Searching for GW bursts wIth the EXPLORER and NAUTILUS detectors

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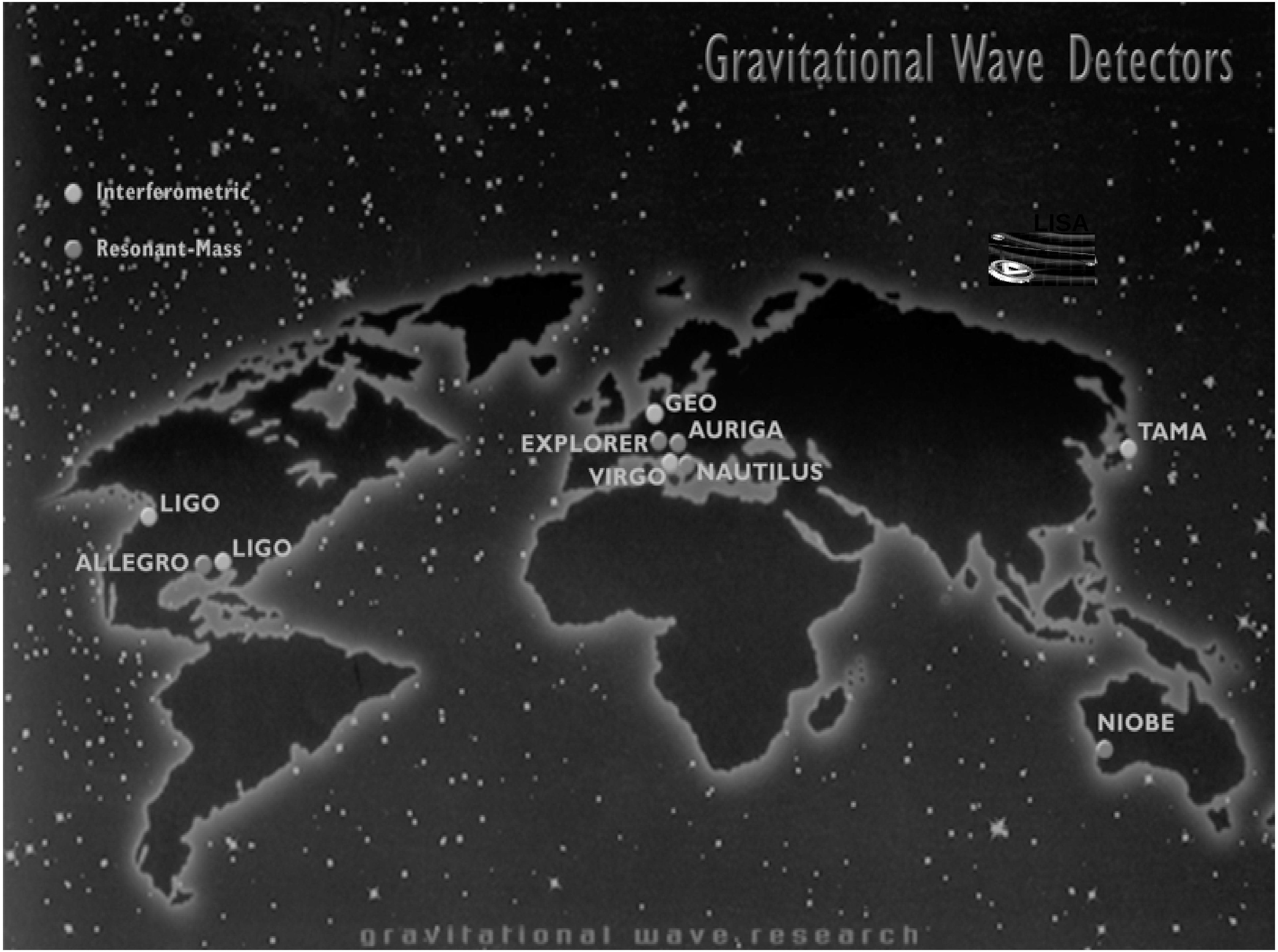
U. of Rome "Tor Vergata" ***and INFN***
ROG Collaboration

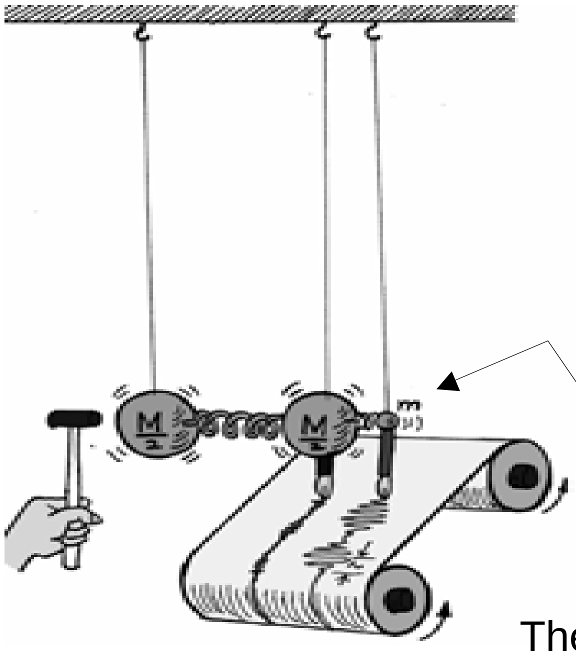
La Thuile - 10 march 2003



Gravitational Wave Detectors
Interferometric
Resonant-Mass
LISA
GEO
AURIGA
EXPLORER
VIRGO
NAUTILUS
TAMA
LIGO
LIGO
ALLEGRO
NIOBE
gravitational wave research

GWs excite those vibrational modes of a resonant body that have a mass quadrupole moment, such as the fundamental longitudinal mode of a cylindrical antenna.

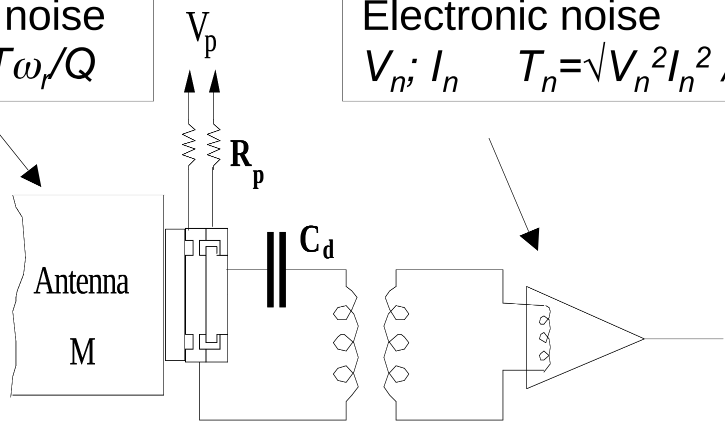
$$\ddot{x}(t) + \tau^{-1}\dot{x}(t) + \omega_0^2 x(t) = \frac{l}{2}\ddot{h}(t)$$



The displacement
of the secondary oscillator
modulates a dc electric field

Thermal noise
$S_F = MkT\omega_r/Q$

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



$$v(t) \propto x(t) + n(t)$$


NAUTILUS
INFN - LNF

Detectable signals today

BURSTS: Black Hole ($M \sim 10 M_{\odot}$) formation, $10^{-4} M_{\odot}$ into GW

$$SNR = 6 \times 10^{3} \left(\frac{10\,kpc}{r} \right)^{2} \left(\frac{10^{-44}\,Hz^{-1}}{\tilde{h}^{2}} \right) \left(\frac{\Delta f}{1 Hz} \right)$$

SPINNING NEUTRON STARS: Non axisymmetric ($\varepsilon \sim 10^{-6}$) pulsar, $M \sim 1.4 M_{\odot}$

$$SNR \approx 30 \left(\frac{10\,kpc}{r} \right)^{2} \left(\frac{10^{-44}\,Hz^{-1}}{\tilde{h}^{2}} \right) \left(\frac{\varepsilon}{10^{-6}} \right) \left(\frac{T_{obs}}{1 y} \right)$$

COALESCING BINARIES: Inspiraling NS-NS system, $M \sim 1.4 M_{\odot}$

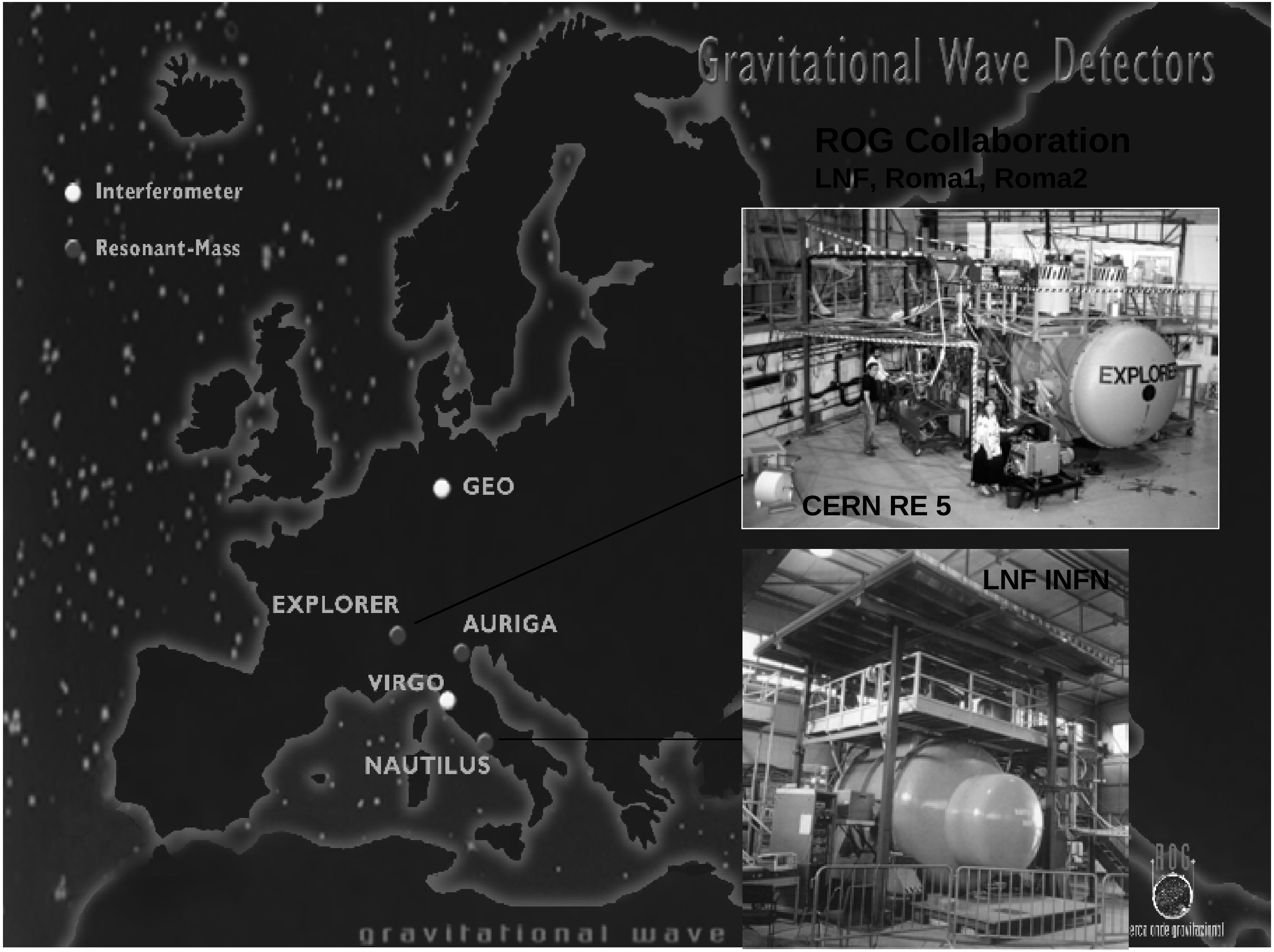
$$SNR \approx 10^{3} \left(\frac{10\,kpc}{r} \right)^{2} \left(\frac{10^{-44}\,Hz^{-1}}{\tilde{h}^{2}} \right) \left(\frac{\Delta f}{1 Hz} \right)$$

STOCHASTIC BACKGROUND: 2 detectors, at distance $d \ll \lambda_{GW}$

$$\Omega_{GW} \approx 2 \times 10^{-3} \left(\frac{f}{900 Hz} \right)^{3} \left(\frac{\tilde{h}_{1,2}}{10^{-22}\,Hz^{-1/2}} \right)^{2} \left(\frac{1 Hz}{\Delta f} \right)^{1/2} \left(\frac{1 y}{T_{obs}} \right)^{1/2}$$

Recent result from ROG Collaboration

Signals or Noise ?


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

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)*

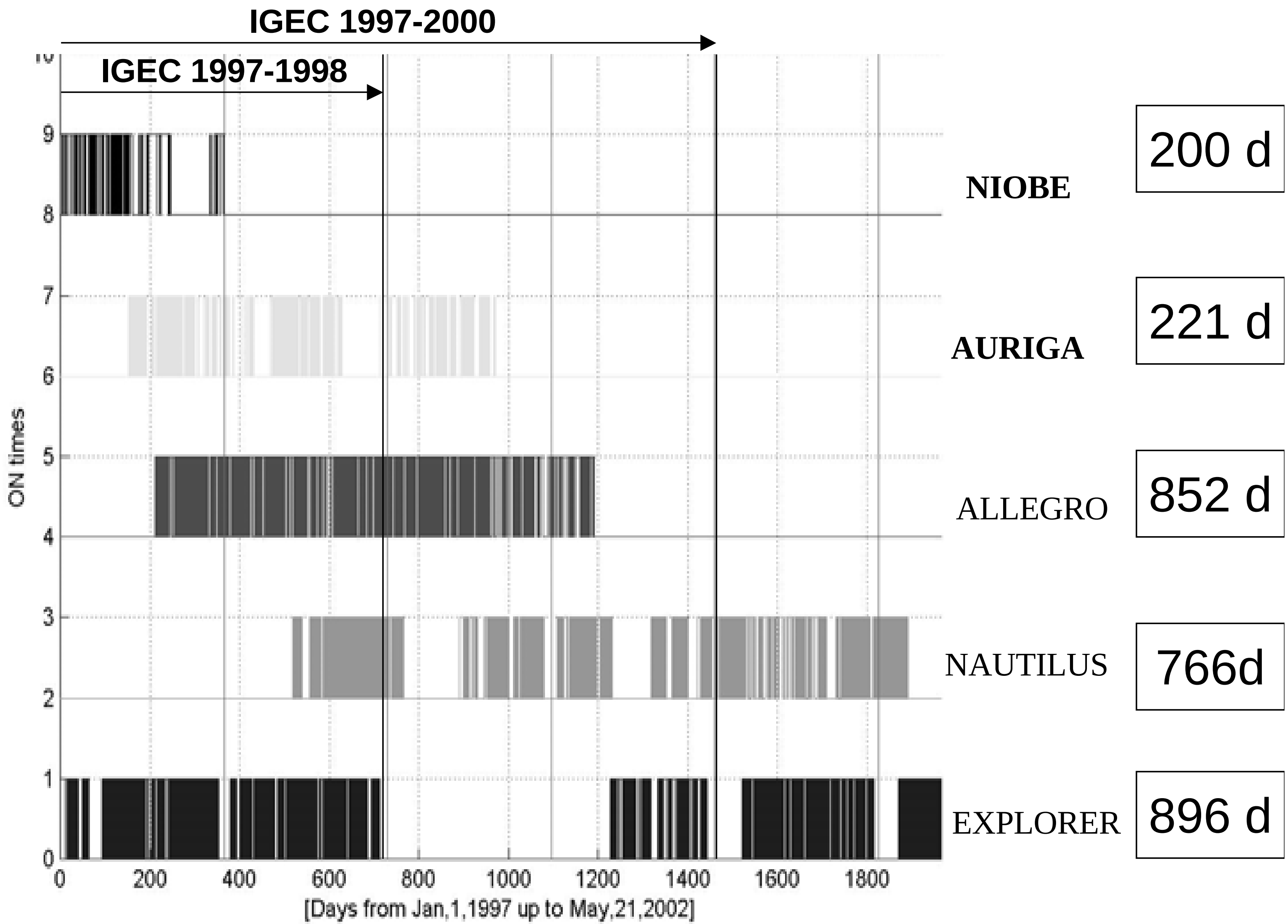
more

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).

ON times of detectors Jan 1997-May,21, 2002



Explorer and Nautilus 2001
CQG 19, 5449 (2002)

90 days of coincident operation
at unprecedented sensitivity
for the detection
of short bursts

$h < 4 \times 10^{-19}$

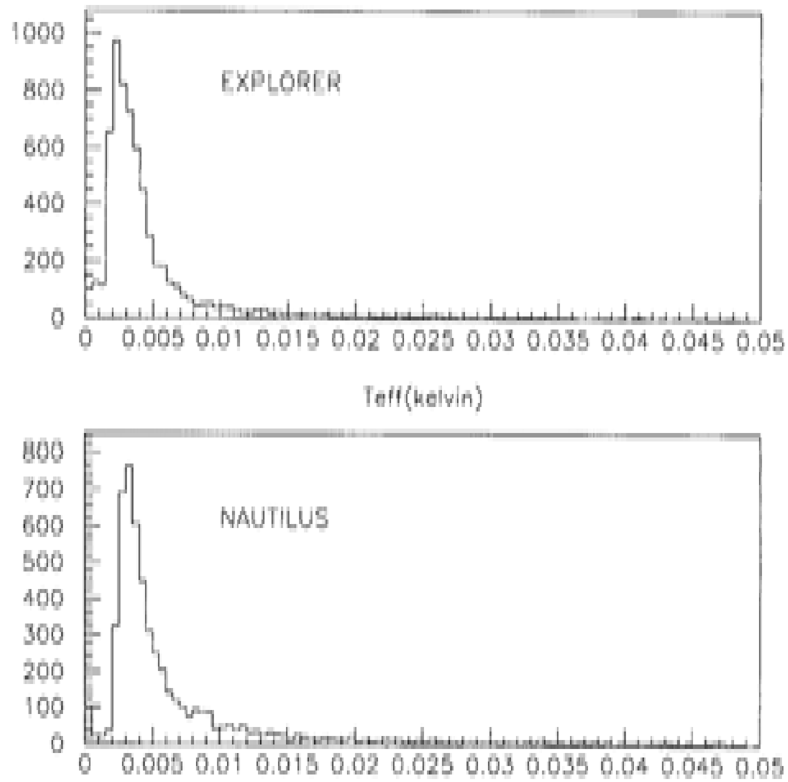
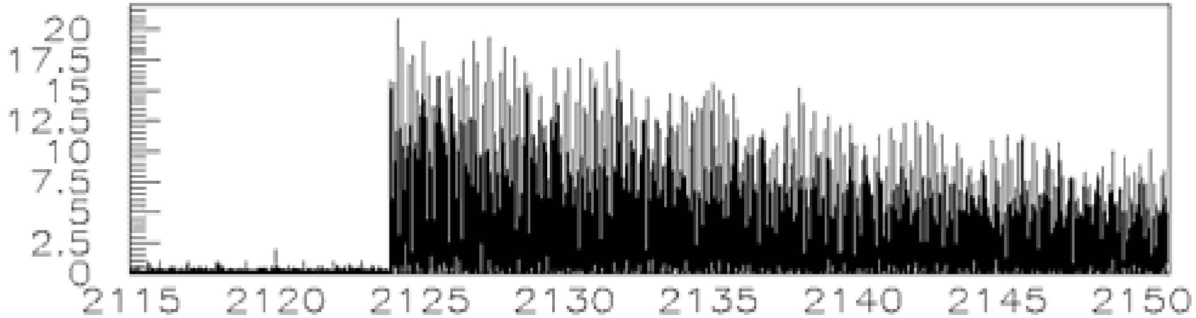


Fig. 2: The distributions of the hourly averages of T_{eff} in kelvin units for EXPLORER and NAUTILUS. We accept only the time periods with hourly averages $\overline{T_{eff}} \leq 10\,mK$.

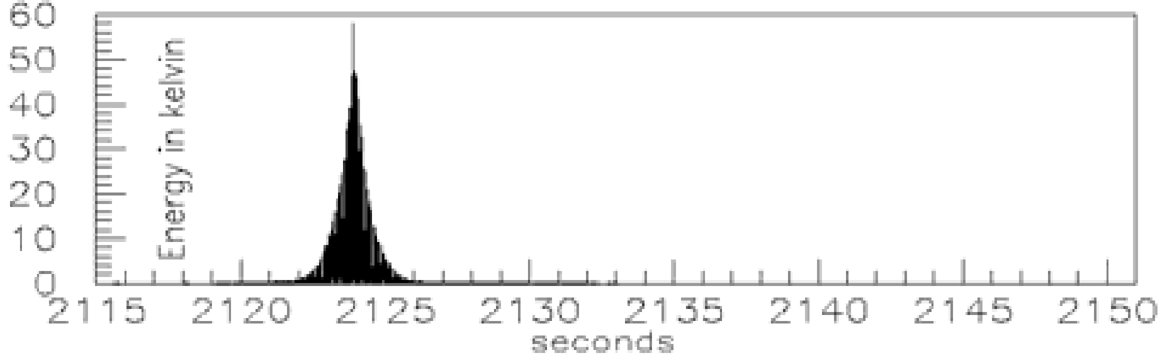
Burst event for a present bar: a millisecond pulse, a signal made by a few millisecond cycles, or a signal sweeping in frequency through the detector resonances. The burst search with bars is therefore sensitive to different kinds of gw sources such as a stellar gravitational collapse, the last stable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

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

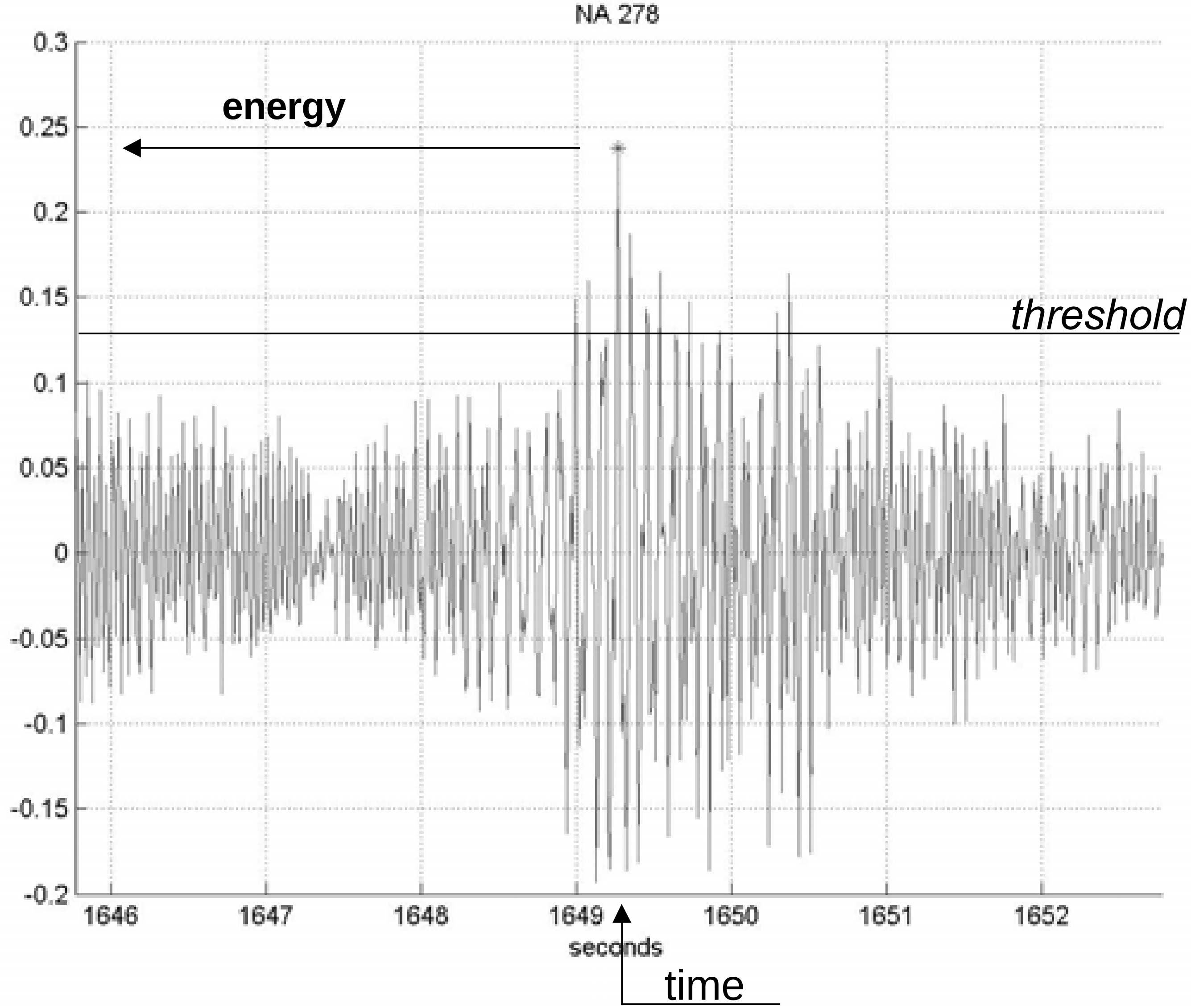
Unfiltered signal (V^2)

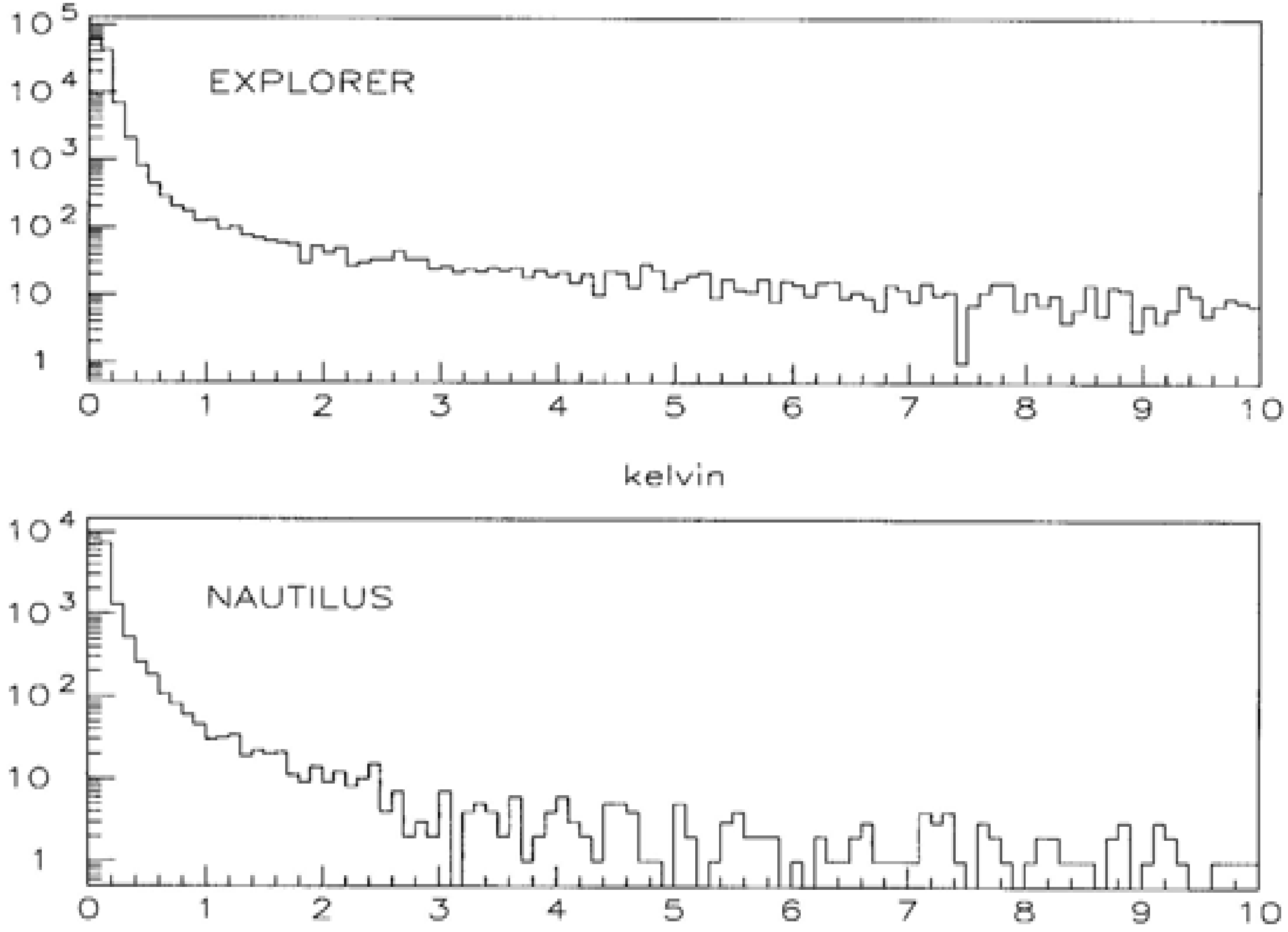


The signal after filtering (kelvin)



Definition of *event*





Distribution of the event energies

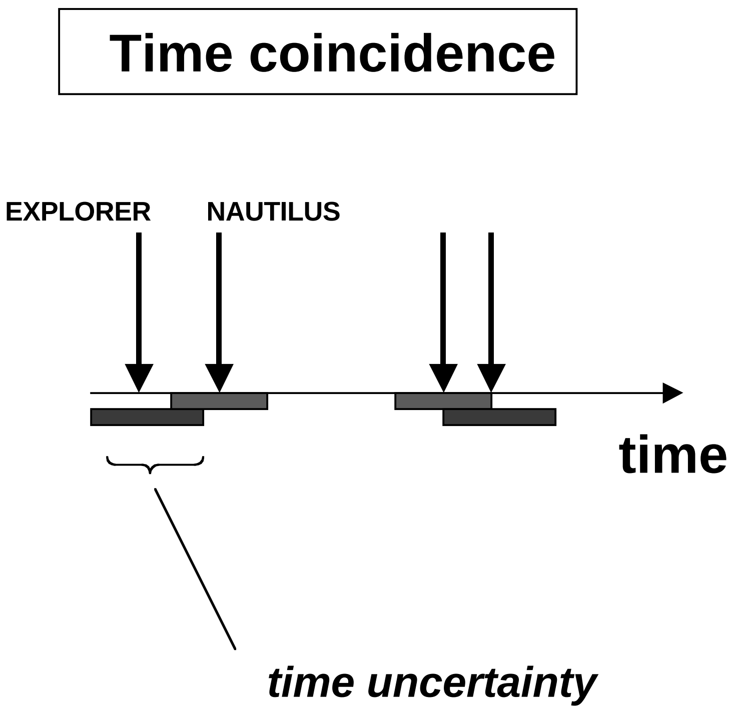
•Because of the inherent weakness of GW signals, and the difficulty in distinguishing them from a myriad of noise sources, the direct detection of a gw burst require coincident detection by multiple detectors with uncorrelated noise.

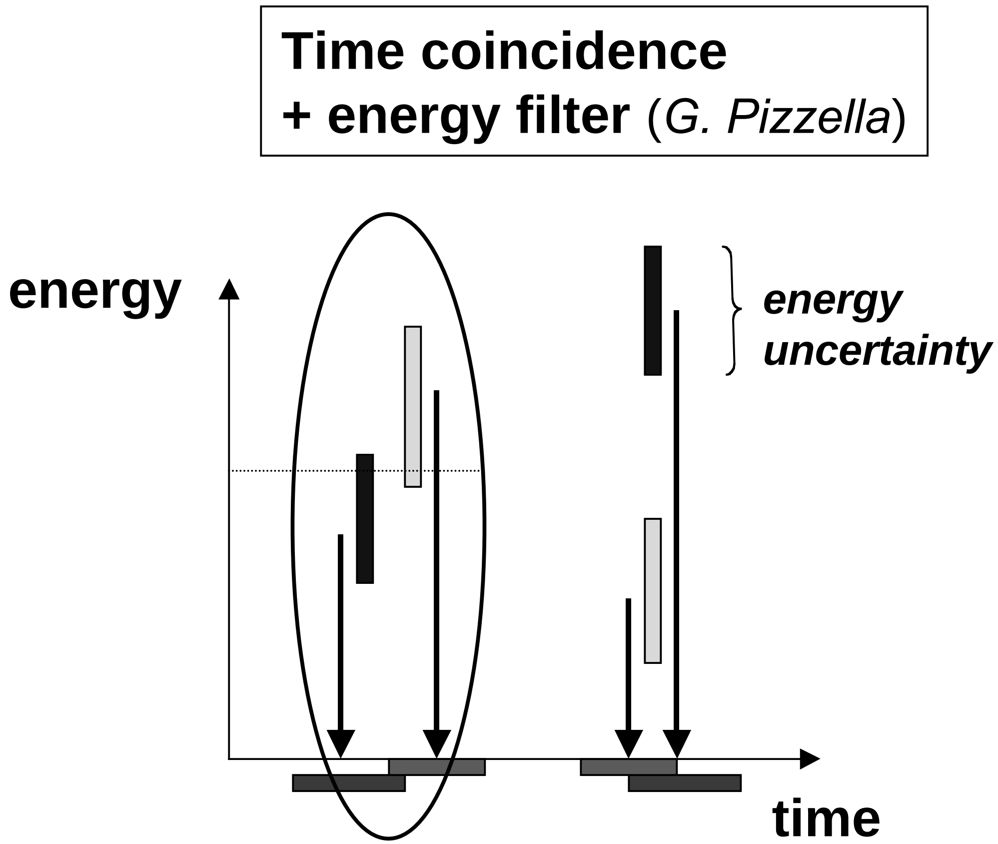
$$n_c << N_1, N_2$$

•Background: expected number of coincidences <n>, during the observation time T

$$\langle n \rangle = \frac{N_1 N_2 \Delta t}{T}$$

This background can be *measured*: one shifts the time of occurrence of the events of one of the two detectors for a number of times, and takes the average


Time coincidence
EXPLORER
NAUTILUS
time
time uncertainty


Time coincidence
+ energy filter (*G. Pizzella*)
energy
energy uncertainty
time

RESULTS

Sidereal time

Solar time

Events

Probability

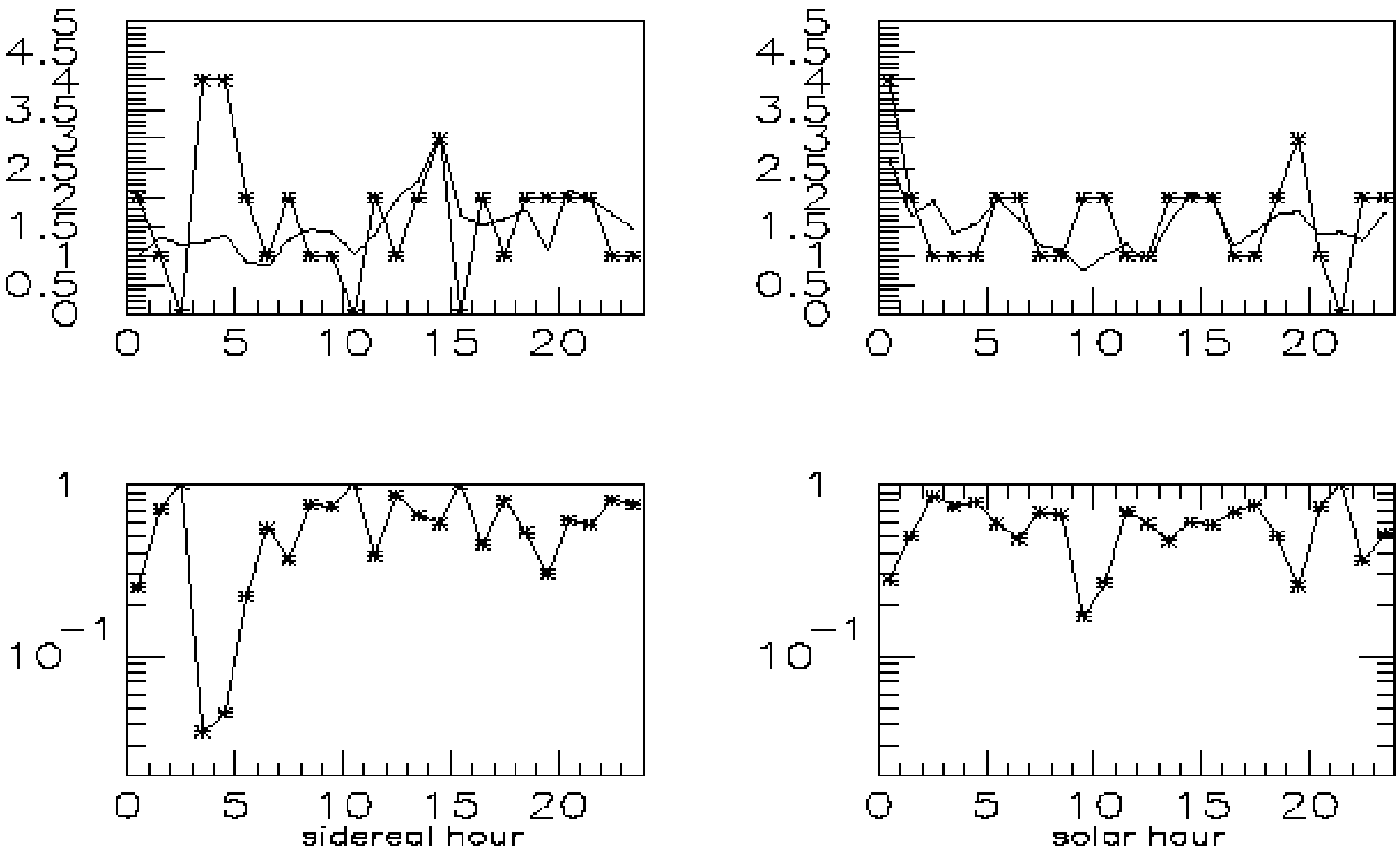


Fig. 7: Result with events in time periods ≥ 1 *hour* of continuous operation. As in fig.5.

*= coincidences ________= accidentals

RESULTS

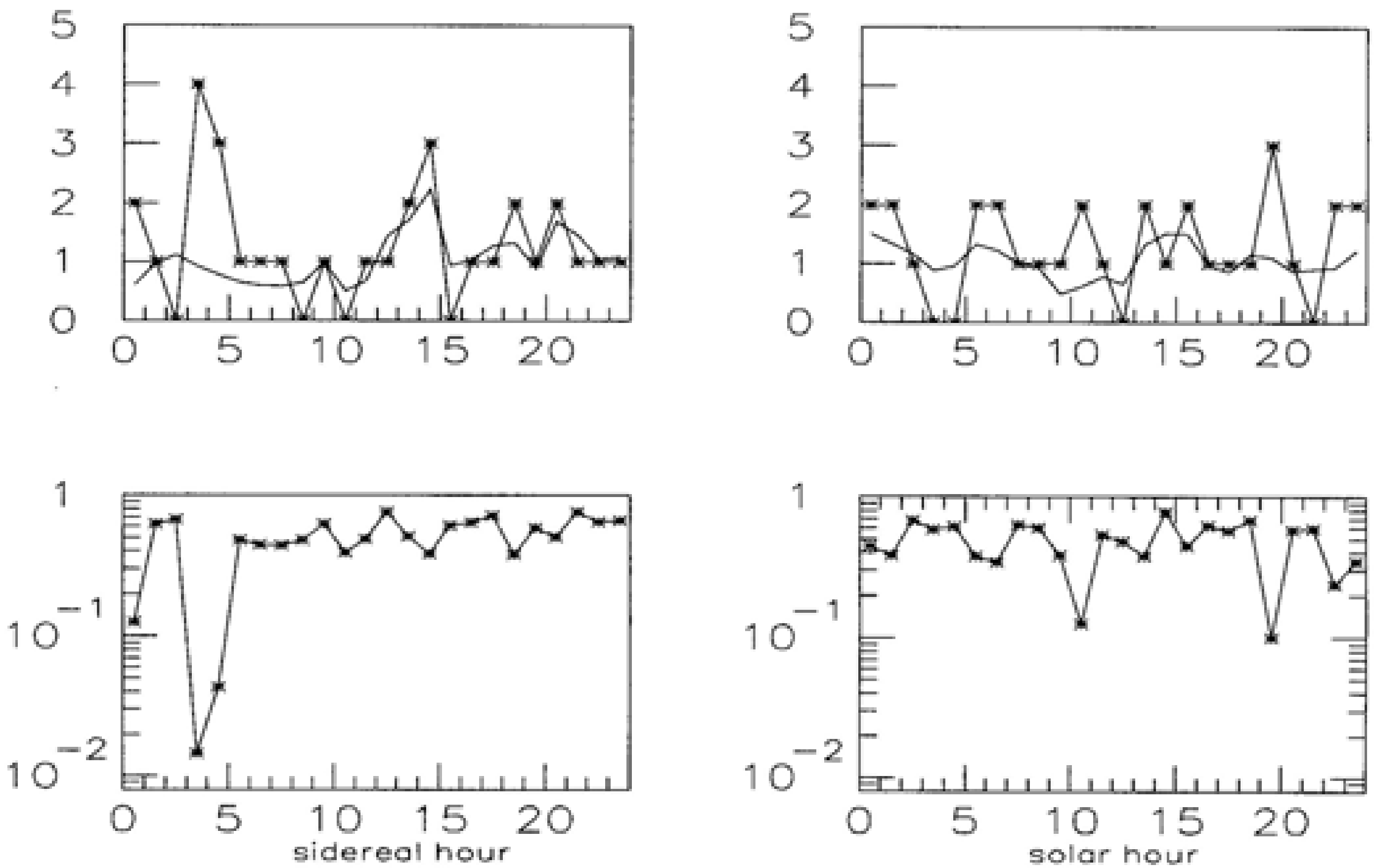
“12 hours continuous operation”

Sidereal time

Solar time

Events

Probability



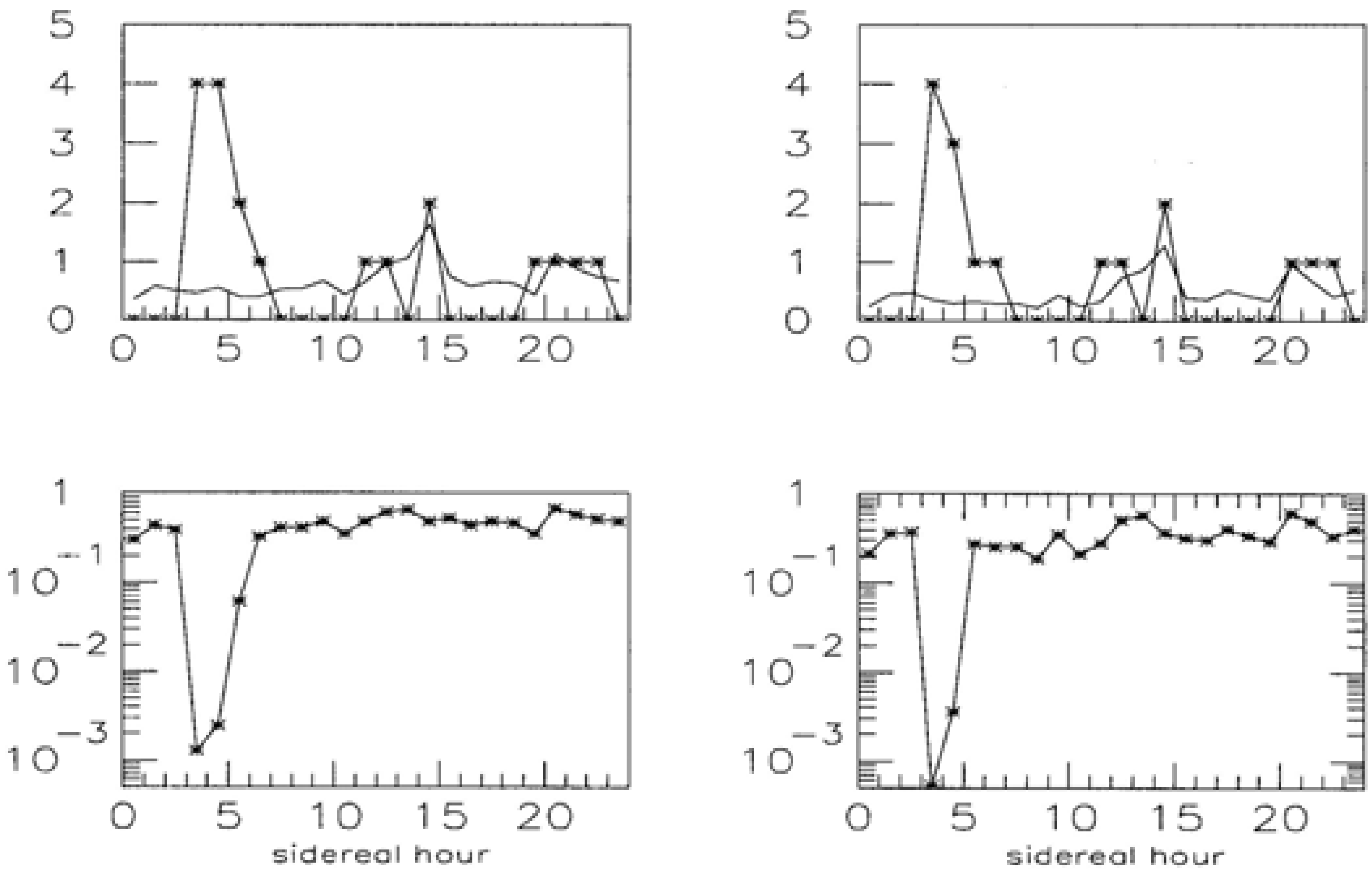
*= coincidences _______= accidentals

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

“a posteriori” threshold

“12 hours”



Events

Probability

*= coincidences ________= accidentals

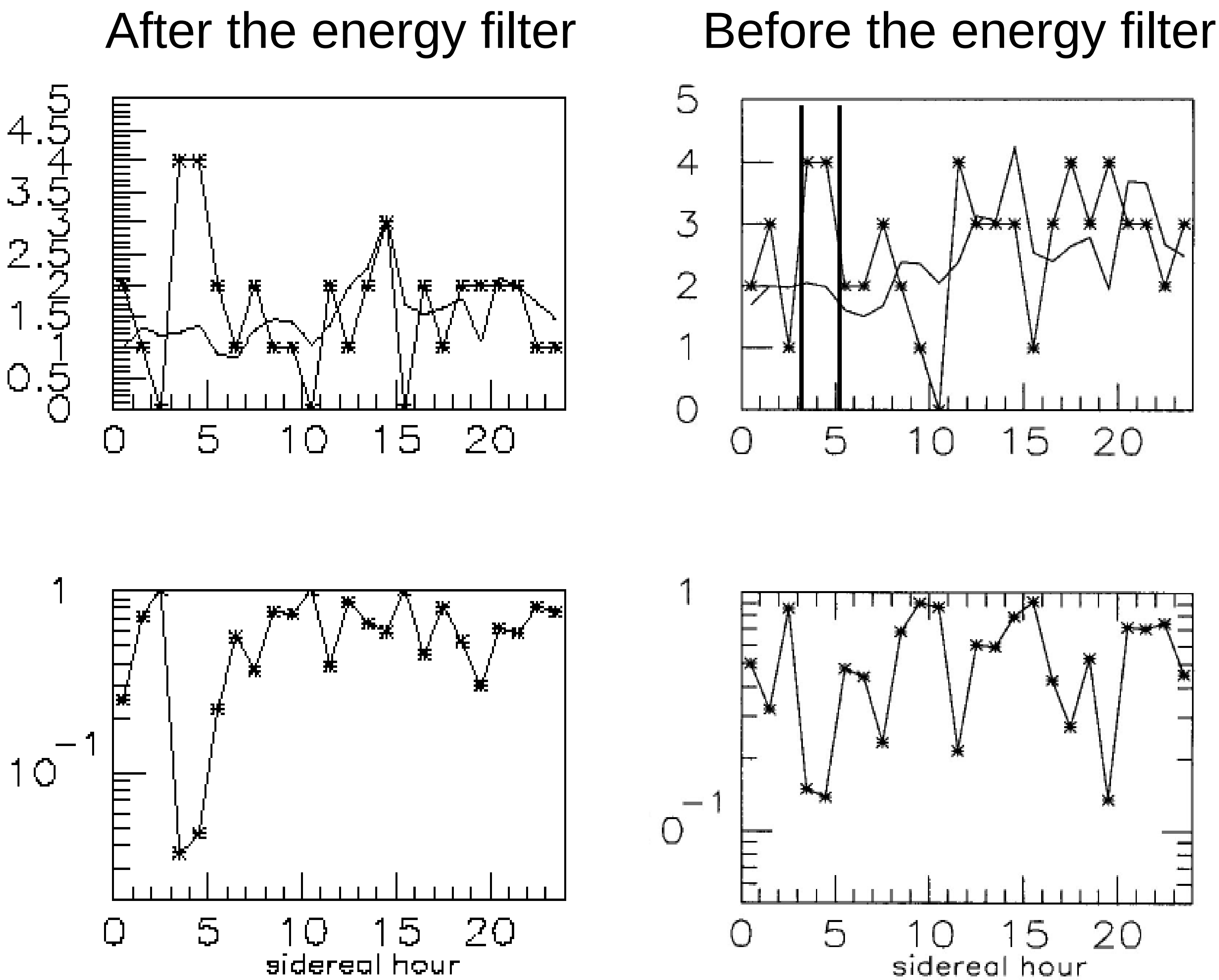


Fig. 7: Result with events in time periods $\geq$ 1 *hour* of continuous operation. As in fig.5.

Energy correlation (no energy filter)

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

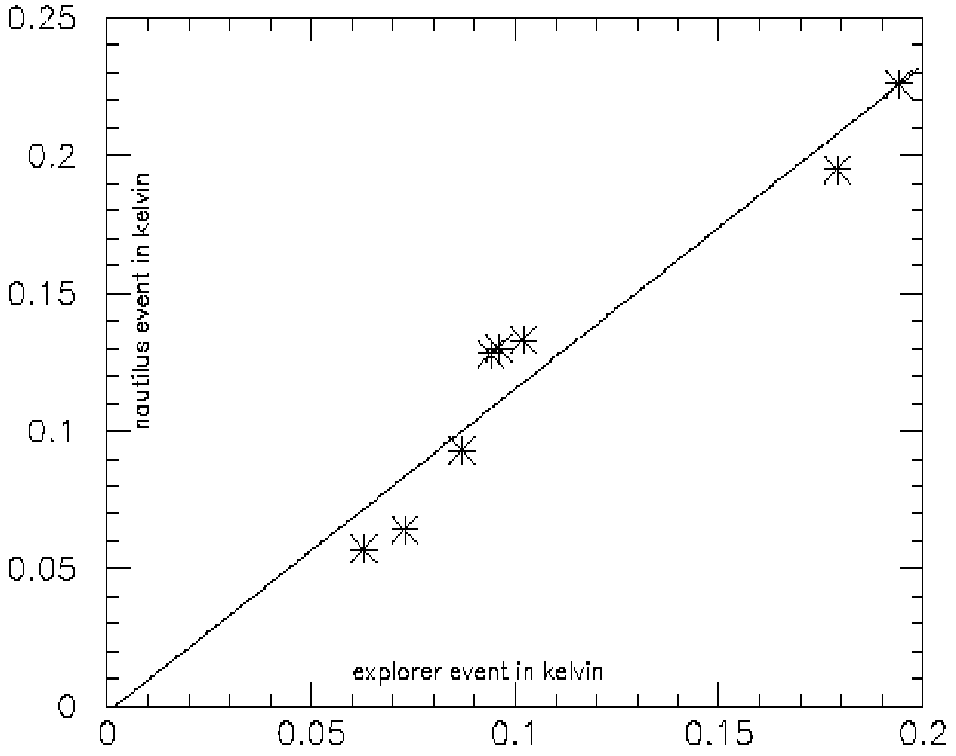
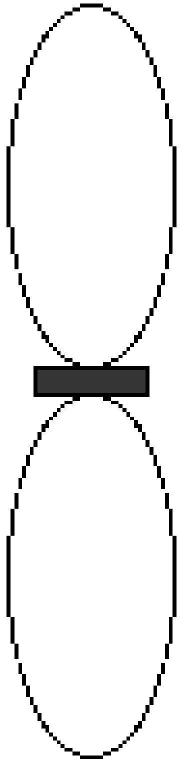
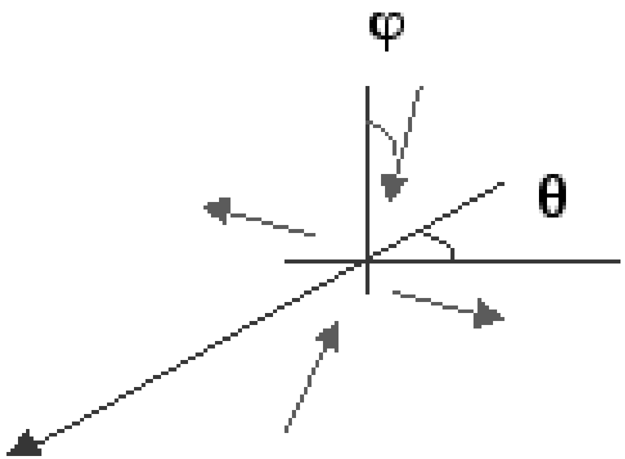


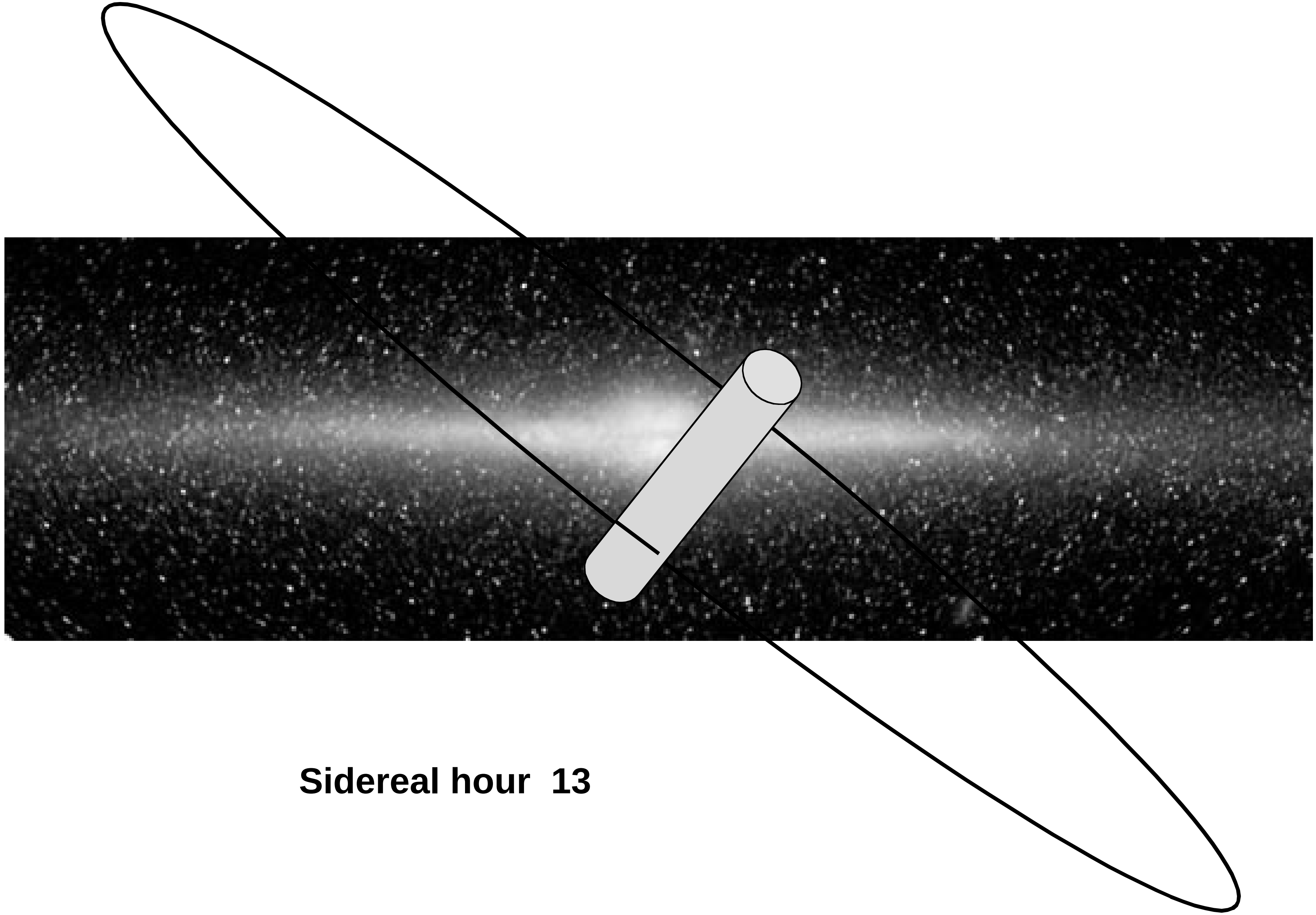
Fig. 8: Correlation between the event energies of NAUTILUS with those of EXPLORER for the eight coincidences occurred in the sidereal hour interval 3 to 5, in time periods $\geq 1\ hour$. The correlation coefficient is 0.96. No energy filter was applied.

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

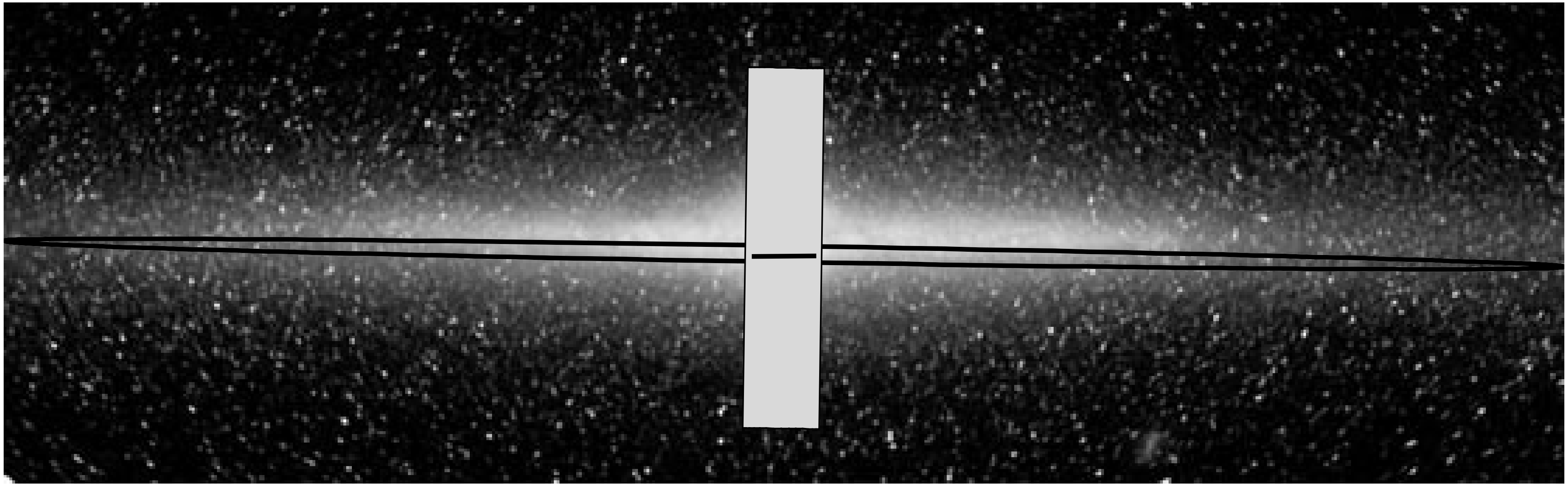
$$\sigma_c = \frac{8}{\pi}\frac{G}{c^3} M v_s^2 \left[\sin^4(\theta)\cos^2(2\varphi)\right]$$





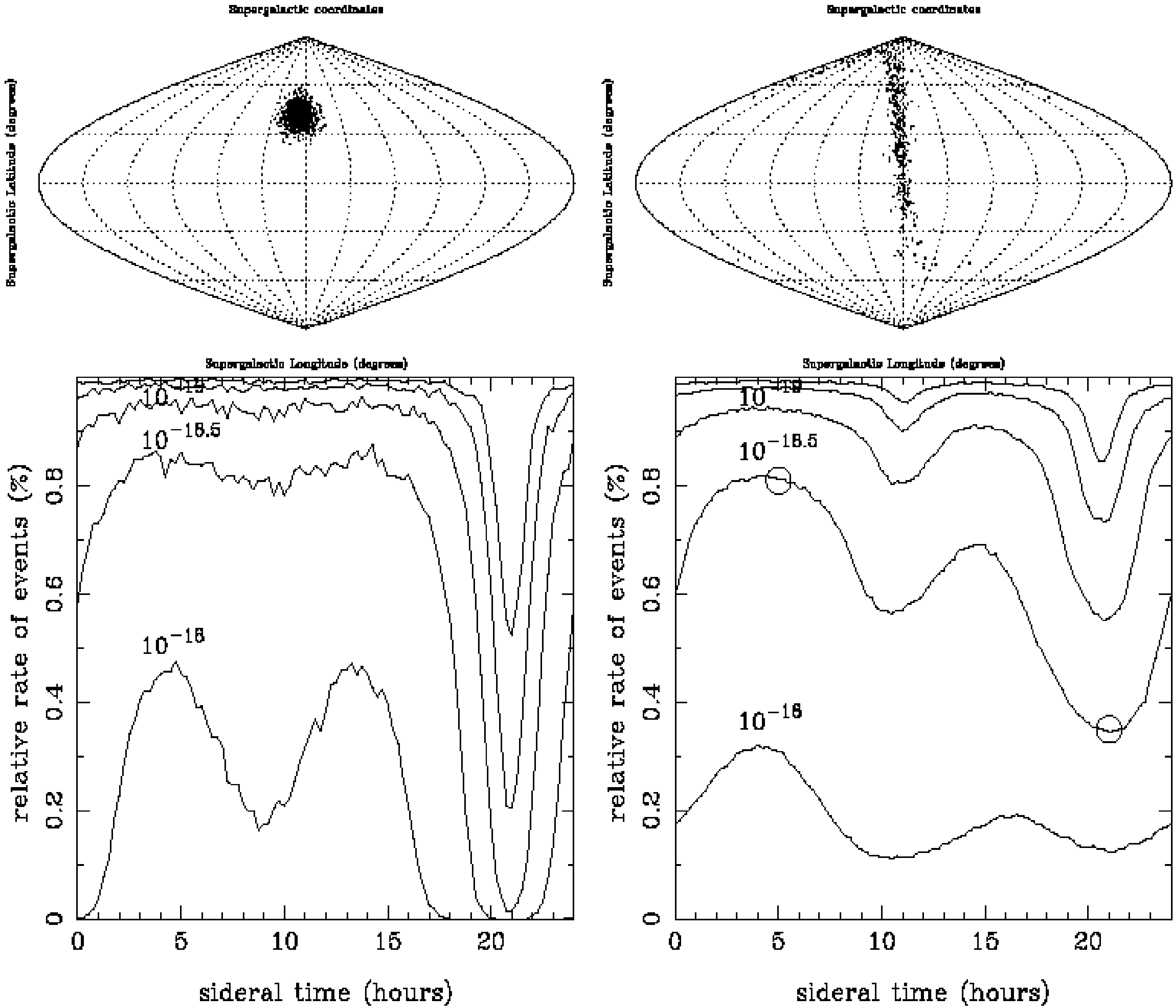


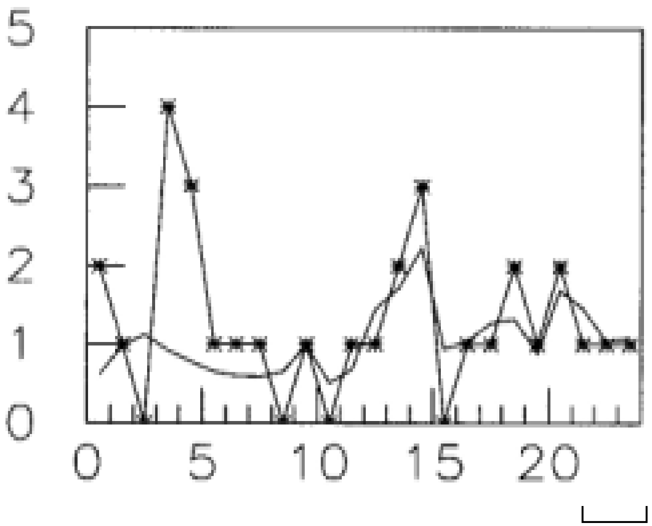
Sidereal hour 13

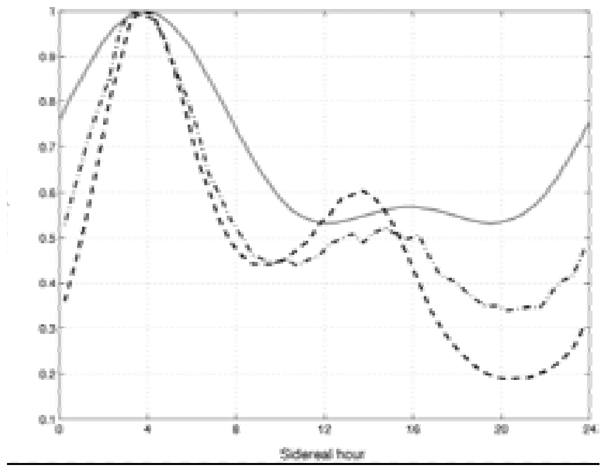


Sidereal hour 4.2

G. Paturel, Yu.V. Barishev *Astro-ph/0211604v1, A&A in press*



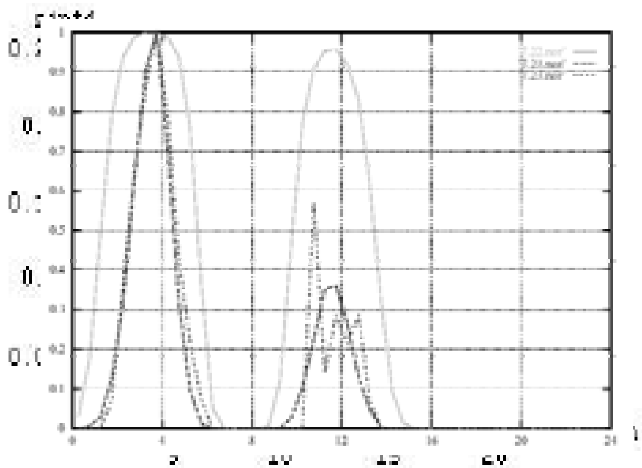


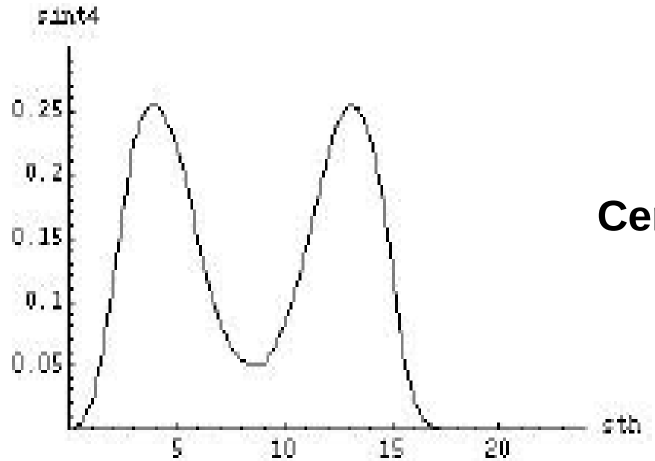


Average Cross sec. On the disc

Visible mass 10-18
0.5 10-18

Center
10-18
0.5 10-8
polarized





Center 10-18

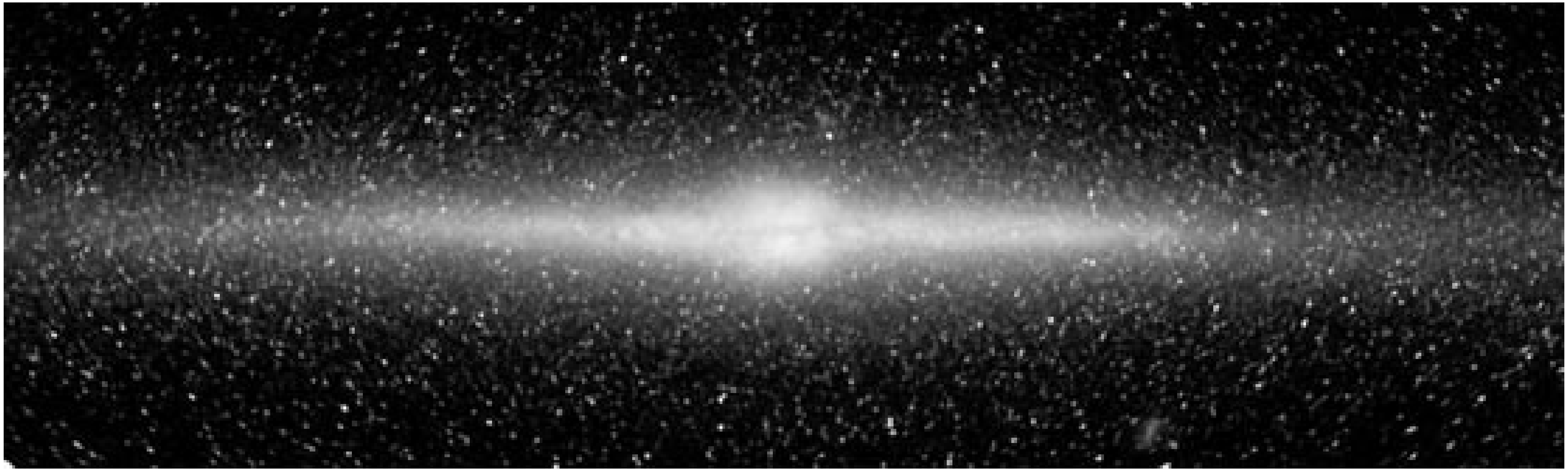
Analysis based on Bayesian statistics in preparation

Indication:

- Hundreds events/year
- $E_s \sim 100$ mK; $h_{1ms} \sim 2 \times 10^{-18}$; $M_{gw} \sim 0.004\ M_o$
- From galactic disc

Question:

the amplitudes and rate of the ROG candidate events are compatible with upper limits on GW strengths based on our knowledge of the astrophysical structure of the Galaxy and on theoretical beliefs about the physical laws governing gravitational radiation?



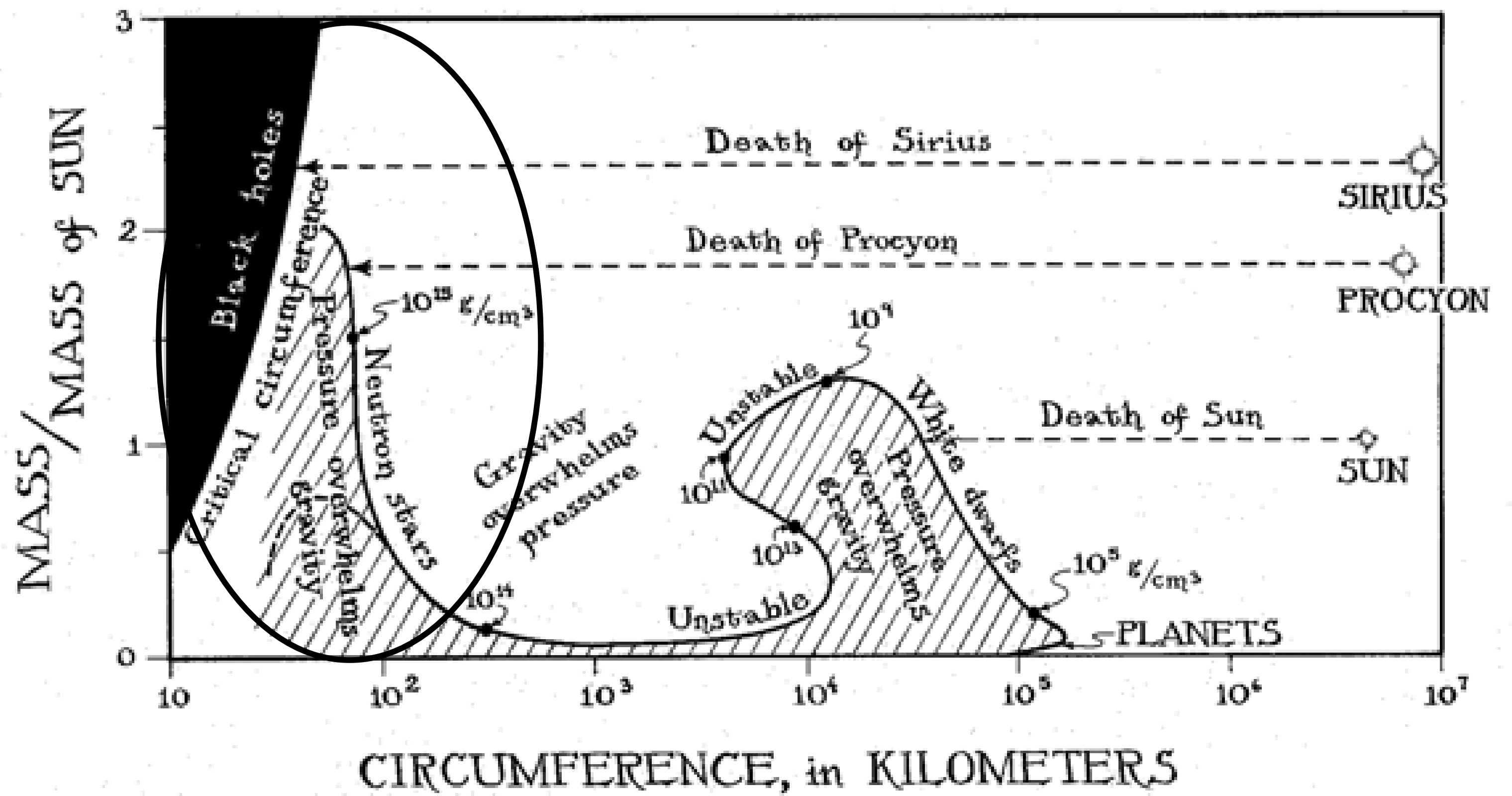
About 1 solar mass per year converted in GW

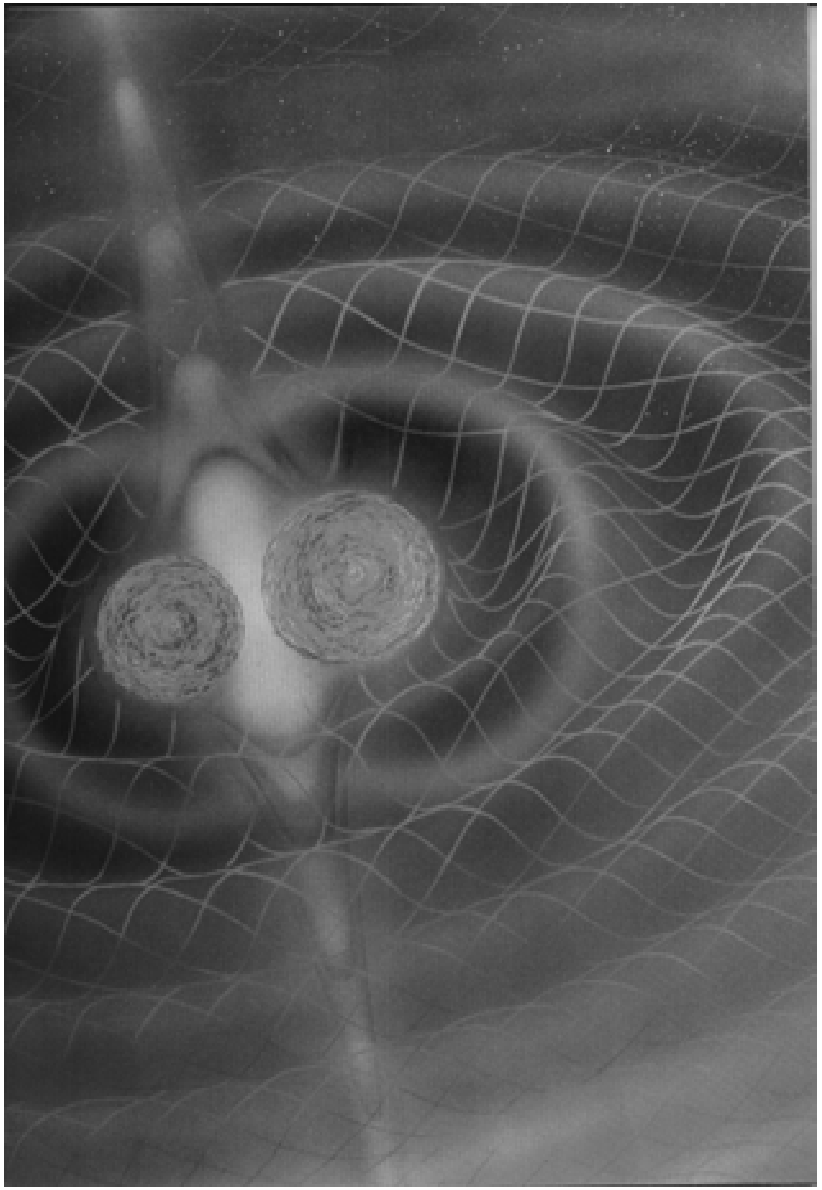
In 10^{10} y, about 10^{10} solar masses ~ few % of the mass of the Galaxy

Frequency emitted by a dynamic system of density ρ :
kHz frequencies correspond to nuclear densities

$$f \sim \sqrt{G\rho}$$

Sources: compact objects
pulsars, stellar gravitational collapse, last orbits of an inspiraling neutron star or black hole binary system, its merging, and its final ringdown.
Bar detectors can reveal unique features of matter at **extreme densities** and **strong gravitational fields**





$< E_S >$ ~ 100 mK ; $<r>$ ~ 10 kpc

Possible source:
inspiral and coalescence of double compact objects

$$E_s \propto M_c^{5/3} r^{-2}$$

$$M_c \equiv (m_1 m_2)^{3/5} (m_1 + m_2)^{-1/5}$$

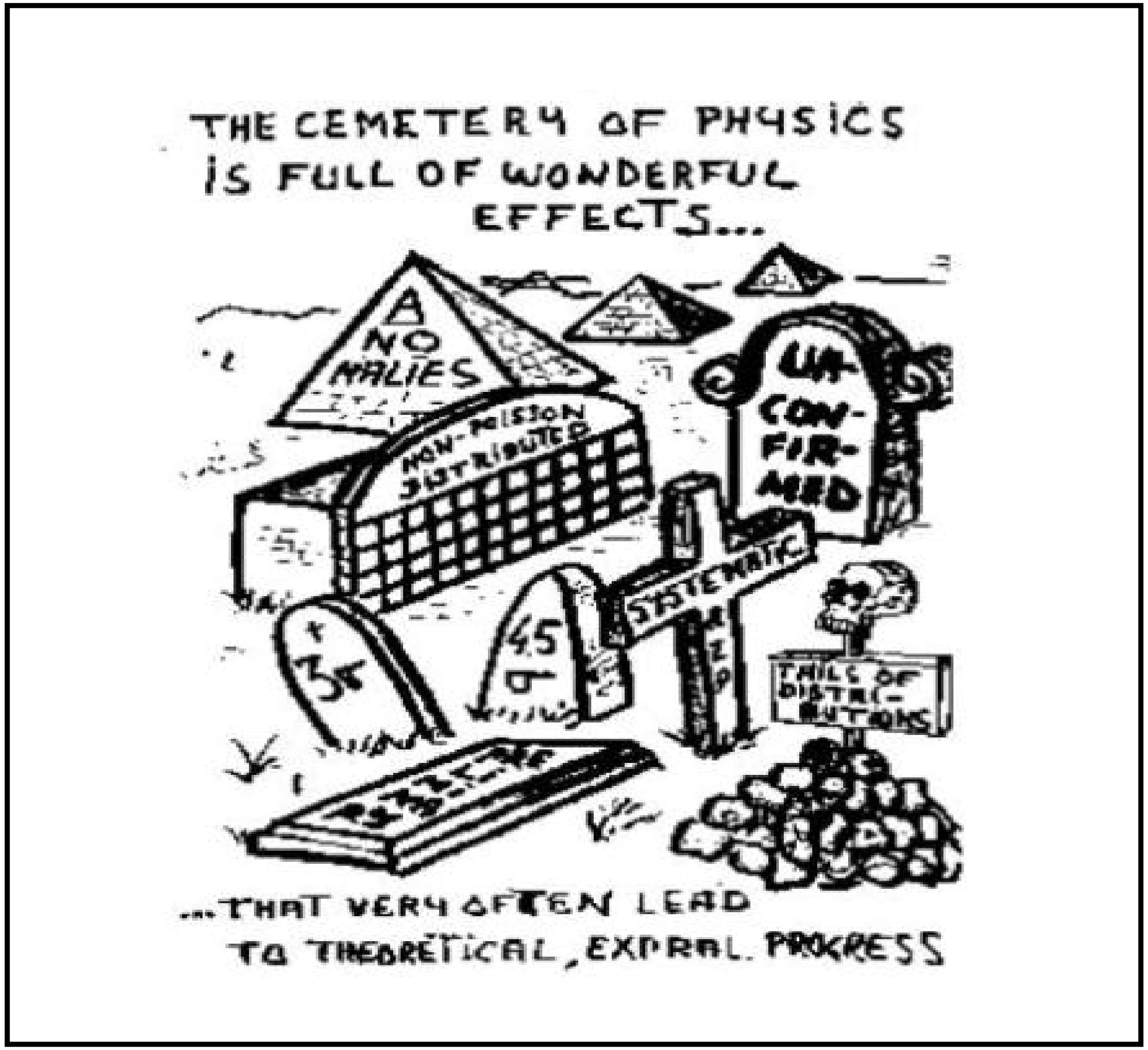
$$\Rightarrow M_c \approx 1 M_o$$

Is there an enormous number of compact objects of solar mass size in the Galaxy ?

The abundance of compact objects in our Galaxy is largely unknown because they emit little radiation unless they happen to be accreting material from a companion star, or, for NS, if they happen to emit pulsar radiation in our direction.

Gravitational microlensing surveys have the potential to detect completely dark object, and for most microlensing events, the mass can be estimated (crudely) based upon the observed Einstein ring diameter crossing time.

A recent analysis of the microlensing events by the MACHO and MPS Collaborations [Bennet et al. 2002] show that several of these events may be explained as microlensing by BHs of mass > 1Mo and suggests that a BH mass fraction as high as ~10% of the Milky Way's stellar mass might be possible.
These results appear to indicate that most stellar mass BHs do not reside in X-ray binary systems where they are most easily observed.



Experimental obituary
(courtesy of A. De Rujula)

Conclusions

• The sensitivity of modern resonant-mass detectors is such that the strongest plausible astrophysical sources could be detected.

• The reported indications by the ROG group cross the benchmark of “nihil obstat” upper limit on the strength of the wave, being within the reported experimental upper limits and do not overturning cherished beliefs about the structure of the Galaxy or the physical laws governing gravitational radiation.

• More data are needed for any further consideration.