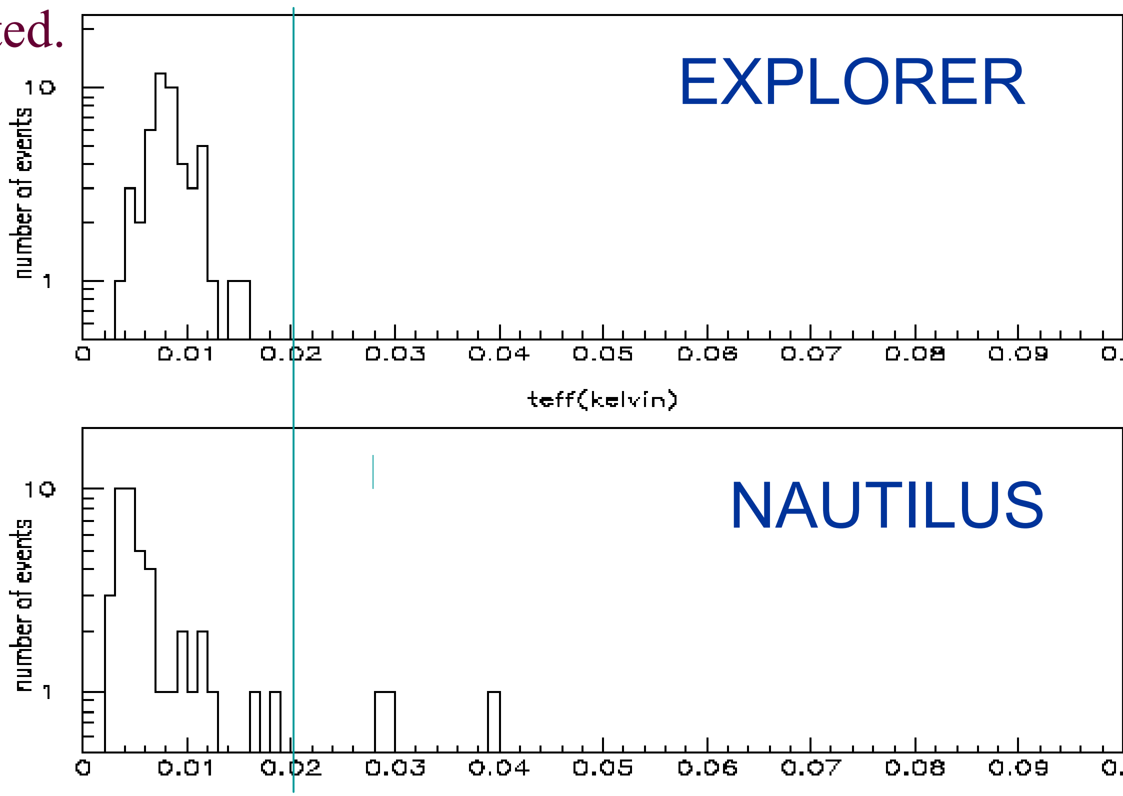
h=5. 7 10-19

Cross-correlation analysis

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

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

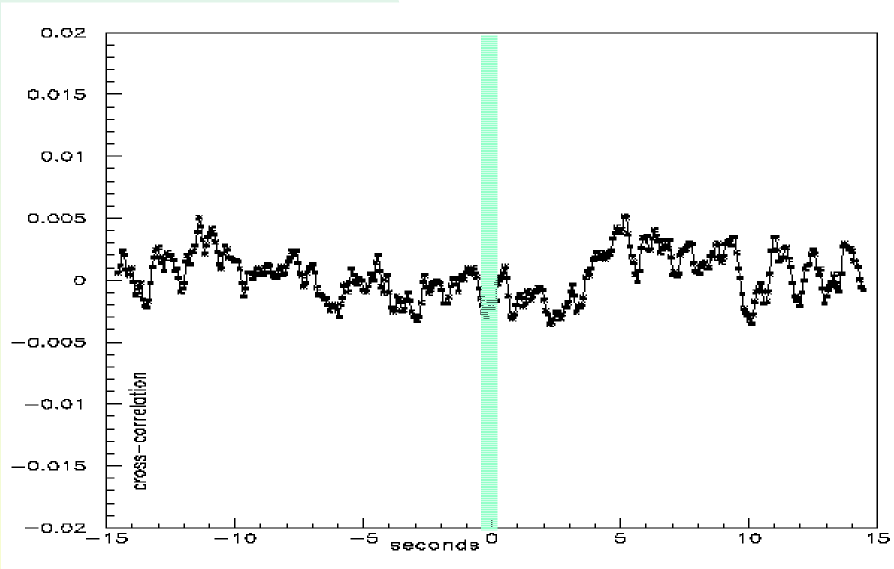
47 GRB are analyzed



Cross-correlation result

EXPLORER x NAUTILUS 2001

R(t′) cross-correlation function (averaged on the 47 GRBs) relative to the energy of the two GW detectors.



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

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

Astone et al. (ROG Coll), Phys. Rev. D 66 102002 (2002).

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.

Conclusions

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

No significant correlation has been found

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

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

The conditions are rapidly improving:

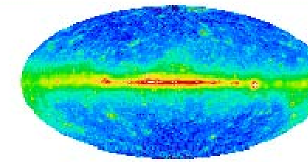
The next generation of GRB missions,
the improving performances of the present GW detectors,
the imminent runs of the GW interferometric detectors,
will lead up to higher sensitivity in the measurement.

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

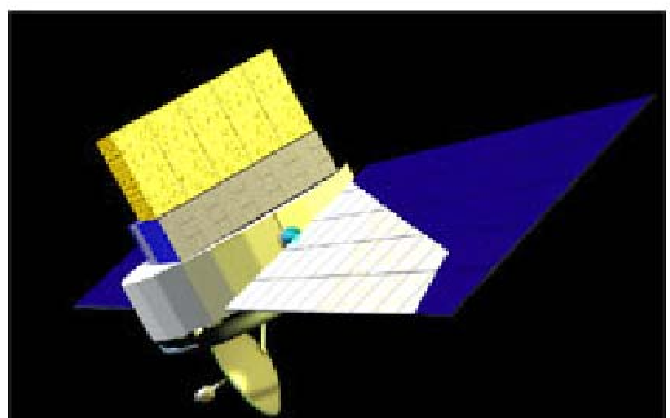
The Gamma Ray Large Area Space Telescope

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[1,2], G. Barbiellini[3], P. Caraveo[1], V. Cocco[4], E. Costa[7], G. Di Cocco[6], C. Labanti[6], F. Lon
S. Mereghetti[1], A. Morselli[4], A. Pellizzoni[5], P. Picozza[4], L. Piro[7], M. Prest[3], and S. Vercellone[1]

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 (∼ 1/5 of the whole sky), and excellent timing capability (∼ 1 ms deadtime) are ideal to study gamma-ray bursts (GRBs). AGILE is expected to detect ∼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.