Resonant Mass Detectors

- IGEC
- Principles
- The detectors
- Transducers + Matching
- Spuria
- Results : Stochastic
  CW
  Bursts
- The future
  Bandwidth + sensitivity
  Spheres
  Cross Corr with LIGWDs.

Resonant Mass Gravitational Wave Detectors

International Gravitational Events Collaboration

4K Al bar	ALLEGRO	LSU	Hamilton/Johnson
2K Al bar	EXPLORER	Rome group	Coccia/Pizzella
4K Nb bar	NIOBE	UWA	Blair/Tobar/Ivanov
100mK Al bar	NAUTILUS	Rome Group	Coccia/Pizzella
100mK Al bar	AURIGA	INFN Legnaro	Cerdonio

Spherical Detector Development

Rome Group	Coccia
Leiden	Frossati
Sao Paulo	Aguiar

HISTORY OF RESONANT BAR DETECTORS

1969	Weber announces coincidences. T_n ~ 100K.
1970-71	Weber type detectors at Munich, Glasgow, Paris, IBM[redacted], BTL, Moscow, Rome. T_n ~ 10K.
1970	Cryogenic bar projects begin at LSU, Stanford, Rome, Perth (1976).
1972	Improved Weber bars give null results.
1973-76	Understanding of the Quantum Limit.
1976	Bar project begins: Perth.
1980	First cryogenic bar operates: Stanford.
1980's	Transducers, antenna patterns, isolators, filters.
1988-90	Coincidence experiments, T_n ~ 6mK.
1990's	Ultra cryogenic bars, Nautilus, Auriga.
1995	Massive spherical detectors proposed. Leiden, Rome, Sao Paulo.
1997	Three antennas in operation.
1998	Deep cross correlation demonstrations: Nautilus - Explorer.
1997-99	Multiple antenna coincidence analysis.
1998	Deep pulsar search, 47 Tuc.
1999	New low limits to burst signals.
2000's	Advanced transducer systems.
	Prototype spheres. Massive (International?) Spherical Antenna.

IGEC

International Gravitational Event Collaboration

03 Nov. 1999
02:41:44 UTC

The Agreement
The full text signed at CERN

About the IGEC Agreement
Motivations

Members
Information and Links

Detectors' Status
Present on/off status of each detector

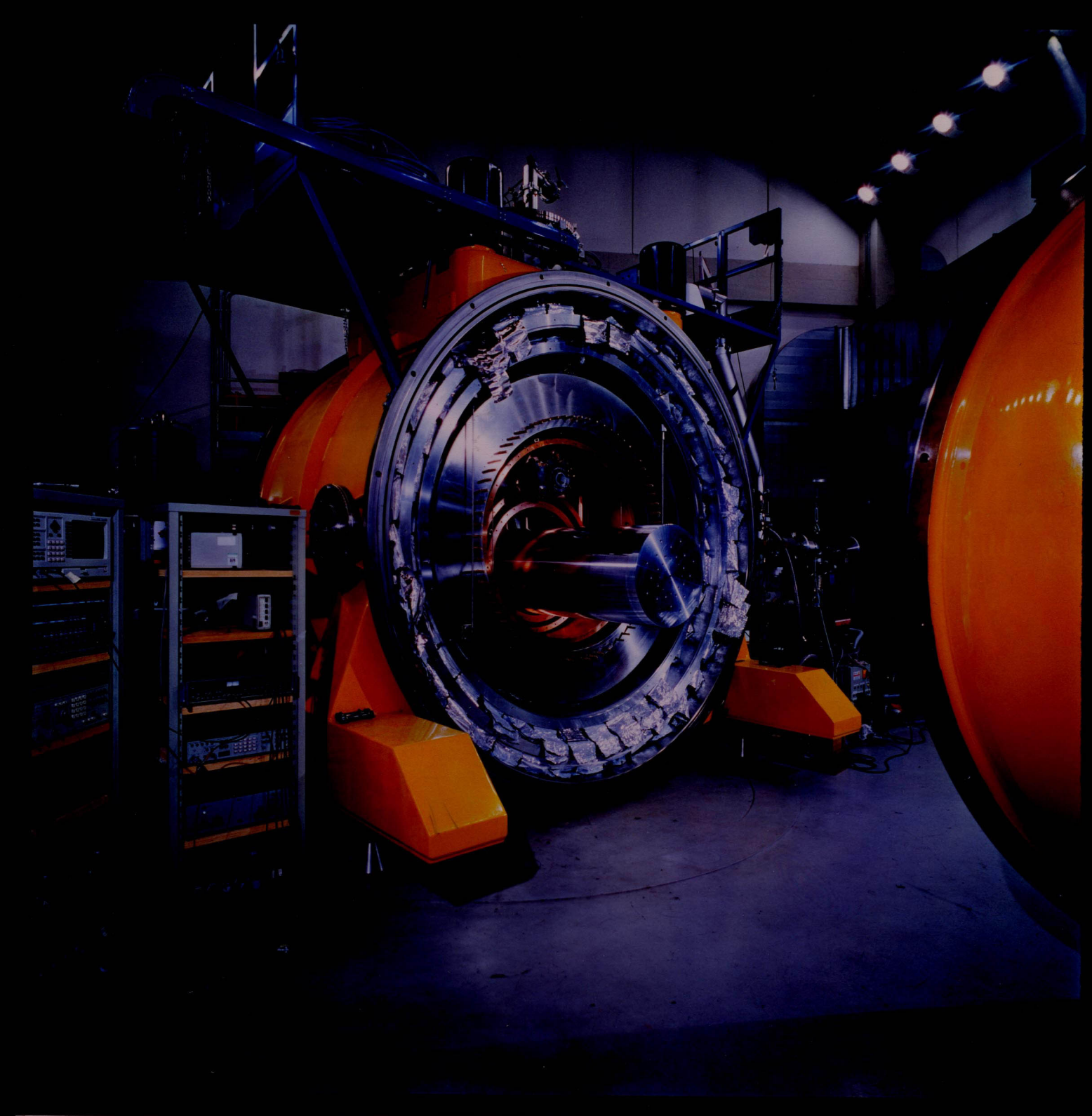

Internal Documents
Password protected area

Latest News

- 22-Apr-1999 - **New Nautilus and Explorer data available**
  The Rome group has posted data for the June-December 1998 period, IGEC compliant
  [Read more...]
- 04-Mar-1999 - **Added section of detector's on/off status**
  A new section has been added to the IGEC Web site, to monitor and log each detector's operating status. Please **read inside** this news for more details and how to operate the section.
  [Read more...]
- 03-Mar-1999 - **NIOBE data is now IGEC compliant**
  NIOBE has sent again data of 1997, now complying with the IGEC protocol, in particular START/STOP are shown.
  [Read more...]

Read More News

These Pages are beeing designed by Vasco Crivelli-Visconti
Please contact me at vasco@speedit.com



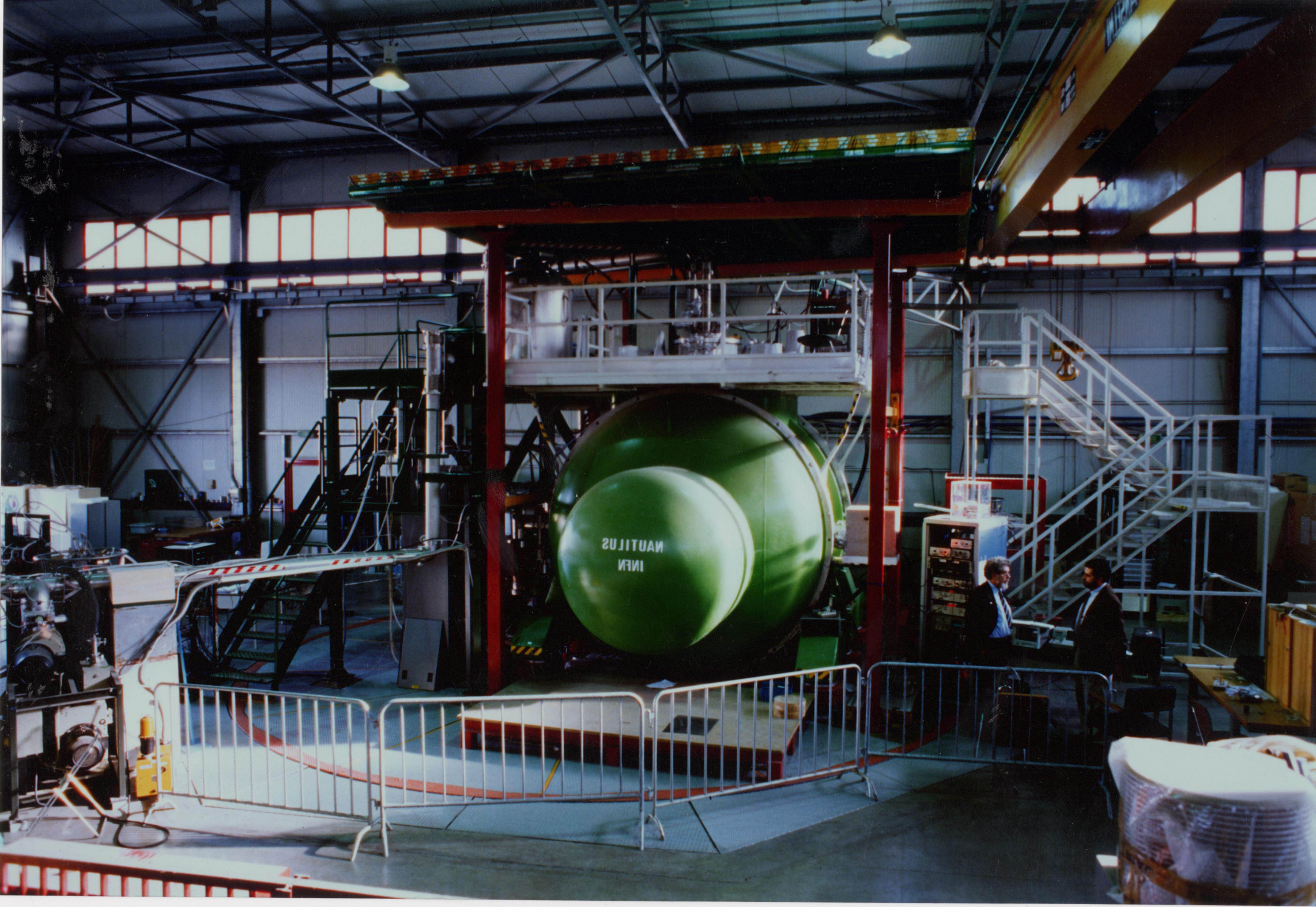
M= 2.3 tons (Al 5056) L= 3m T= 100 mK Q= 10^7

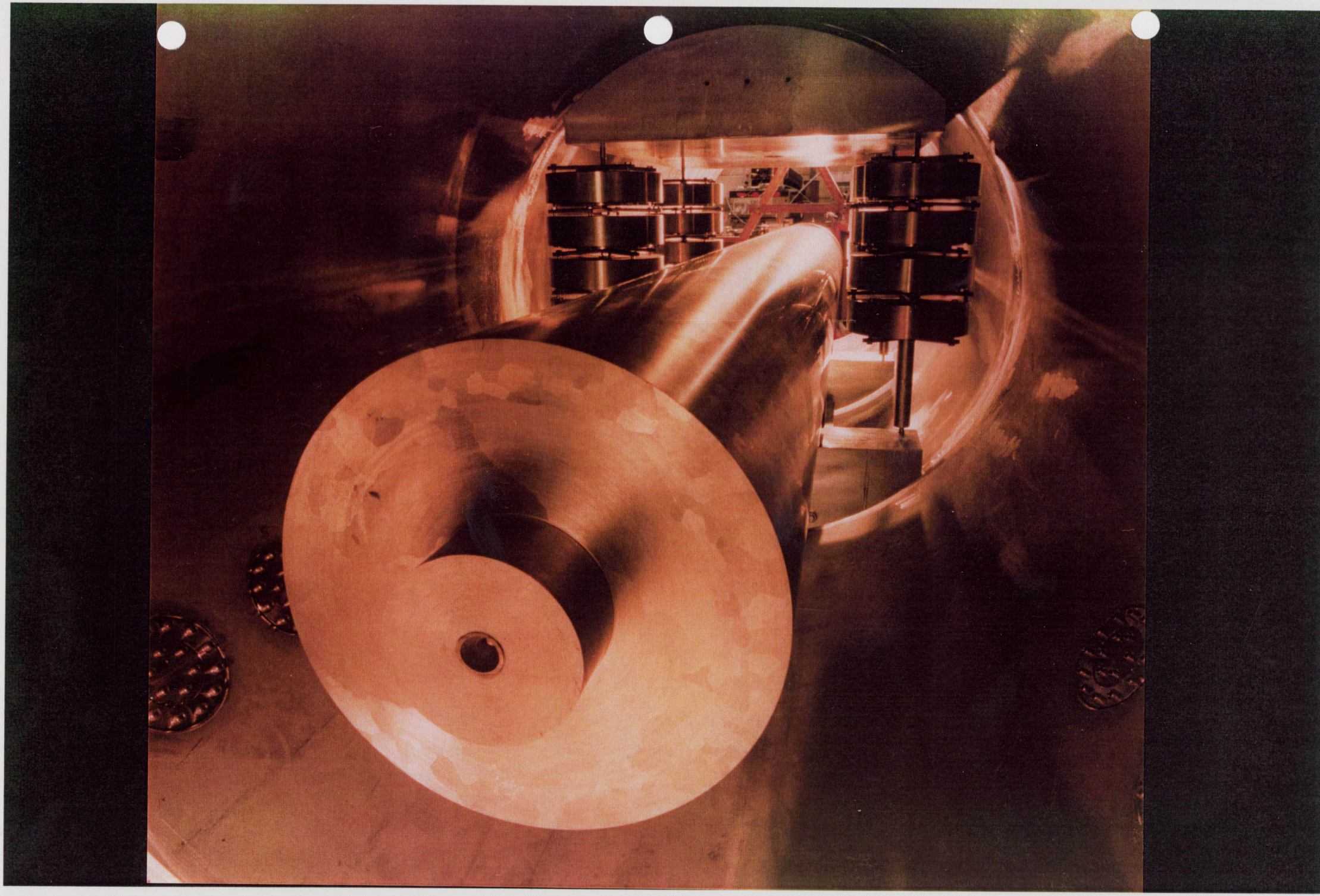
$\nu \simeq 900$ Hz

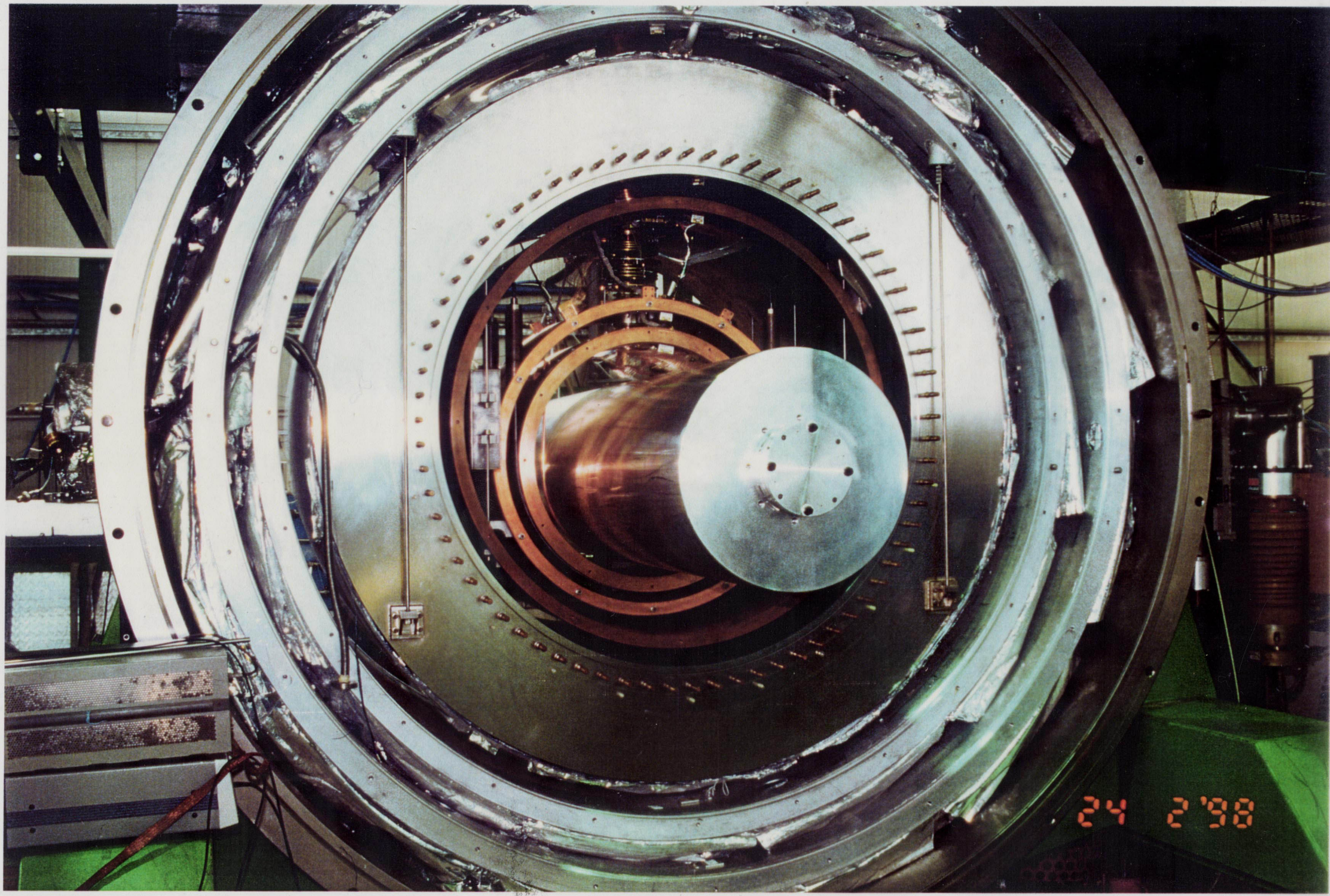
$\Delta\nu = 1$ Hz

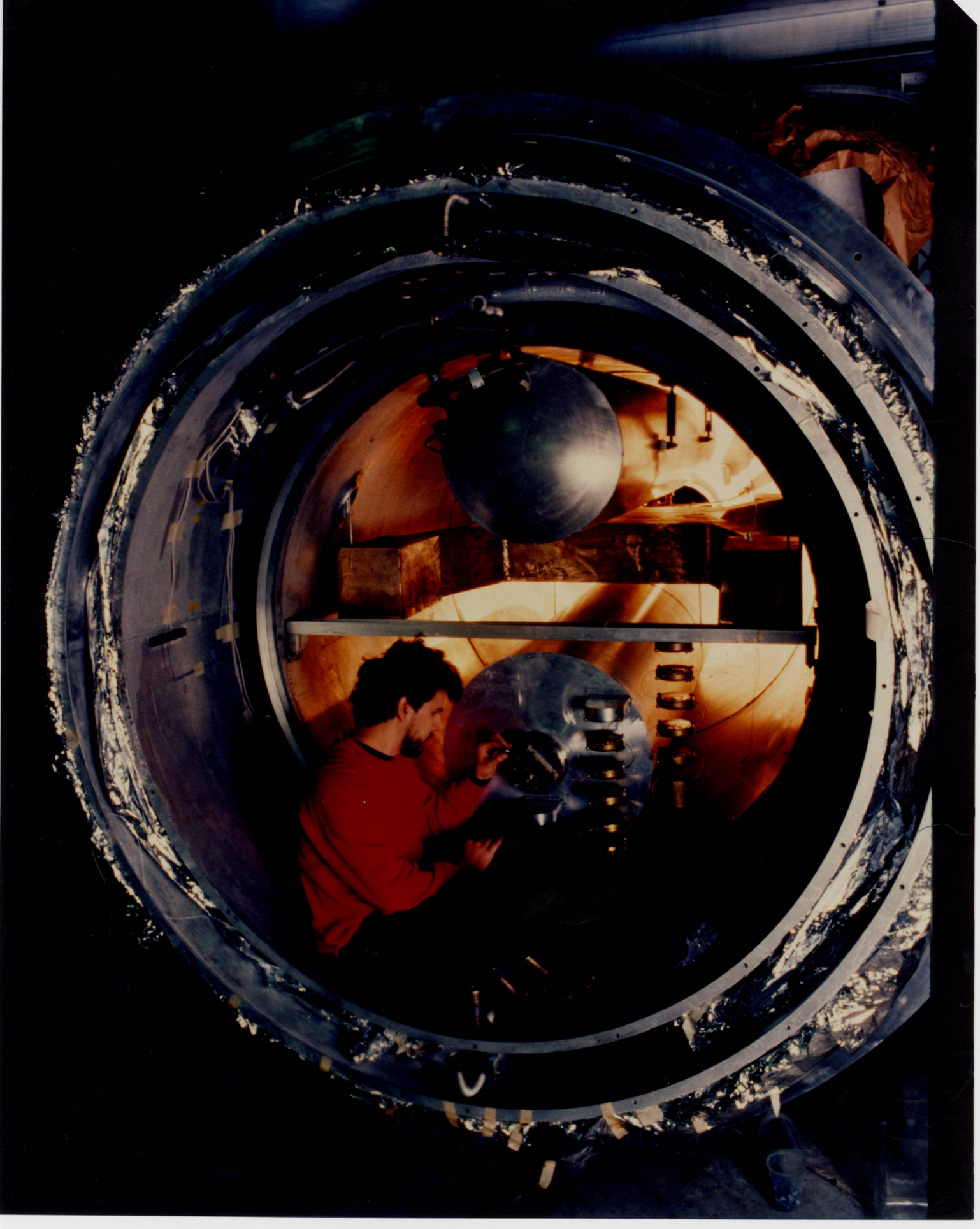
$h \simeq 4 \times 10^{-19}$

AURIGA @ INFN LEGNARO NATL. LAB.
(Padua, Italy)


NAUTILUS
INFN




24 2'98



Resonant Mass Detector

- Energy deposited by burst $F(\omega)$

$$\text{Energy} \sim F(\omega) \cdot \frac{G}{c^3} \cdot M v_s^2 \cdot f(\theta, \phi)$$

$F(\omega)$: incoming wave; M: antenna; $f(\theta, \phi)$: orientation

- Thermal noise

$$x^2(\omega) \sim \frac{kT}{2 Q M v_s^2 \ell^2 \omega}$$

T: low temperature; Q: low loss; M: large Mass

- Transducer : series noise
  back actron noise

Quantum limit $\sim \hbar\omega$

- Optimum filter

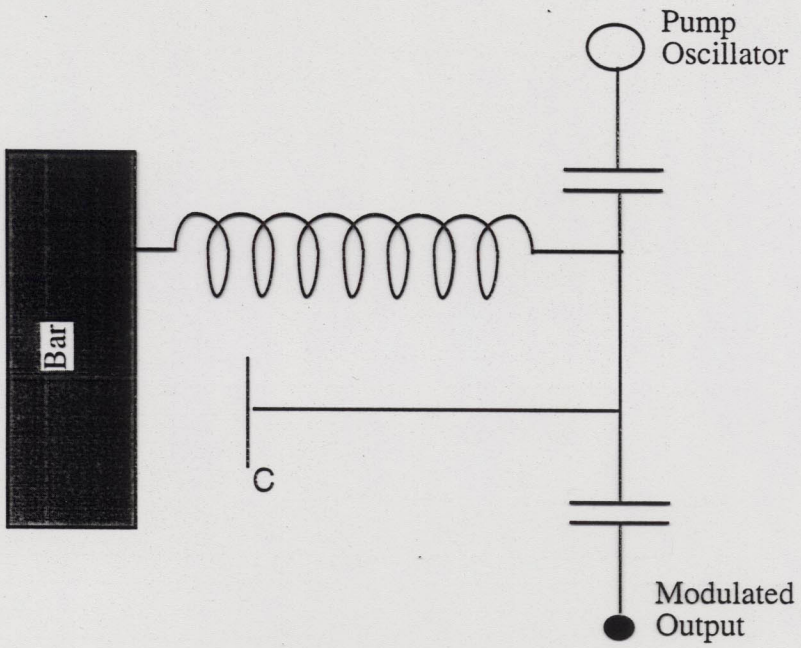
Units

$\tilde{h}$: strain spectral density strain / $\sqrt{Hz}$

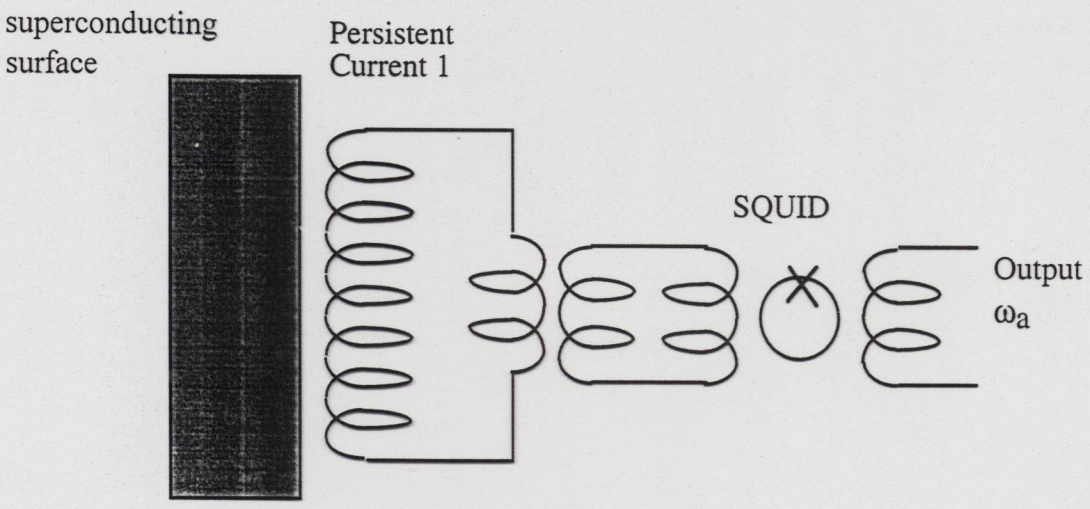
h : strain amplitude of burst $\frac{\Delta L}{L}$

T_n : noise temperature
effective temperature
for burst detection.

$h(T_n)$: $h \sim$ few $\times 10^{-19} \sqrt{\frac{T_n}{1mk}}$

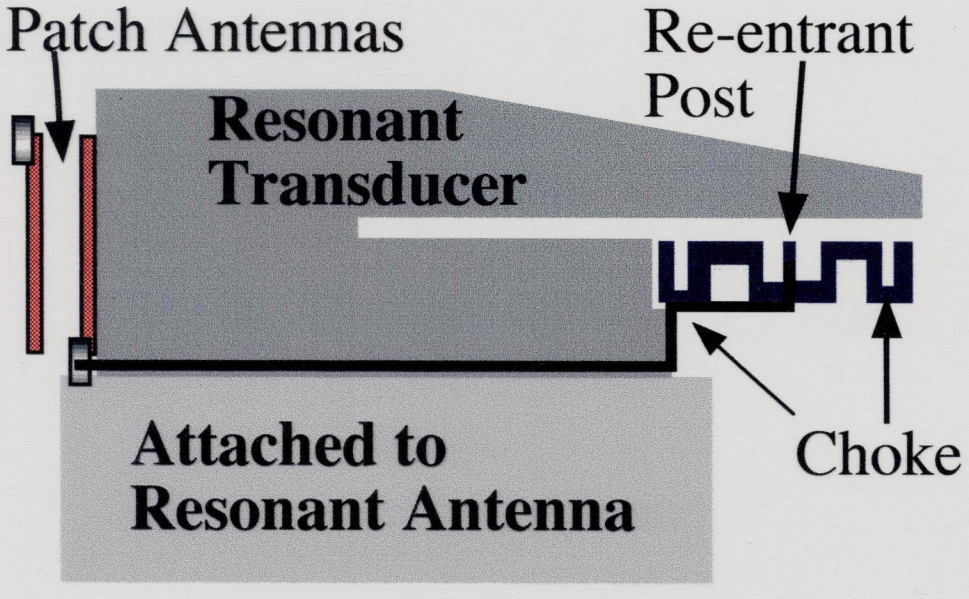

Pump
Oscillator
Bar
C
Modulated
Output

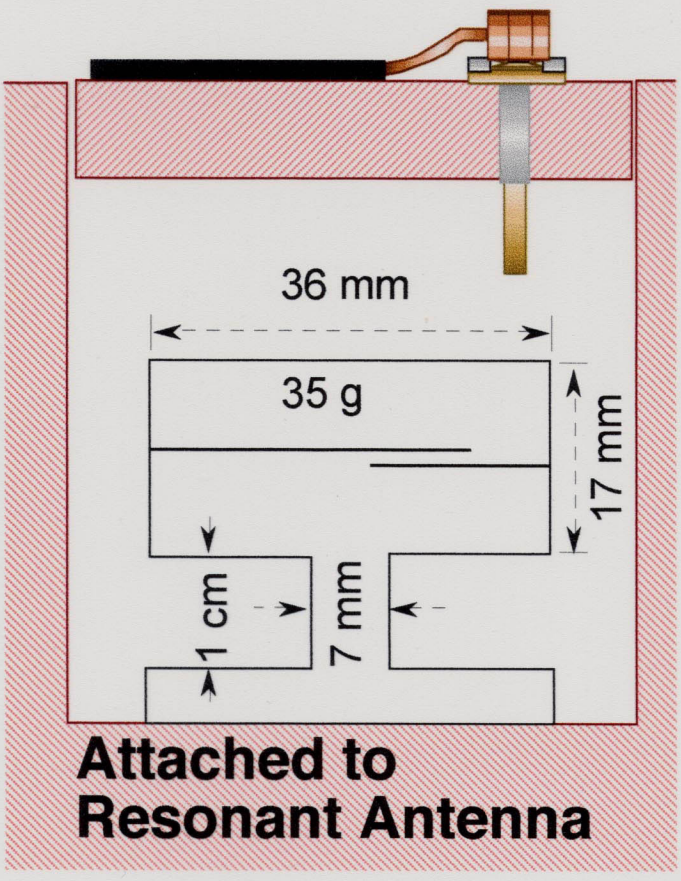
(a)

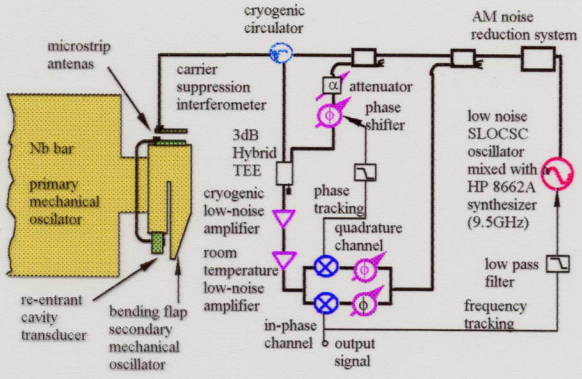

superconducting
surface
Persistent
Current 1
SQUID
Output
ω_a

(b)

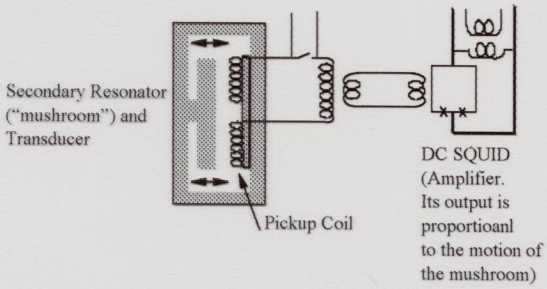
Parametric Transducers



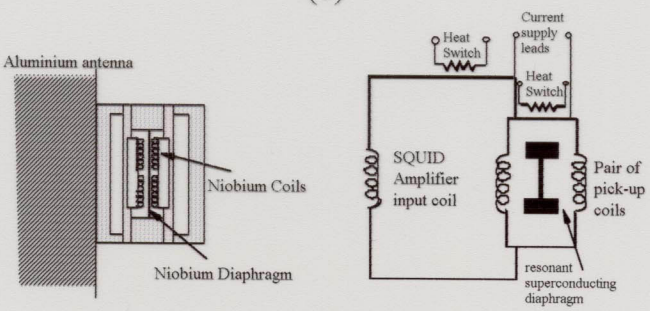




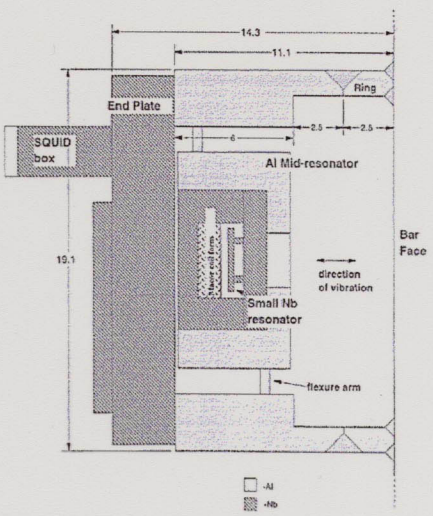
(a)



(b)

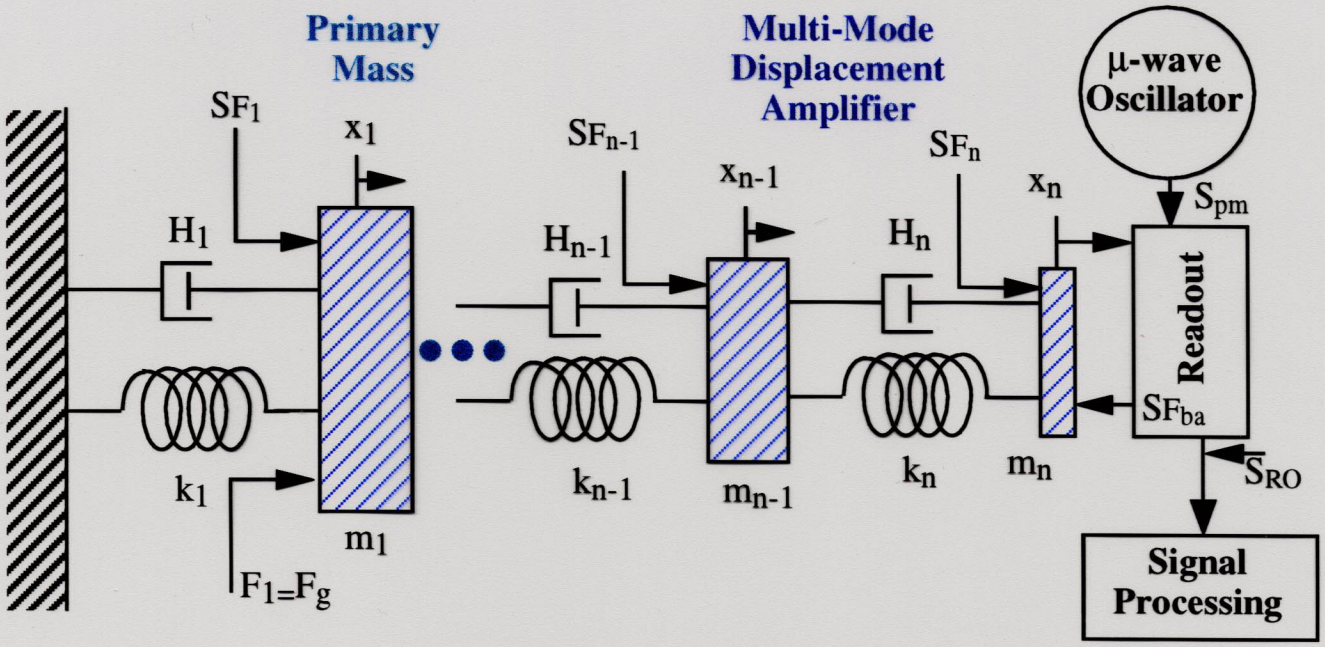


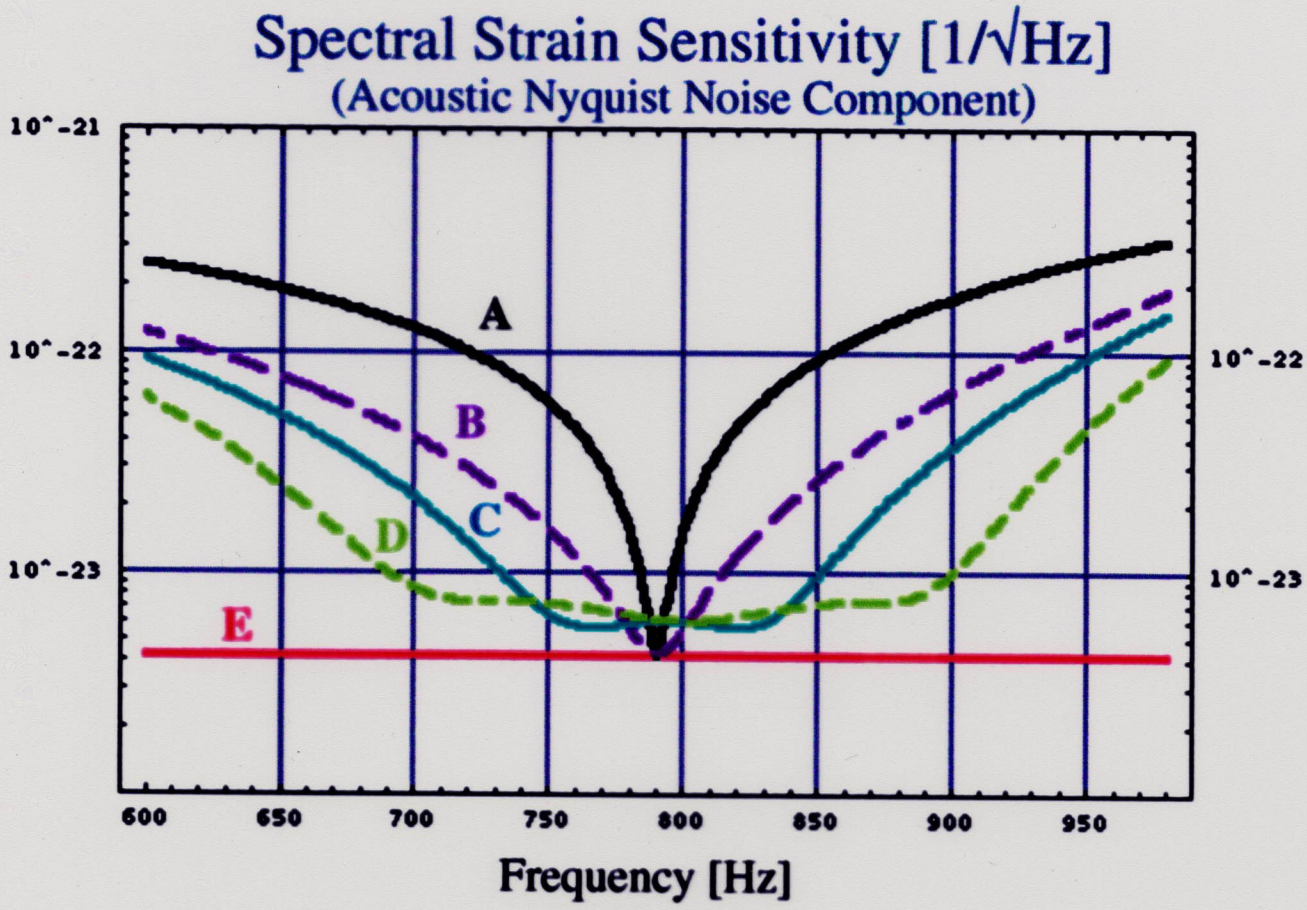
(c)



(d)

Bar antenna transducer readout systems. a) Bending flap; b)mushroom; c)diaphragm; d) multi-mode transducer.


Primary Mass
Multi-Mode Displacement Amplifier
μ-wave Oscillator
SF1
x1
H1
k1
m1
F1=Fg
SFn-1
xn-1
Hn-1
kn-1
mn-1
SFn
xn
Hn
kn
mn
Spm
Readout
SFba
SRO
Signal Processing



GRAIL DETECTOR

Model Parameters

$T = 15$ mK

$Q_{CuAl} = 1.6 \cdot 10^7$

$Q_{Spph} = 10^9$

$\sqrt{Sx} = 0$ m/√Hz

E: Sphere Acoustic Nyquist Noise

A: 2-Mode

$m_1 = 42 \cdot 10^3$ kg

$m_2 = 0.035$ kg

B: 3-Mode

$m_1 = 42 \cdot 10^3$ kg

$m_2 = 38$ kg

$m_3 = 0.035$ kg

C: 4-Mode

$m_1 = 42 \cdot 10^3$ kg

$m_2 = 4.0 \cdot 10^2$ kg

$m_3 = 3.7$ kg

$m_4 = 0.035$ kg

D: 5-Mode

$m_1 = 42 \cdot 10^3$ kg

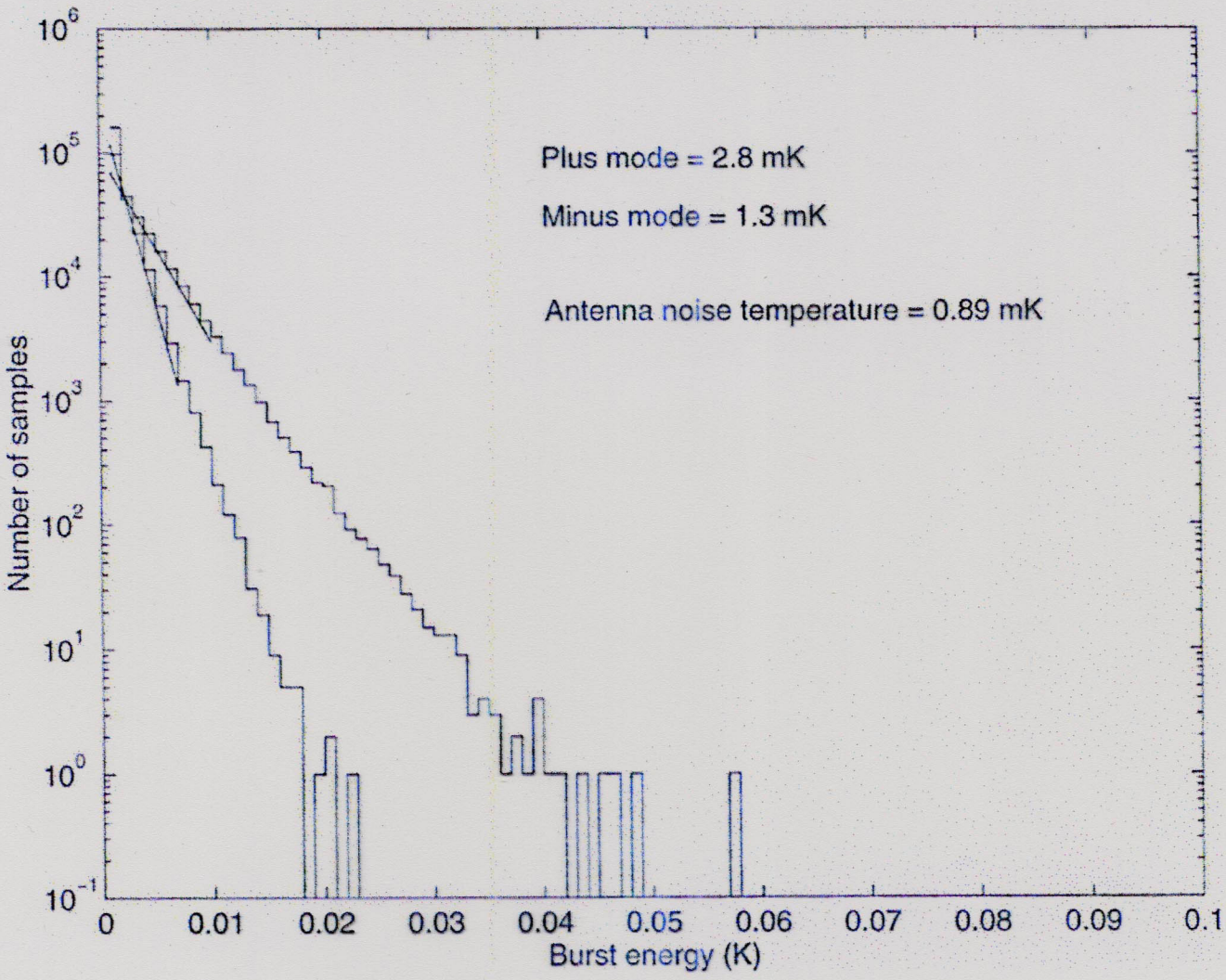
$m_2 = 1.3 \cdot 10^3$ kg

$m_3 = 38$ kg

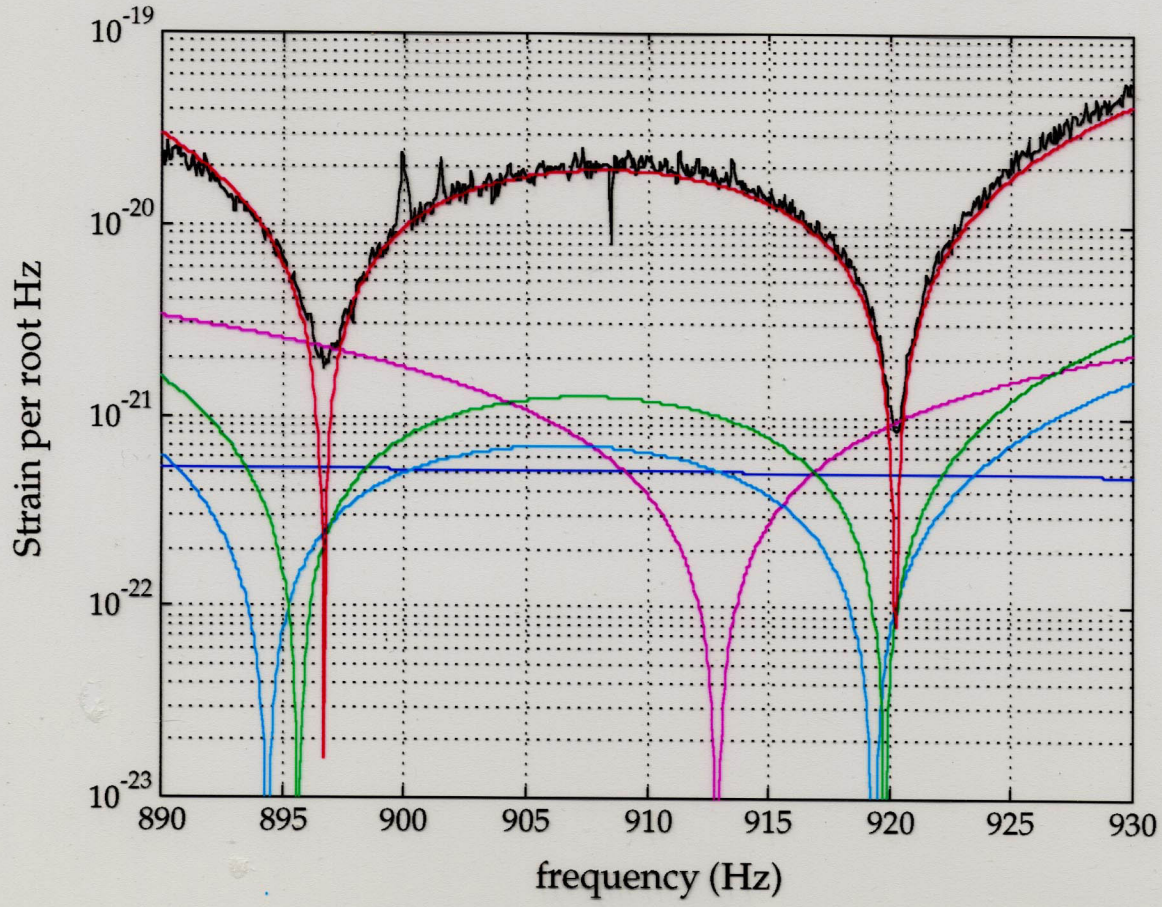
$m_4 = 1.2$ kg

$m_5 = 0.035$ kg

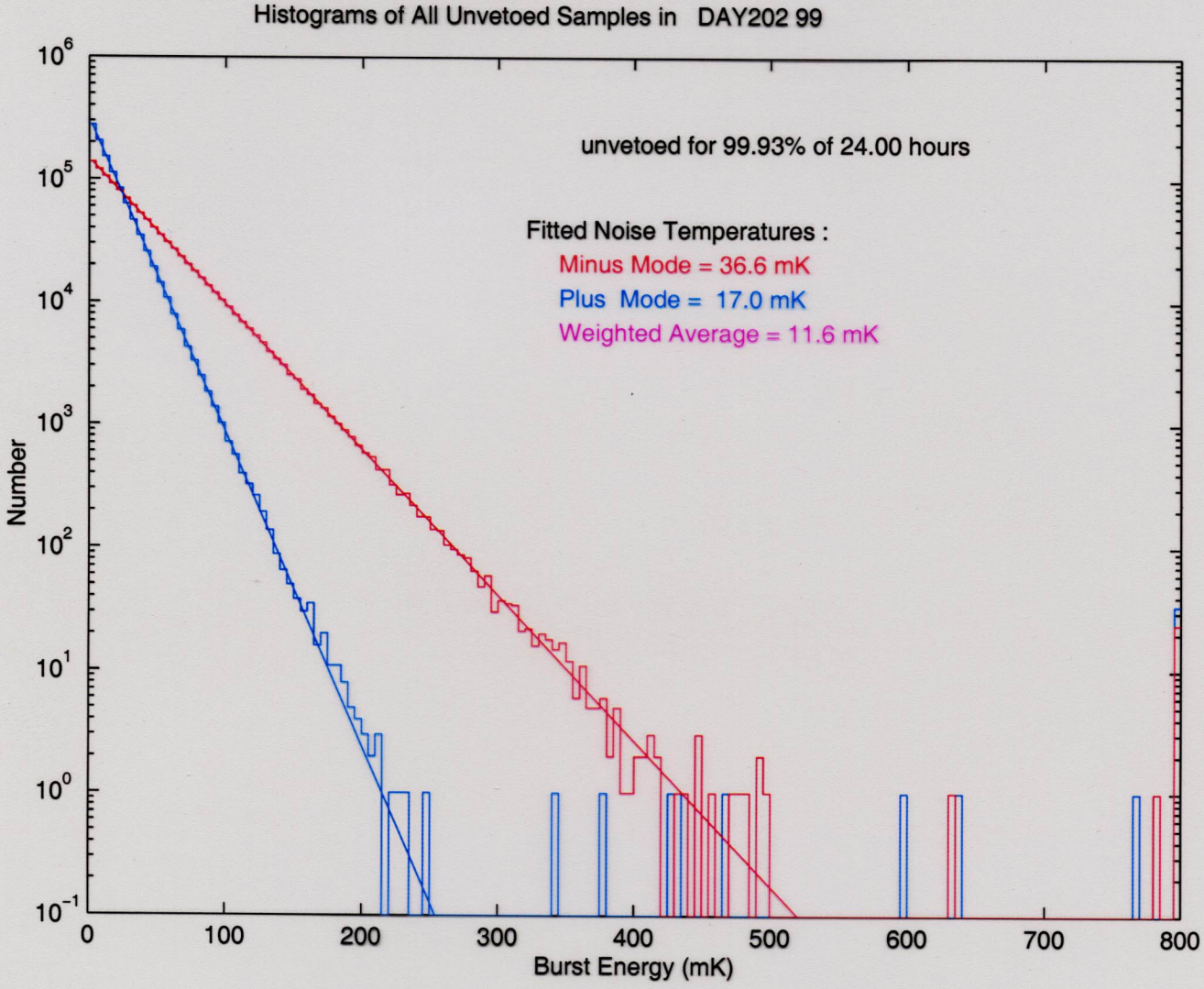
Dr. Michael Tobar
University of Western Australia

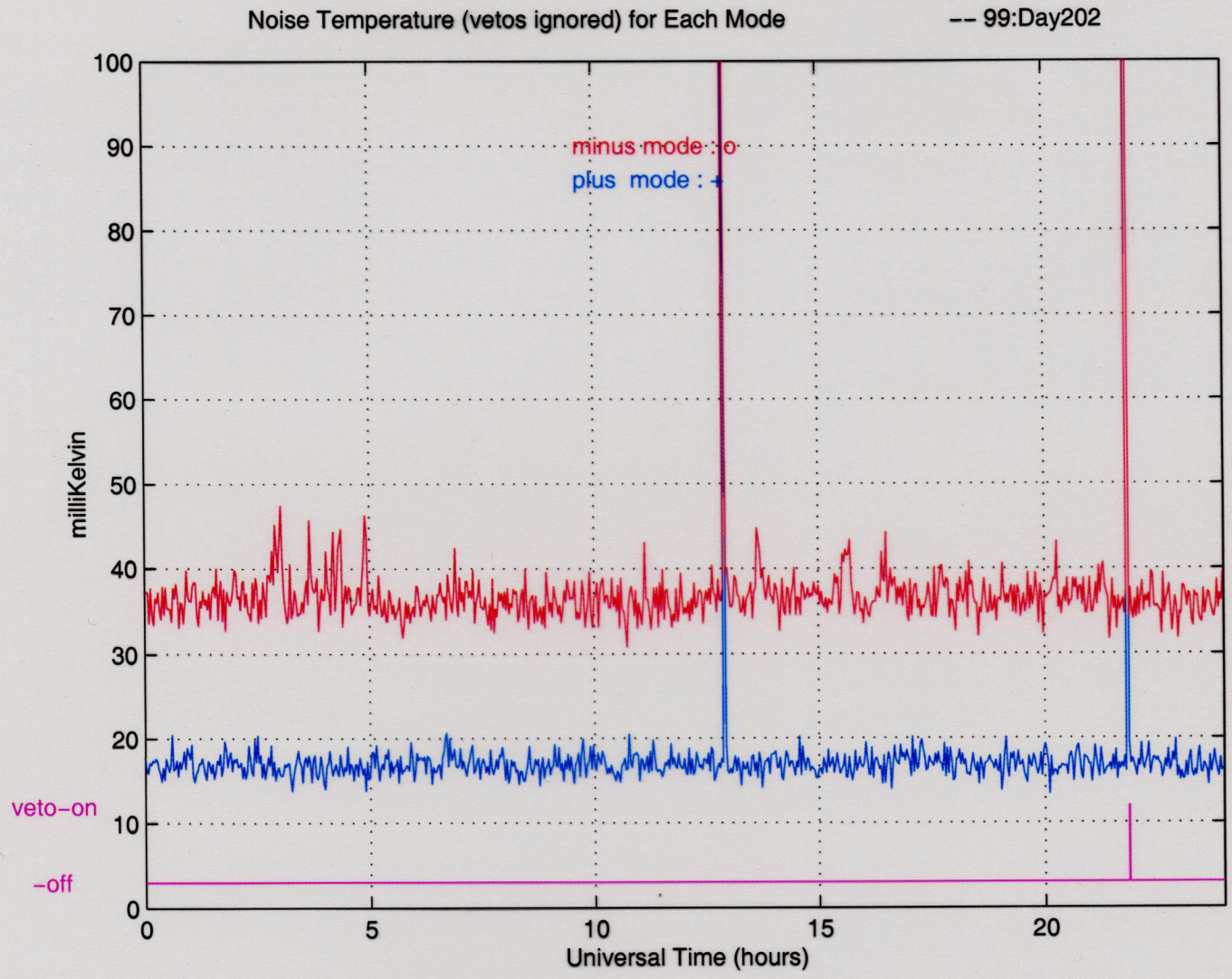

Plus mode = 2.8 mK
Minus mode = 1.3 mK
Antenna noise temperature = 0.89 mK
Number of samples
Burst energy (K)
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

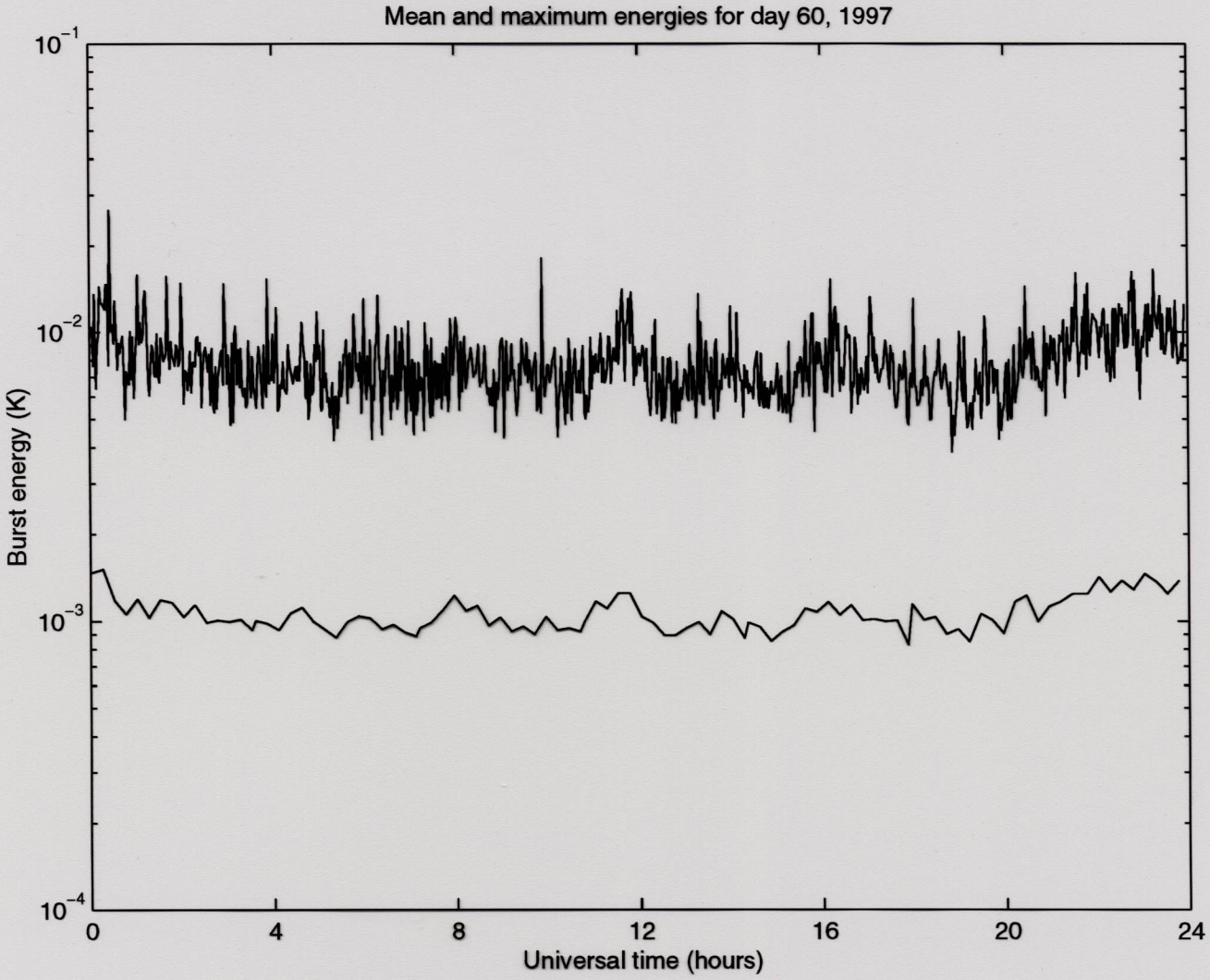
Measured Strain Noise Spectral Density of ALLEGRO



Measured strain noise spectral density of ALLEGRO and the various noise contributions which are predicted from the noise model of the detector.
— Measured total noise, — antenna brownian, — transducer brownian,
— transducer electrical loss, — SQUID white noise, — SQUID back action.


Histograms of All Unvetoed Samples in DAY202 99
unvetoed for 99.93% of 24.00 hours
Fitted Noise Temperatures :
Minus Mode = 36.6 mK
Plus Mode = 17.0 mK
Weighted Average = 11.6 mK
Number
Burst Energy (mK)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0
100
200
300
400
500
600
700
800


Noise Temperature (vetos ignored) for Each Mode
-- 99:Day202
minus mode : o
plus mode : +
milliKelvin
100
90
80
70
60
50
40
30
20
10
0
veto-on
-off
0
5
10
15
20
Universal Time (hours)


Mean and maximum energies for day 60, 1997
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Burst energy (K)
0
4
8
12
16
20
24
Universal time (hours)

Bars are

Well behaved

Well understood

Excellent Data

Major improvements underway

Teaching us how to cope with spuria

Nautilus Cosmic Rays

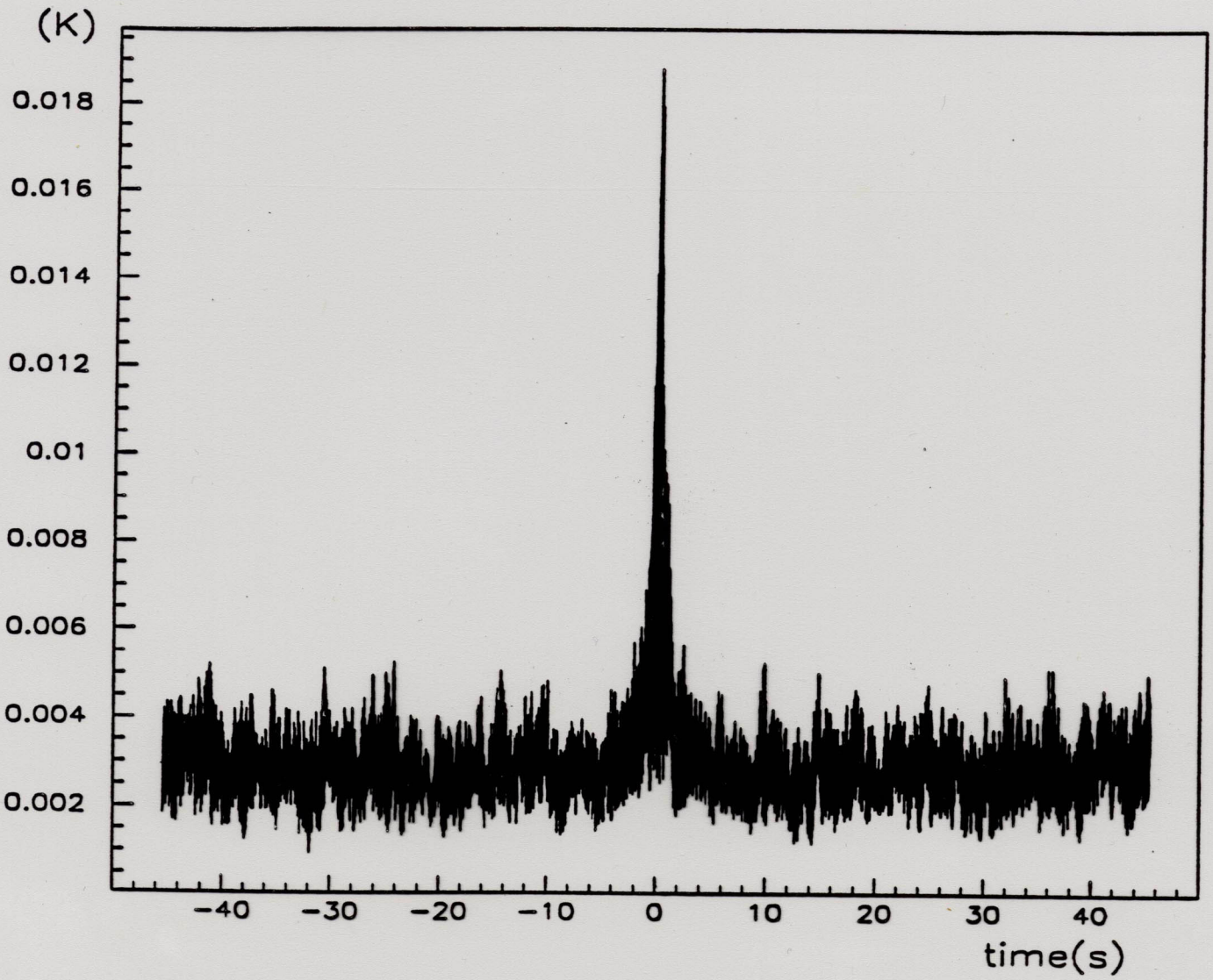
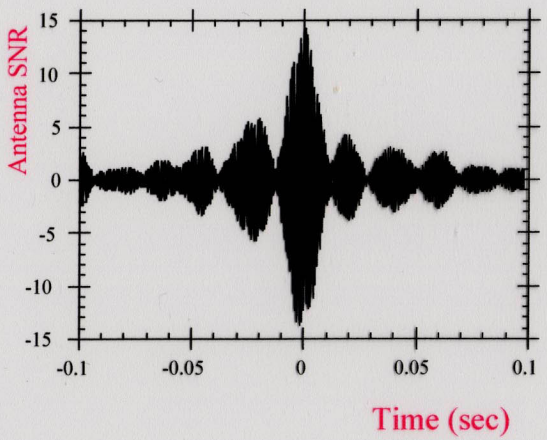


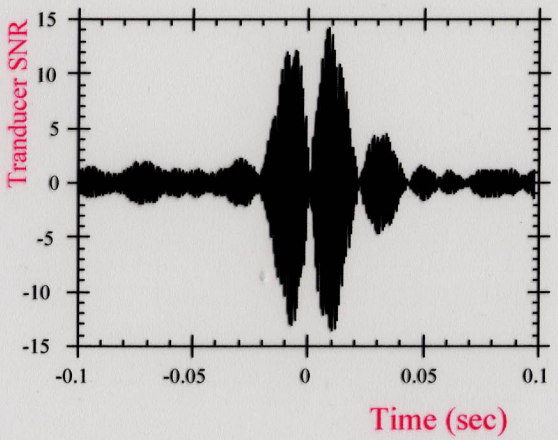
FIG. 2. The weighted average energy over 46 (for M=

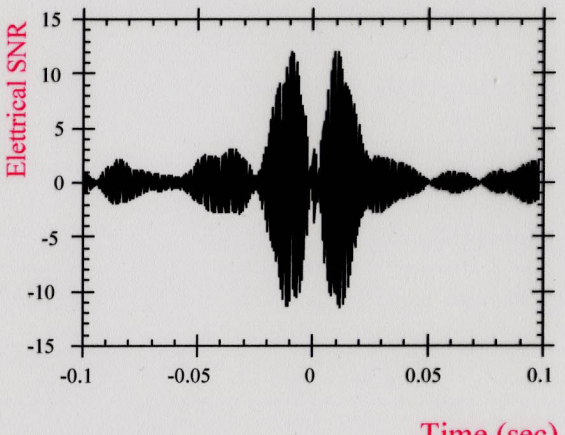
versus time. A large signal appears at the cosmic ray arri

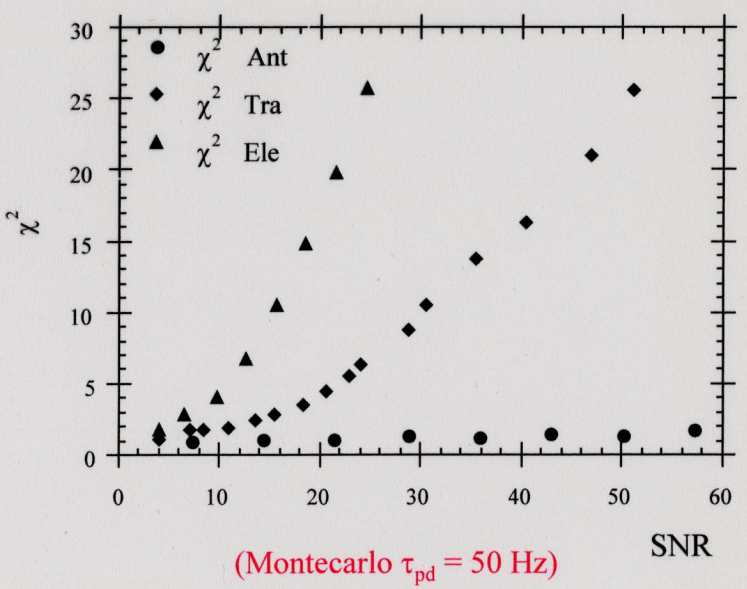
AURIGA $\chi 2$ Test : spuria rejection

[Nucl. Phys. B49, 104 (1996)]

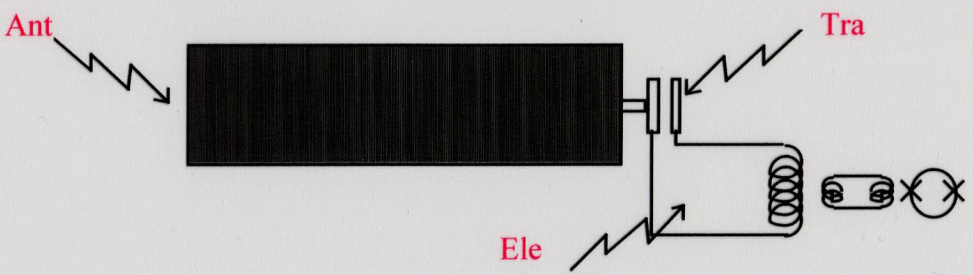








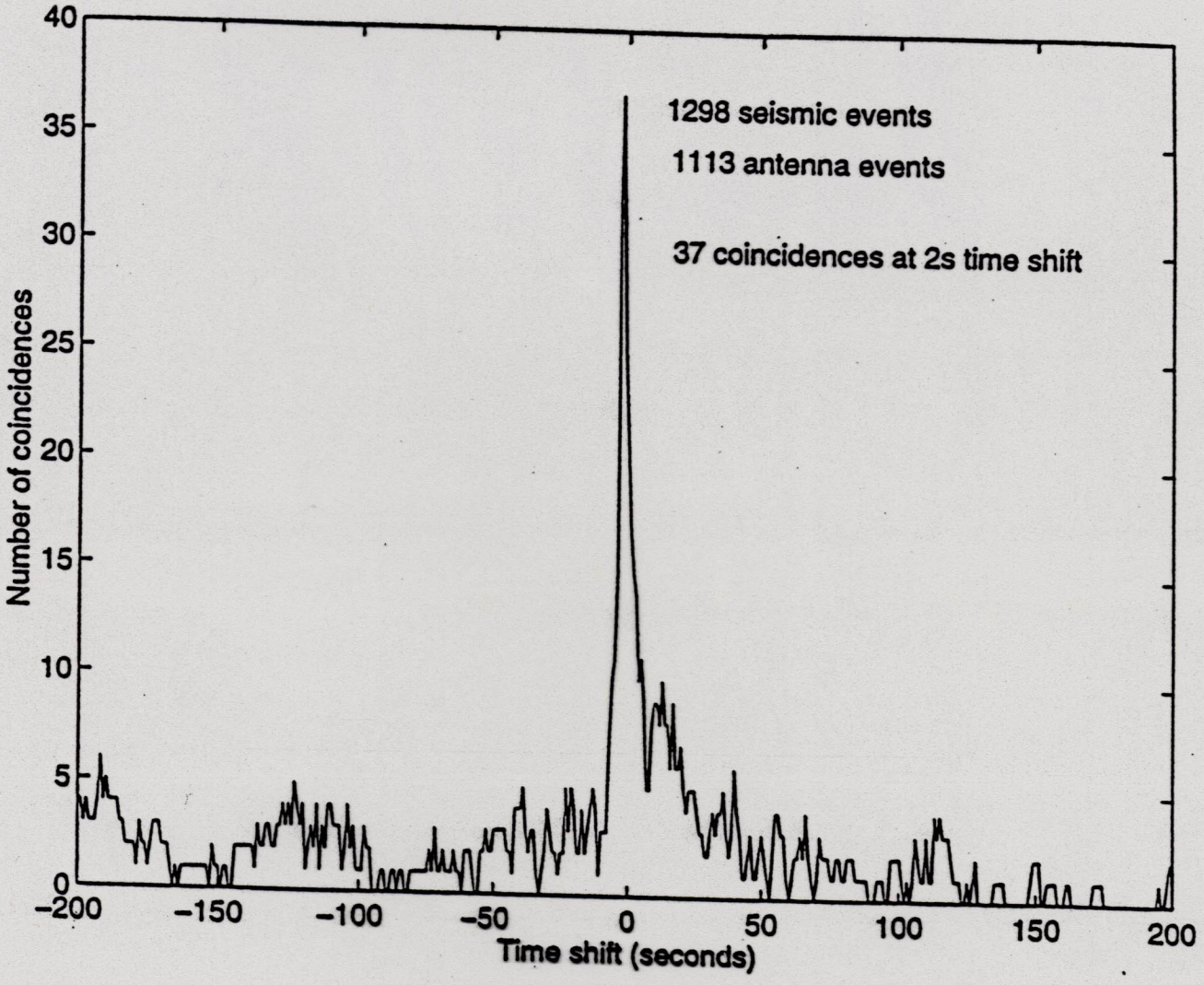
(Montecarlo τ_{pd} = 50 Hz)

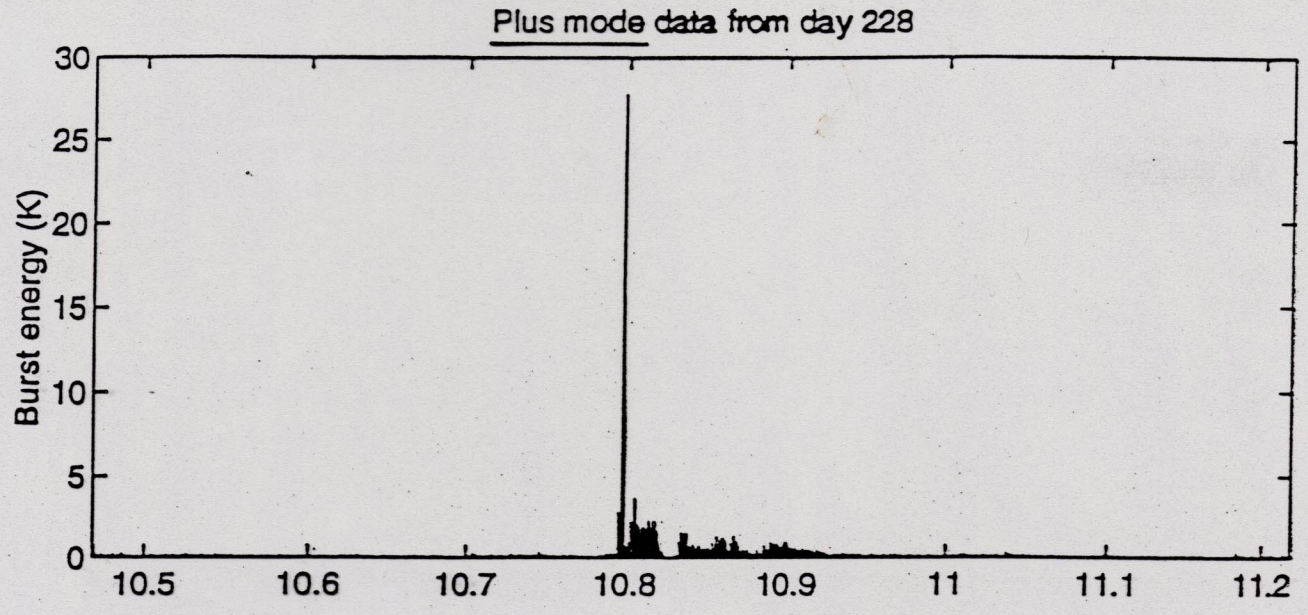


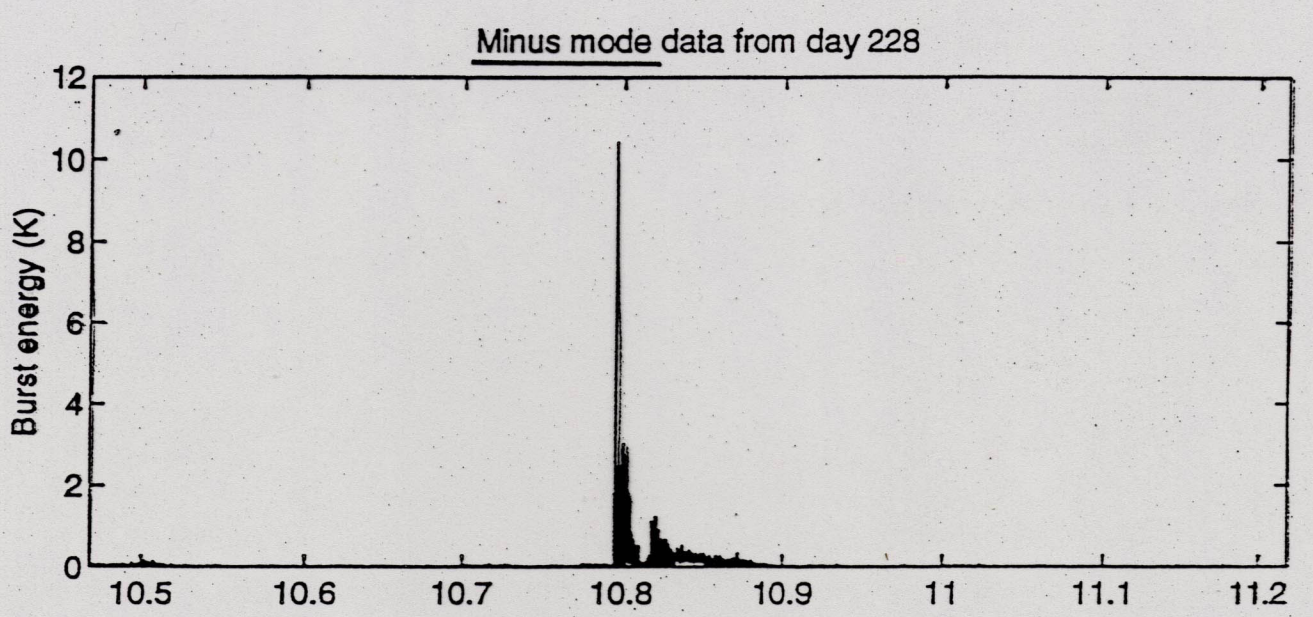
$$\langle \chi^2 \rangle = 1 + \lambda\, SNR^2$$

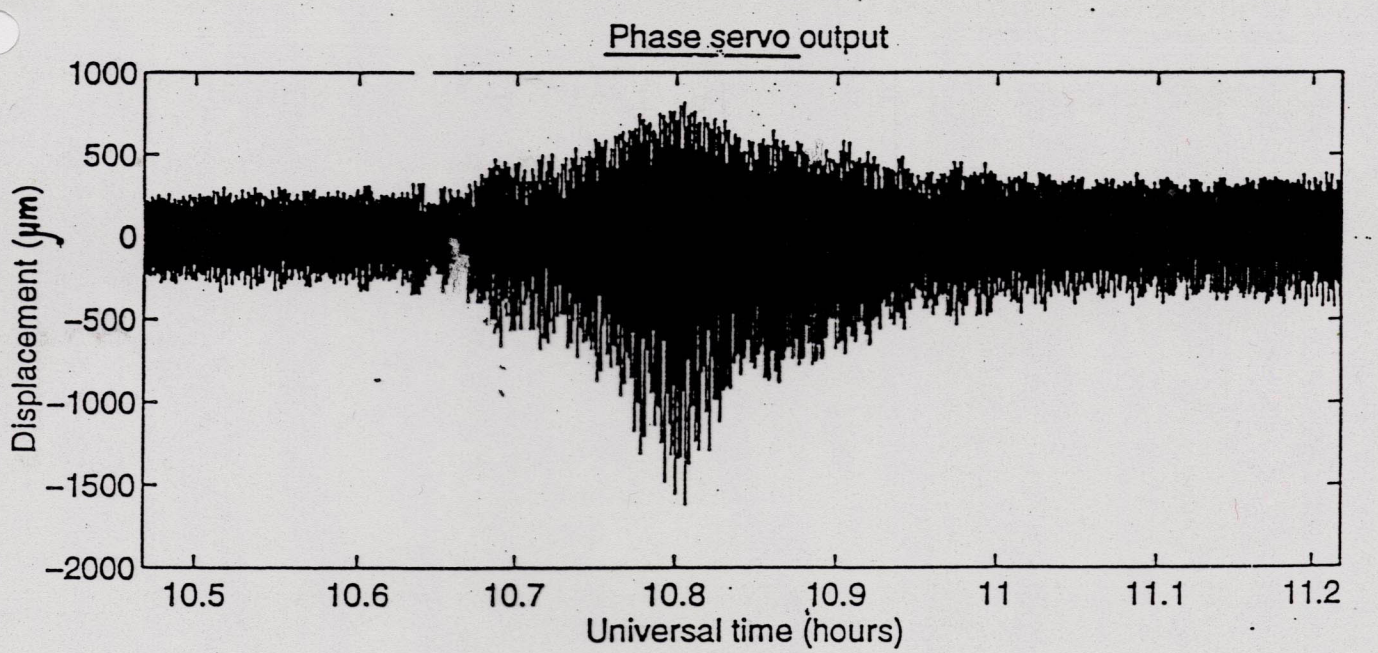
Test with a room temperature bar
Electrical Spurious events generated after the amplifier

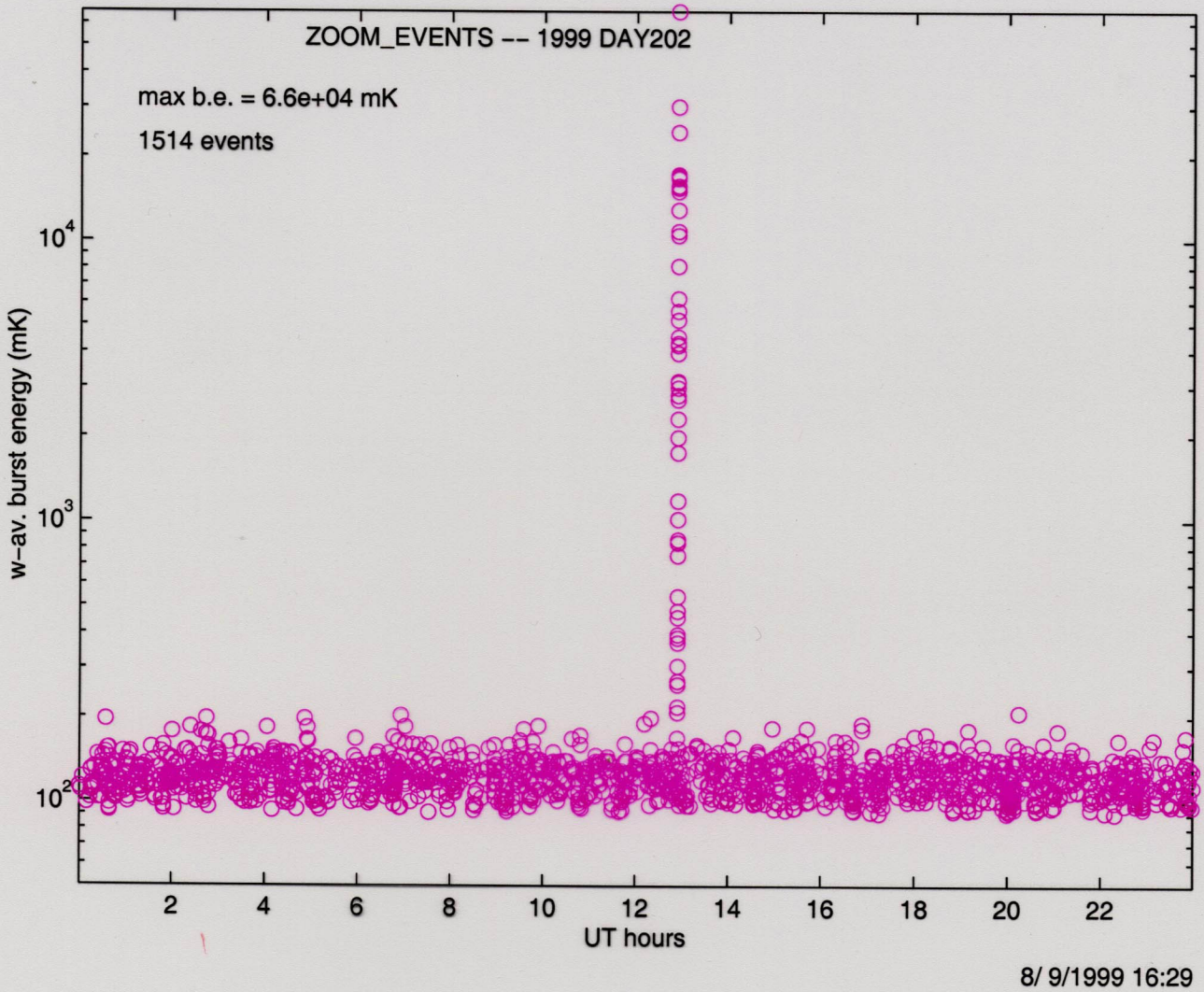
$\lambda = 0.1$

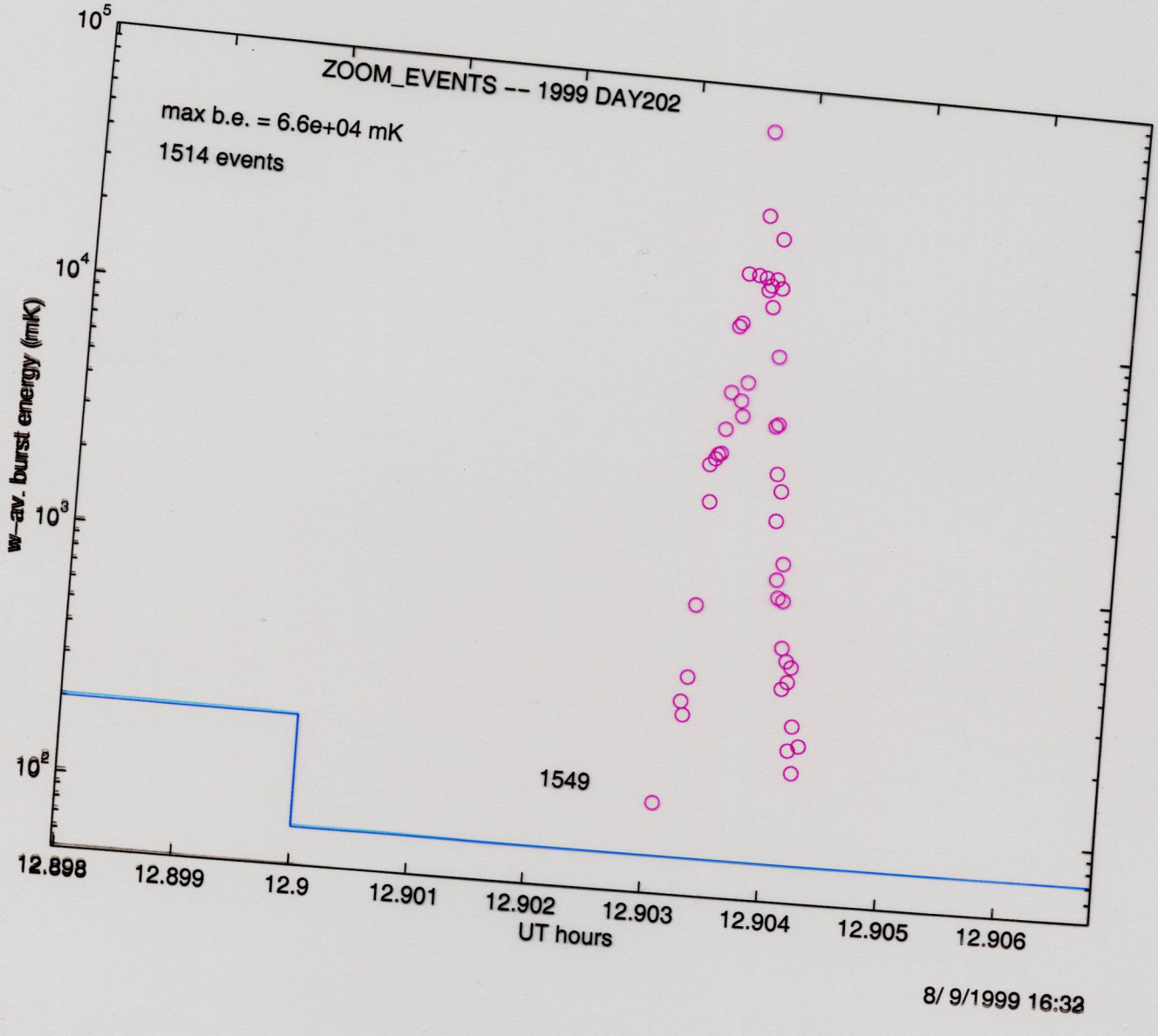

1298 seismic events
1113 antenna events
37 coincidences at 2s time shift
Number of coincidences
Time shift (seconds)
40
35
30
25
20
15
10
5
0
−200
−150
−100
−50
0
50
100
150
200

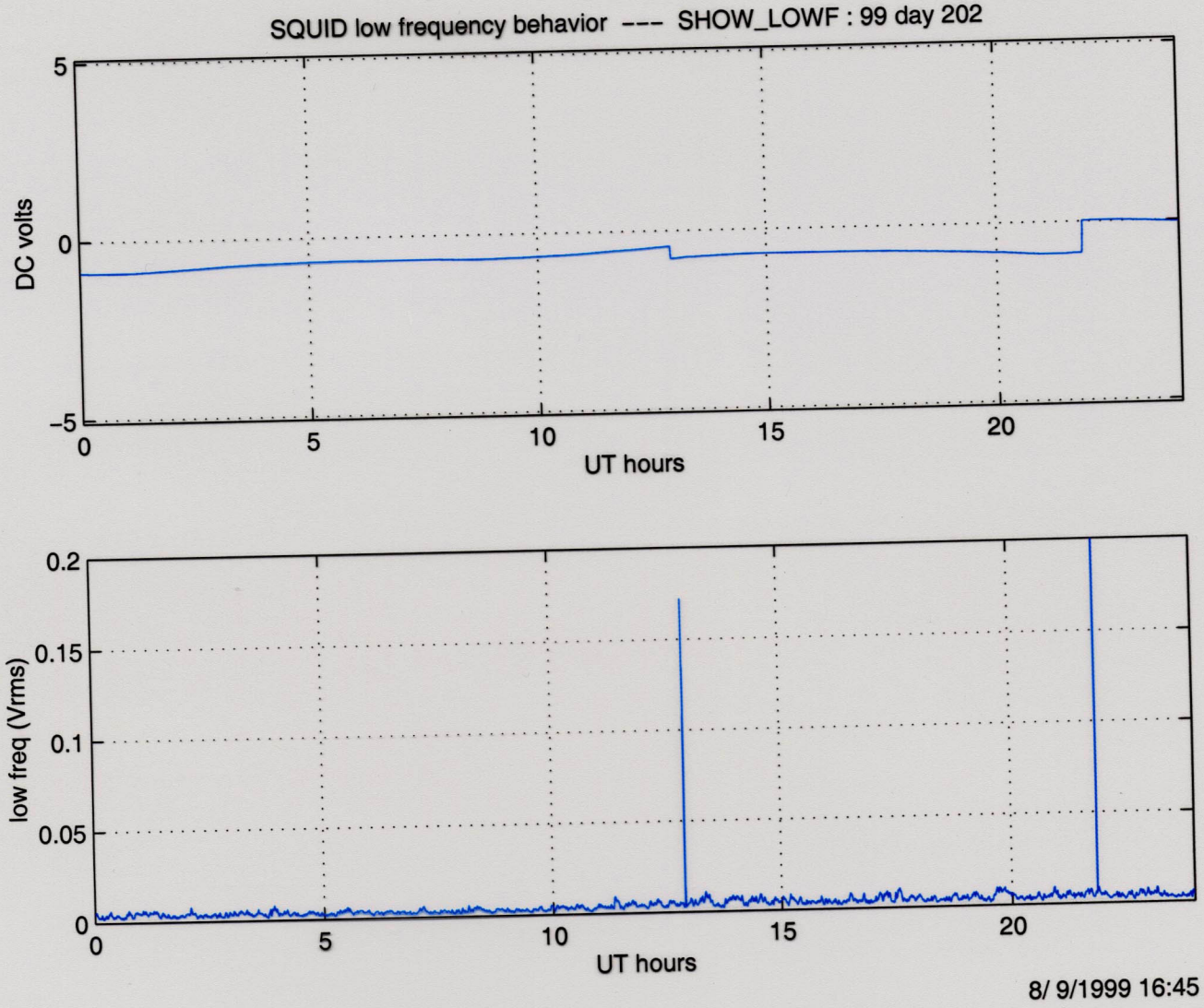

Plus mode data from day 228
Burst energy (K)
30
25
20
15
10
5
0
10.5
10.6
10.7
10.8
10.9
11
11.1
11.2

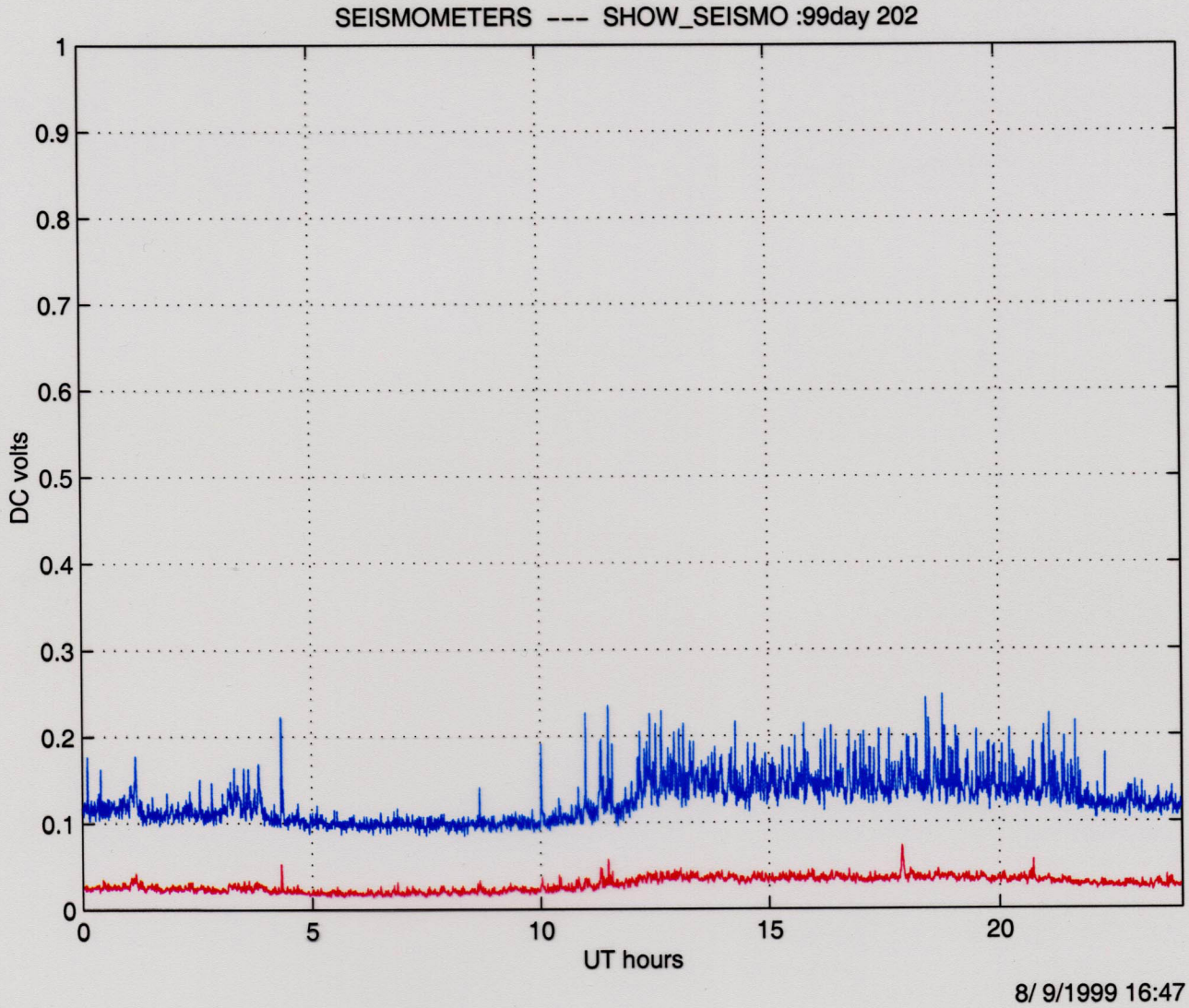

Minus mode data from day 228
Burst energy (K)
12
10
8
6
4
2
0
10.5
10.6
10.7
10.8
10.9
11
11.1
11.2


Phase servo output
Displacement (μm)
1000
500
0
−500
−1000
−1500
−2000
10.5
10.6
10.7
10.8
10.9
11
11.1
11.2
Universal time (hours)

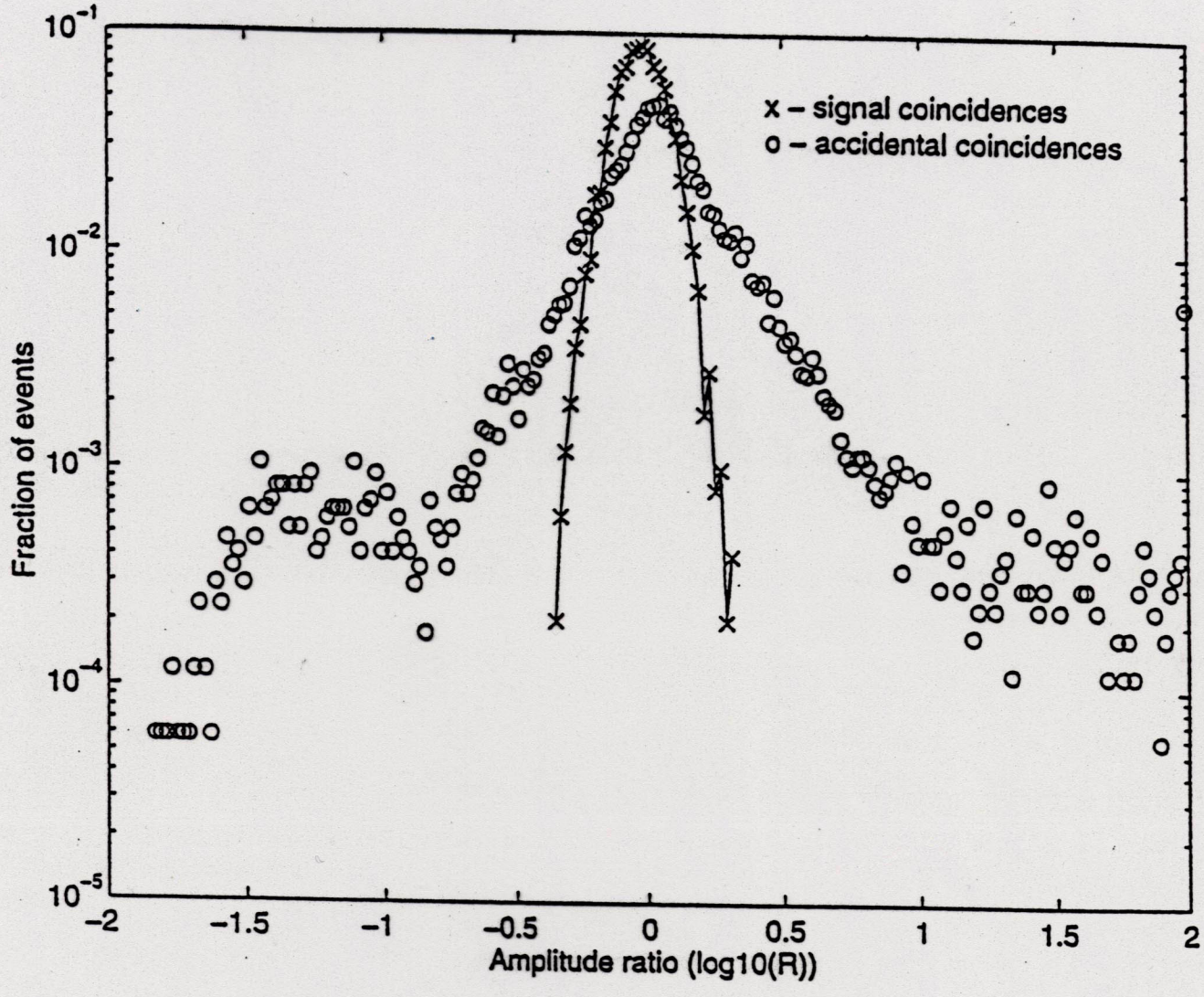

ZOOM_EVENTS -- 1999 DAY202
max b.e. = 6.6e+04 mK
1514 events
w-av. burst energy (mK)
10^4
10^3
10^2
2
4
6
8
10
12
14
16
18
20
22
UT hours
8/ 9/1999 16:29


ZOOM_EVENTS -- 1999 DAY202
max b.e. = 6.6e+04 mK
1514 events
1549
w-av. burst energy (mK)
10^5
10^4
10^3
10^2
12.898
12.899
12.9
12.901
12.902
12.903
12.904
12.905
12.906
UT hours
8/ 9/1999 16:32


SQUID low frequency behavior --- SHOW_LOWF : 99 day 202
DC volts
5
0
−5
0
5
10
15
20
UT hours
low freq (Vrms)
0.2
0.15
0.1
0.05
0
0
5
10
15
20
UT hours
8/ 9/1999 16:45


SEISMOMETERS --- SHOW_SEISMO :99day 202
DC volts
UT hours
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
5
10
15
20
8/ 9/1999 16:47

Amplitude ratio filter removes coincidence candidates with non-allowed amplitude ratios.

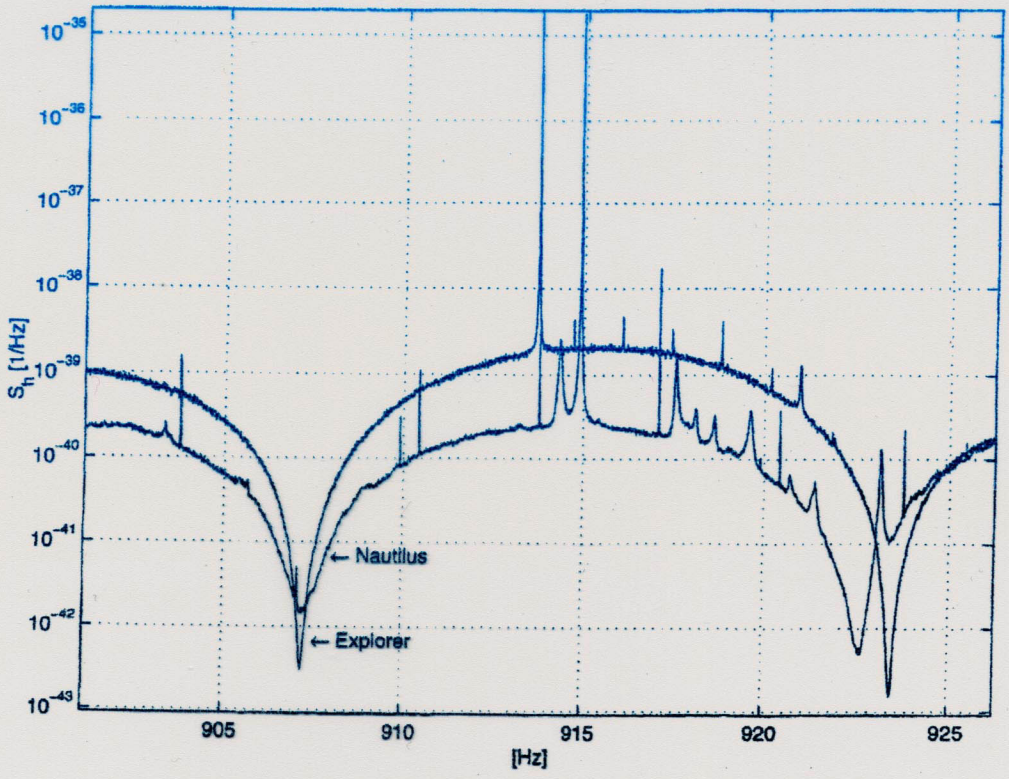


$\tilde{h}_{stoch} \lesssim 10^{-22}$

Cross-correlation measurement of g.w. stochastic background

(Astron. Astrophys. 1999 in press)

EXPLORER and NAUTILUS tuned at f- = 907.2 Hz

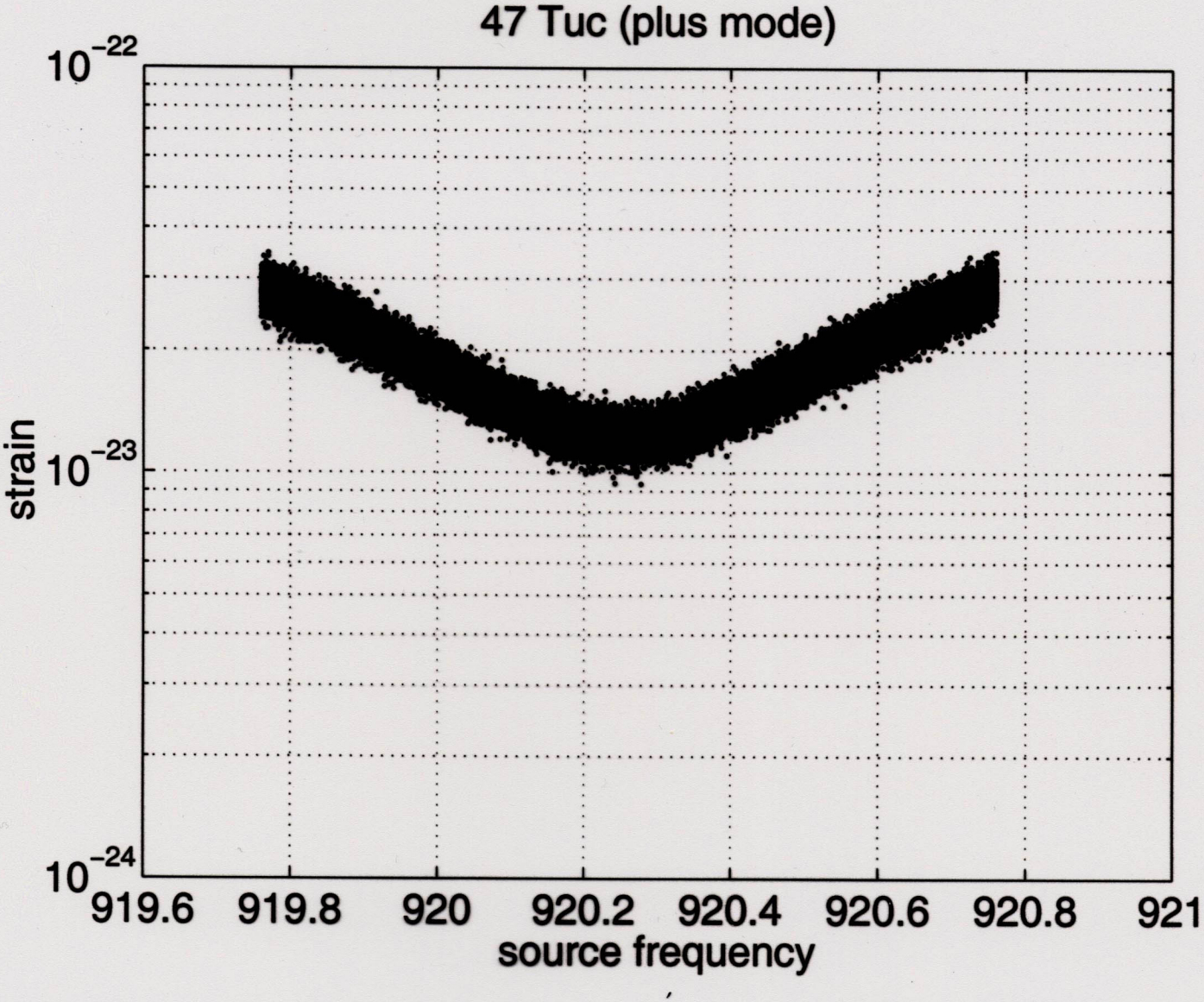


tm = 12.57 hours of data (february 97)

$\Delta f = 0.1$ Hz, between 907.15 and 907.25 Hz

$$\Omega gw \leq 6 \cdot 10$$

Allegro search for pulsars in 47 Tuc.



SUMMARY of ALL EXCHANGED DATA

DETECTOR	TOTAL OBSERVATION TIME y.1997-98 [h]	CANDIDATE EVENTS NUMBER	CANDIDATE EVENTS RATE [/d]
ALLEGRO	9079.82	42839	113.23
AURIGA	3671.29	26817	175.31
EXPLORER	3299.32	20711	150.66
NAUTILUS	2604.17	8764	80.77
NIOBE	4460.84	2600	13.99

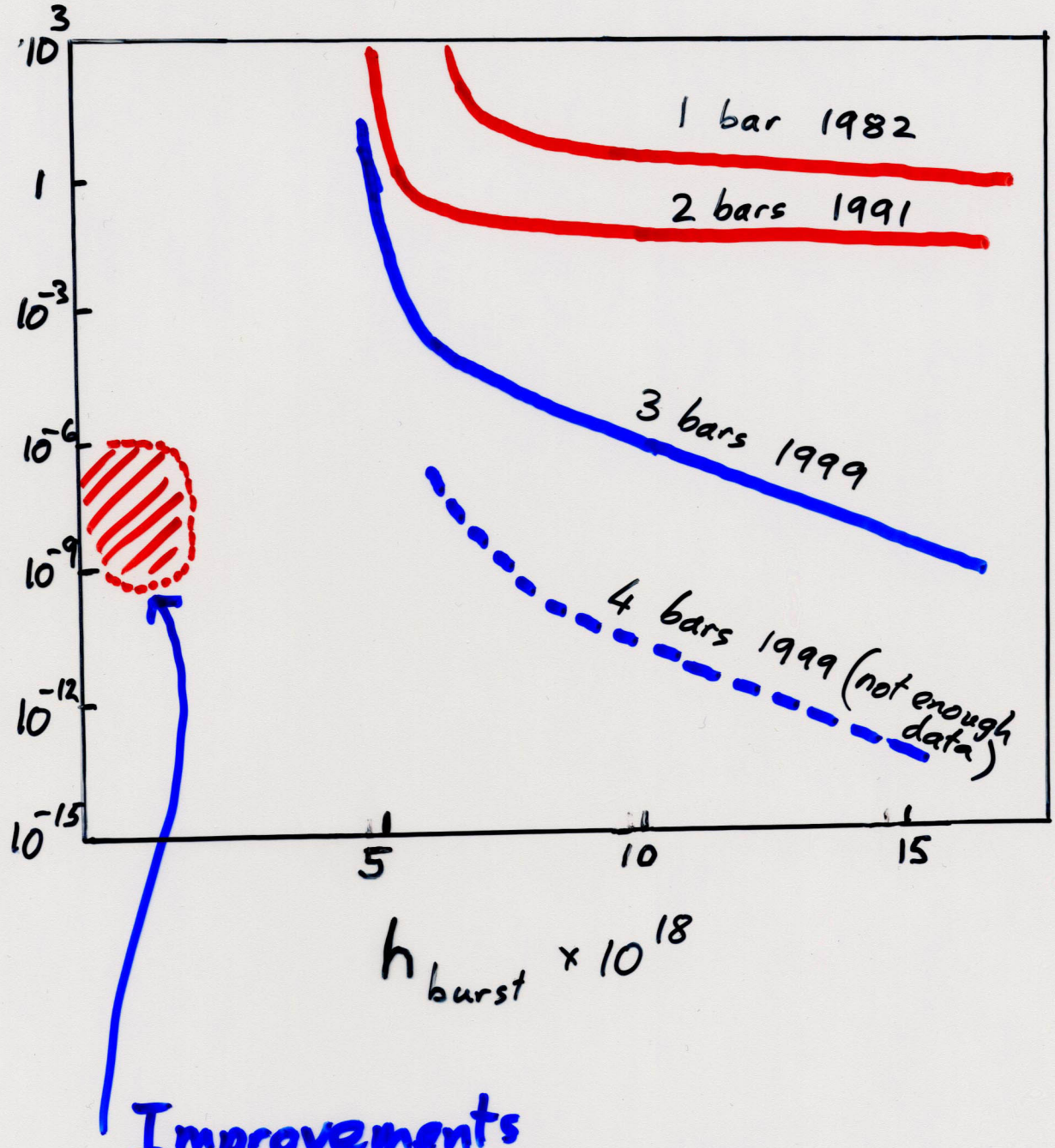
COINCIDENCES: PRELIMINARY RESULTS

FOUR DETECTORS	COMMON OBSERVATION TIME y.1997-98 [h]	NUMBER OF COINCIDENCE S within ± 1 s
ALL-AUR-EXP-NIO	181.50	0
ALL-AUR-EXP-NAU	190.02	0

THREE DETECTORS	COMMON OBSERVATION TIME y.1997-98 [h]	NUMBER OF COINCIDENCE S within ± 1 s
ALL-AUR-EXP	829.92	0
ALL-AUR-NAU	409.24	0
ALL-AUR-NIO	424.24	0
ALL-EXP-NAU	840.04	0
ALL-EXP-NIO	280.68	0
AUR-EXP-NAU	206.02	0
AUR-EXP-NIO	276.30	0
TOTAL	*2151.88*	*0*

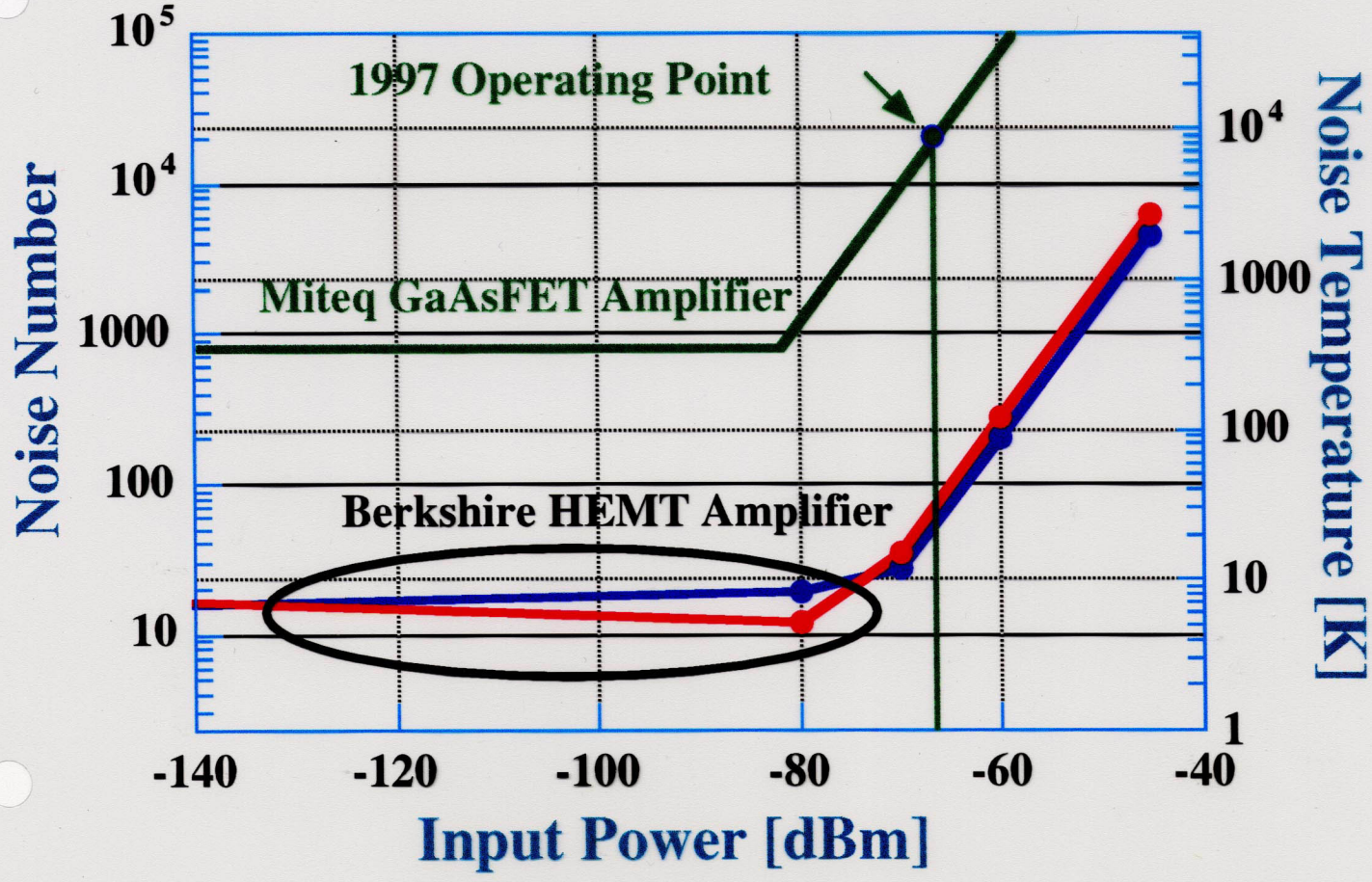
TWO DETECTORS	COMMON OBSERVATION TIME y.1997-98 [h]	Number of events for the first detector	Number of events for the second detector	NUMBER OF COINCIDENCE S within ± 1 s	NUMBER OF COINC. EXPECTED within ± 1 s
ALL-AUR	2437.89	11246	18000	42	46.13
ALL-EXP	2415.96	11320	11887	27	30.90
ALL-NAU	2373.58	11364	7910	17	21.04
ALL-NIO	651.00	3013	403	1	1.04
AUR-EXP	1057.50	7254	5063	14	19.22
AUR-NAU	439.91	3571	922	4	4.16
AUR-NIO	887.91	6002	559	1	2.10
EXP-NAU	899.31	4126	2234	5	5.69
EXP-NIO	453.41	3585	217	1	0.95
TOTAL	*6198.15*	*61481*	*47195*	*112*	131.23

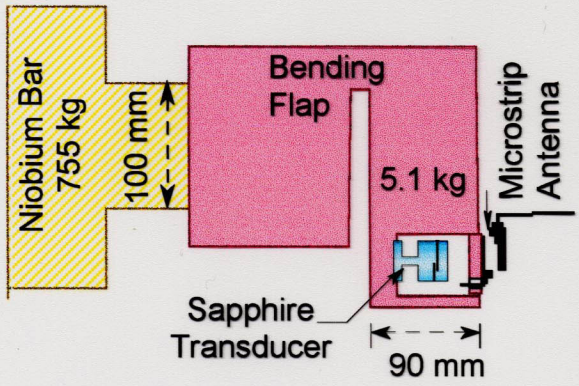
Limits on Bursts

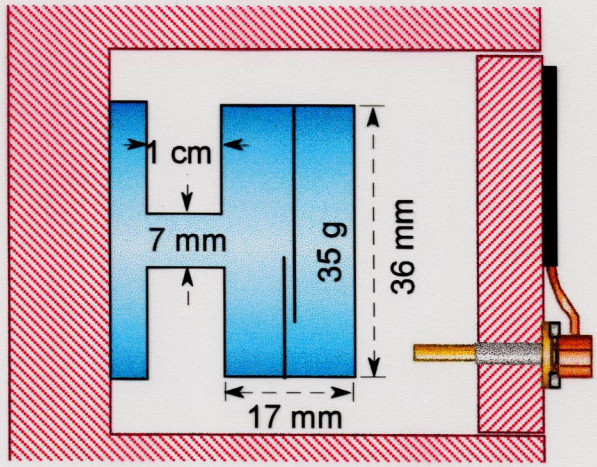


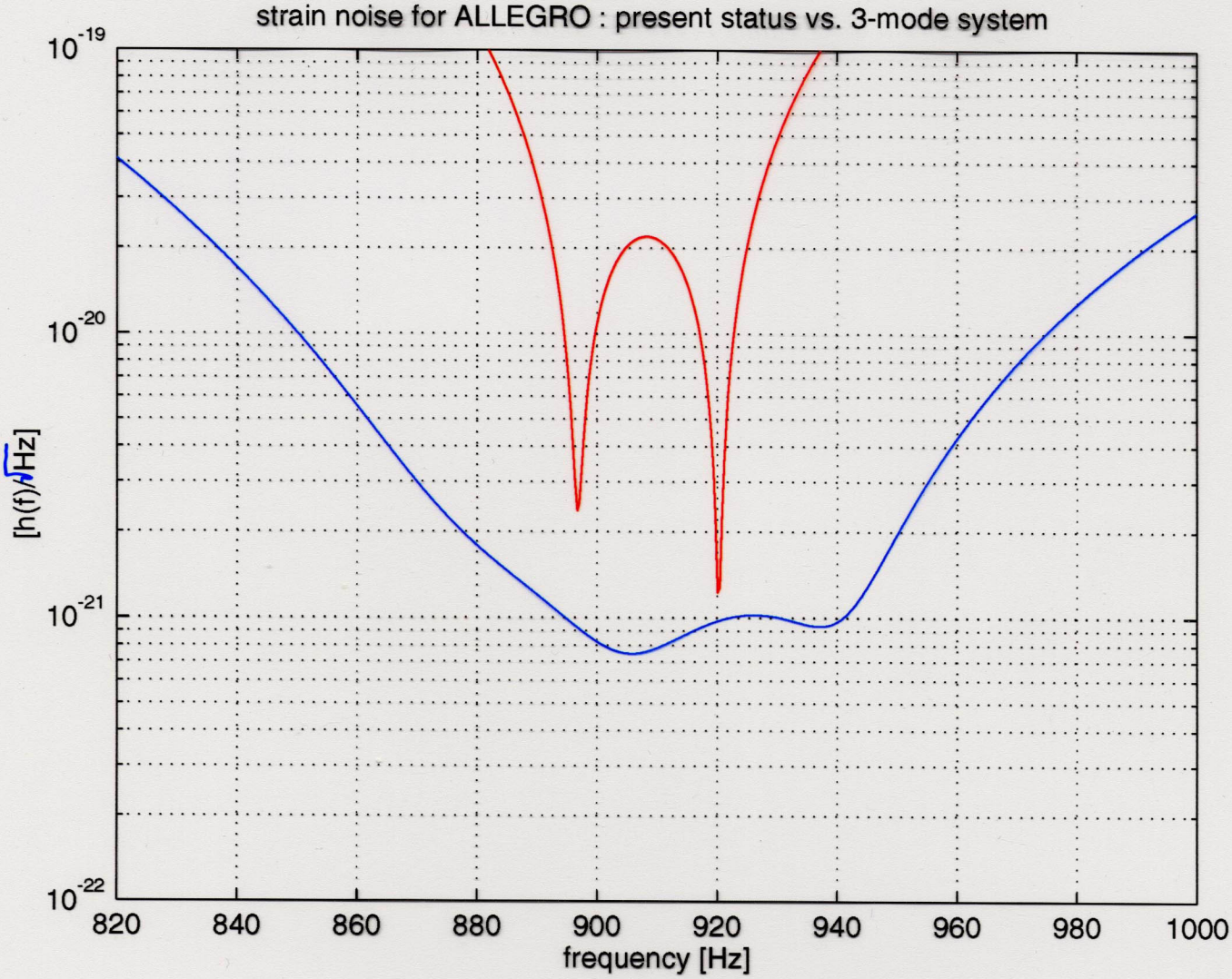
Improvements currently underway will take us here.

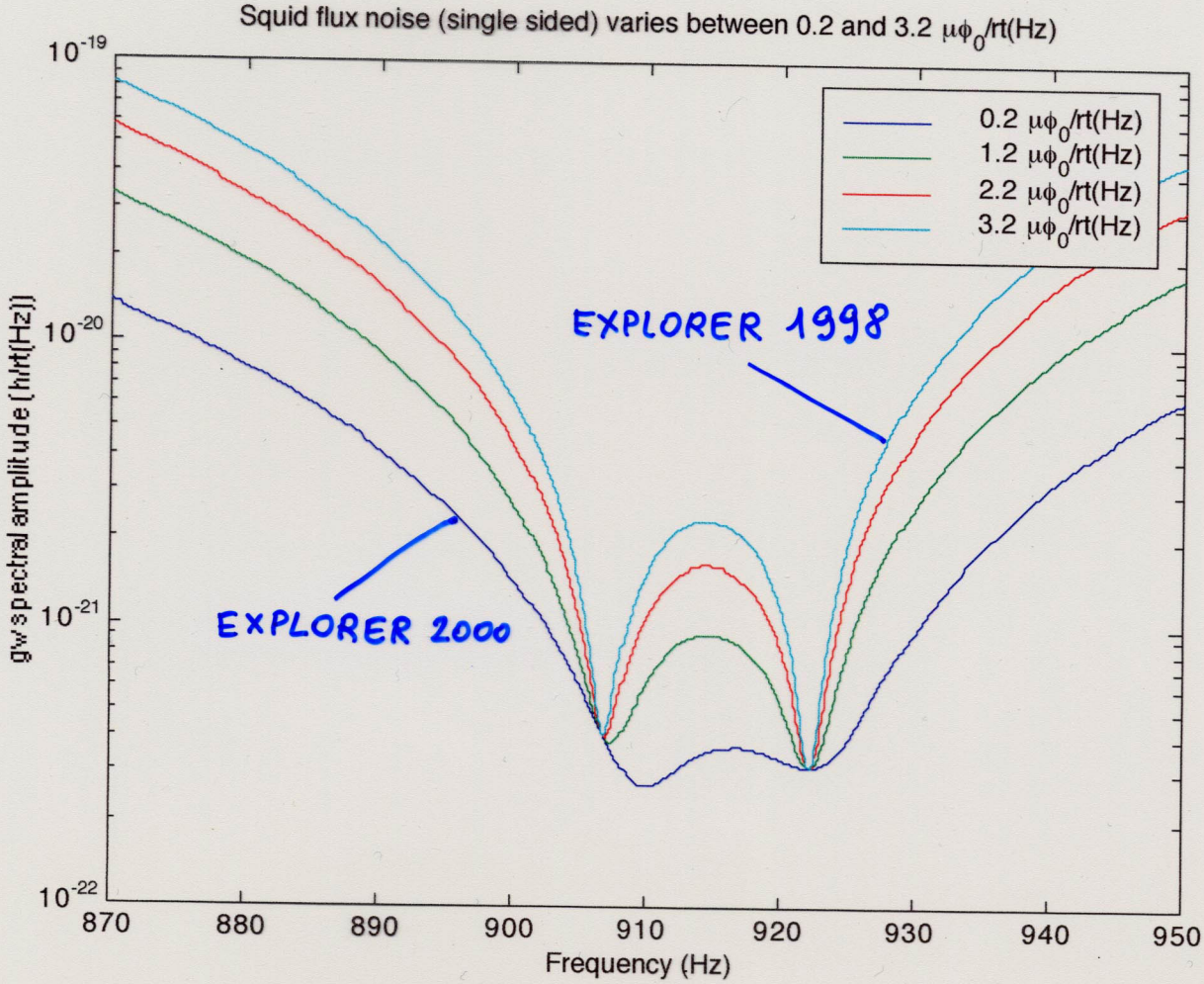
- astrophysically much more interesting.


1997 Operating Point
Miteq GaAsFET Amplifier
Berkshire HEMT Amplifier
Noise Number
Noise Temperature [K]
Input Power [dBm]
10^5
10^4
1000
100
10
10^4
1000
100
10
1
-140
-120
-100
-80
-60
-40


Niobium Bar
755 kg
100 mm
Bending
Flap
5.1 kg
Microstrip
Antenna
Sapphire
Transducer
90 mm

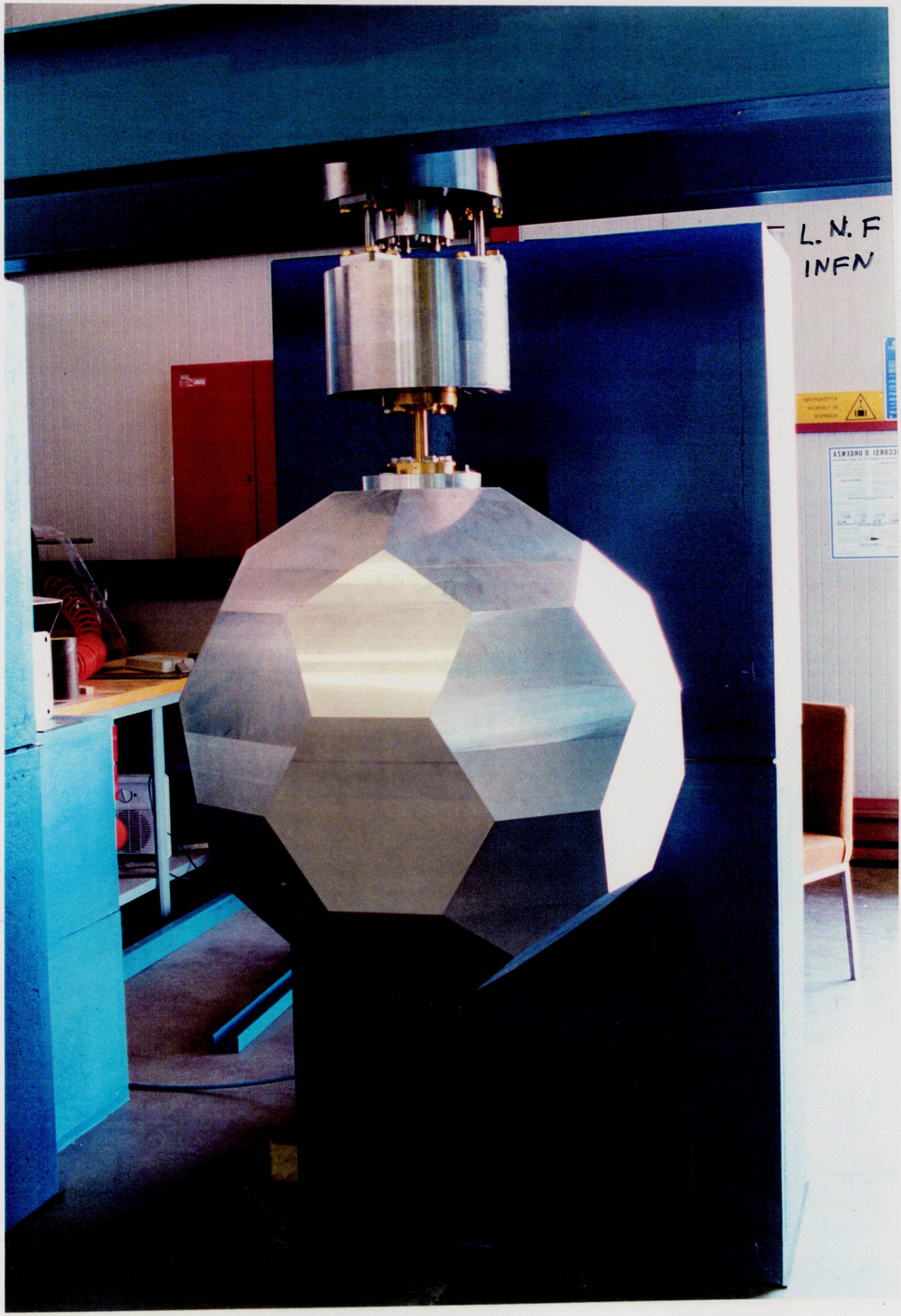

1 cm
7 mm
35 g
36 mm
17 mm


strain noise for ALLEGRO : present status vs. 3-mode system
10^-19
10^-20
10^-21
10^-22
[h(f)/√Hz]
820
840
860
880
900
920
940
960
980
1000
frequency [Hz]

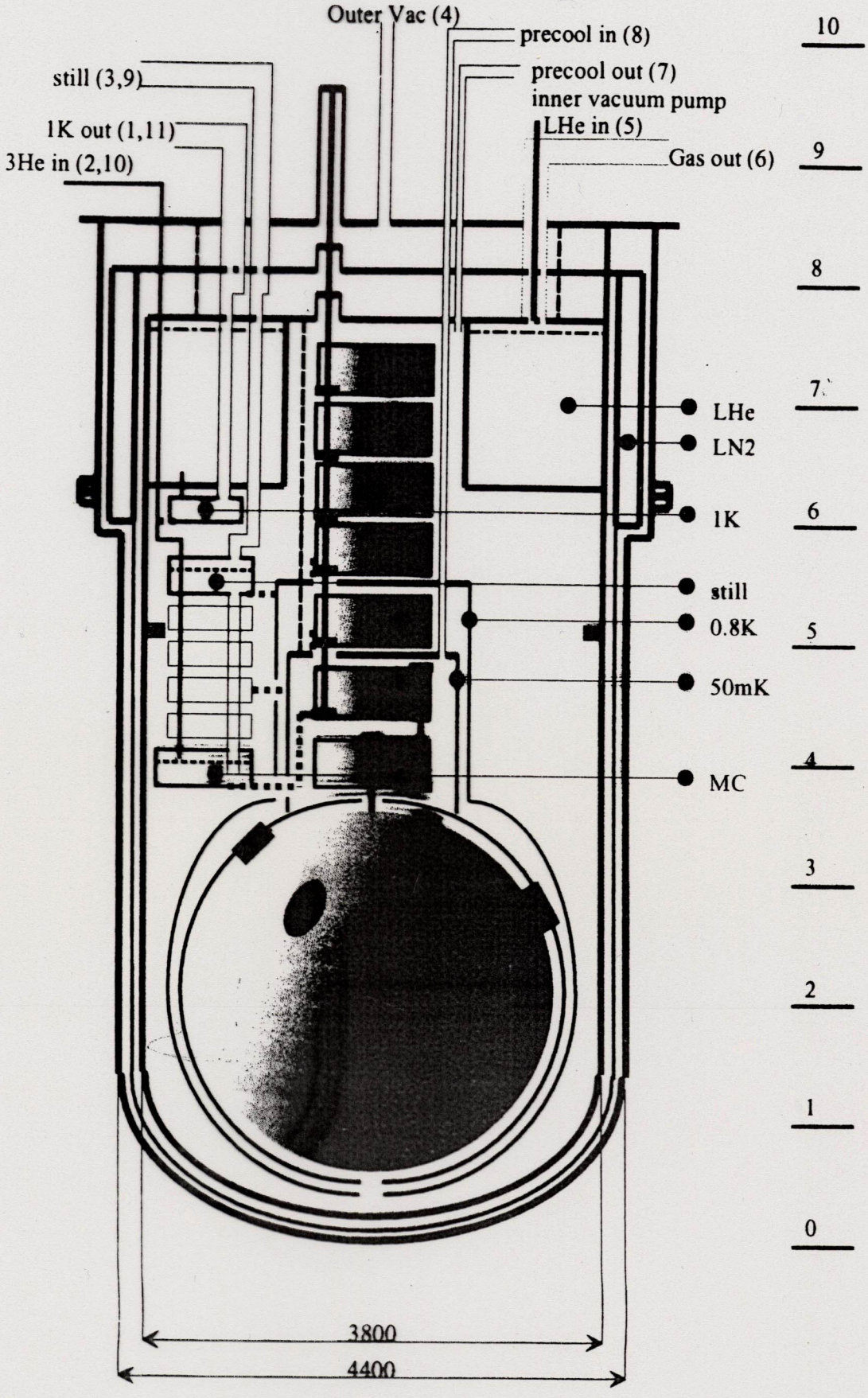


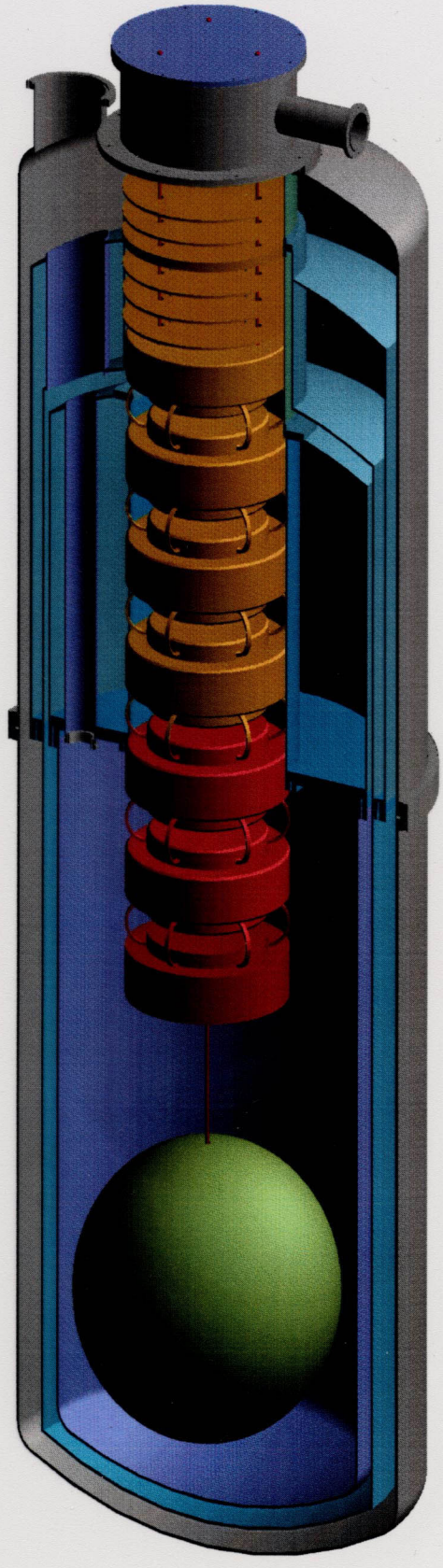
1999 UP GRADE

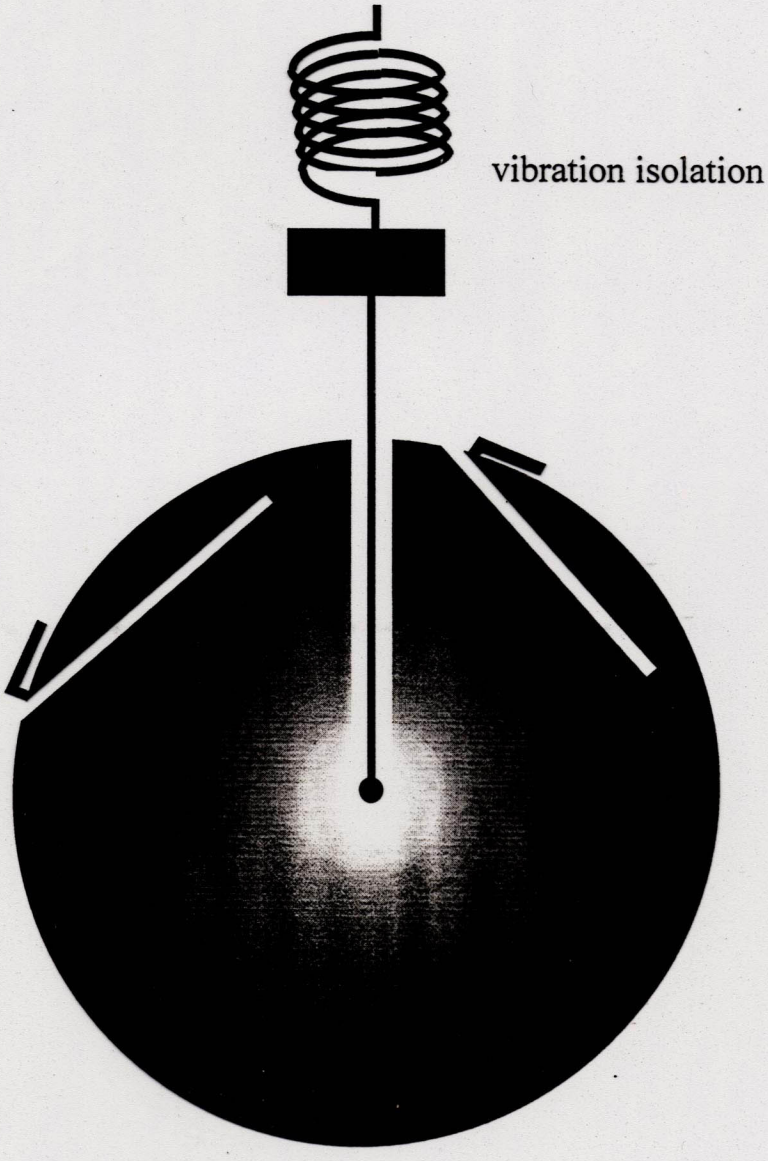
- NEW TRANSDUCER
- NEW DC SQUID


L. N. F
INFN

SCHEMATIC DRAWING OF GRAIL

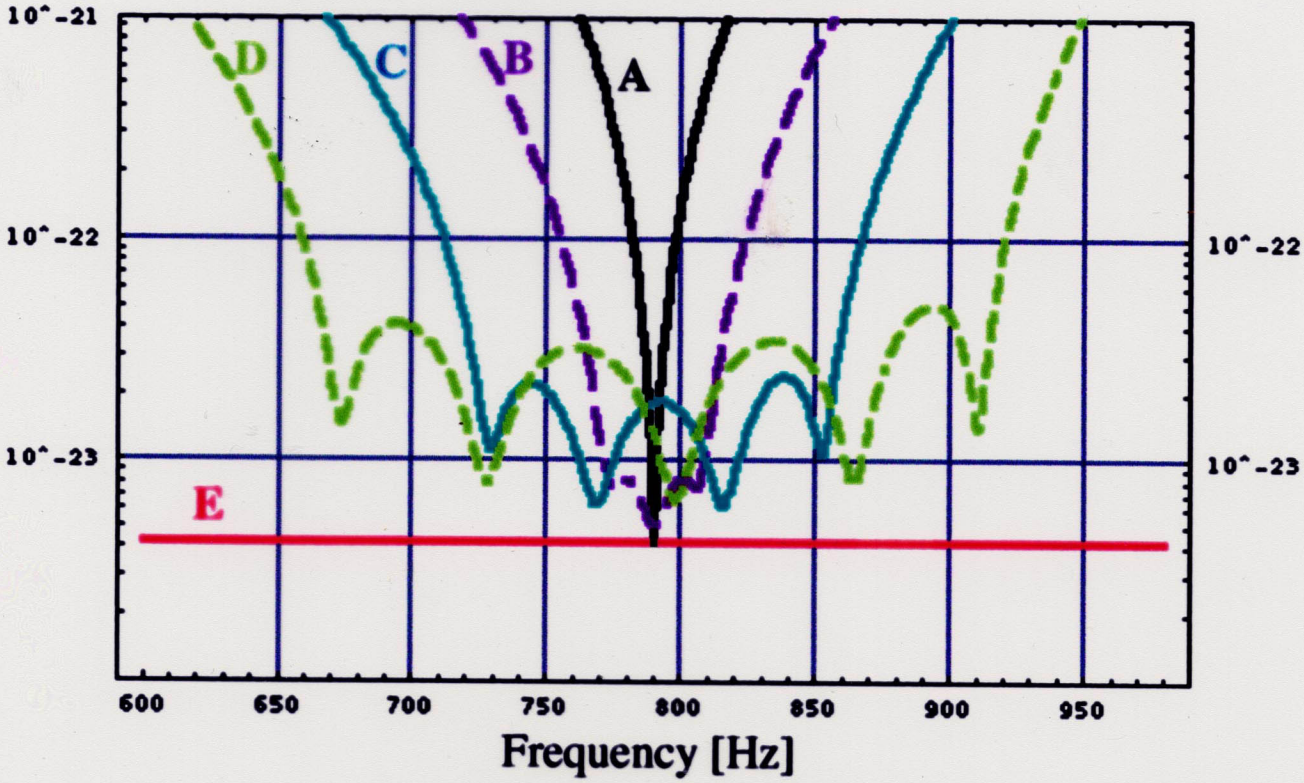





vibration isolation

Spectral Strain Sensitivity [1/√Hz]

(With Sapphire Transducer)



GRAIL DETECTOR

Model Parameters

T = 15 mK

$Q_{CuAl} = 1.6 \cdot 10^7$

$Q_{Spph} = 10^9$

$S_F = 3.65 * 10^{-30}$ N²/Hz

$S_X = 2.2 * 10^{-38}$ m²/Hz

Input Power = 22.5 μW

E: Sphere Acoustic Nyquist Noise

A: 2-Mode
$m_1 = 42 \cdot 10^3$ kg
$m_2 = 0.035$ kg

B: 3-Mode
$m_1 = 42 \cdot 10^3$ kg
$m_2 = 38$ kg
$m_3 = 0.035$ kg

C: 4-Mode
$m_1 = 42 \cdot 10^3$ kg
$m_2 = 4.0 \cdot 10^2$ kg
$m_3 = 3.7$ kg
$m_4 = 0.035$ kg

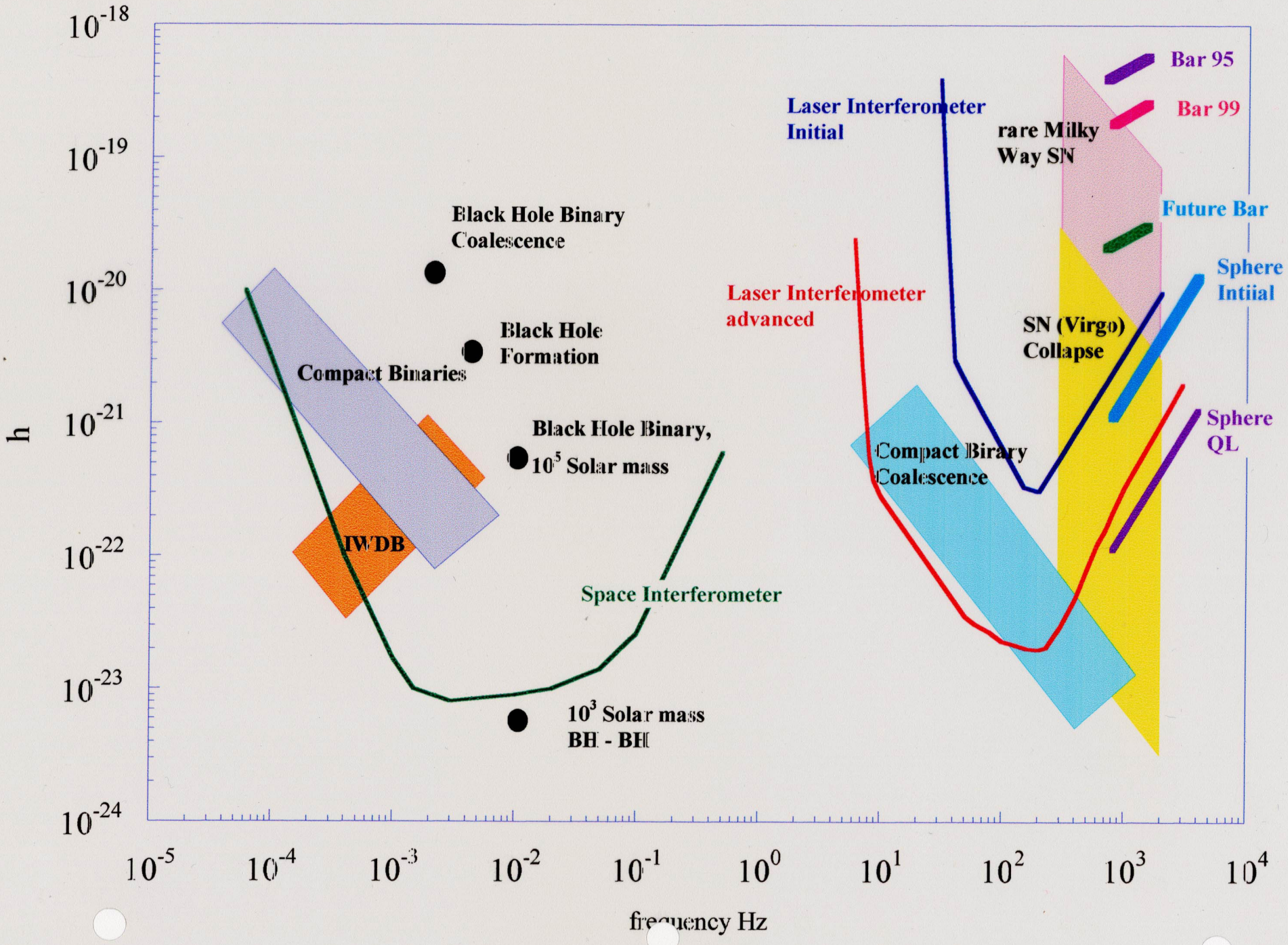
D: 5-Mode
$m_1 = 42 \cdot 10^3$ kg
$m_2 = 1.3 \cdot 10^3$ kg
$m_3 = 38$ kg
$m_4 = 1.2$ kg
$m_5 = 0.035$ kg

Dr. Michael Tobar
University of Western Australia

Conclusion

- Bar technology is not obsolete
- LI's provide healthy competition and impetus
- Bar groups can contribute strongly to understanding LI spuria etc
- Bar + LI combinations can provide ideal cross-correlation facility for stochastic backgrounds.

  LIGO - ALLEGRO
  VIRGO - AURIGA - NAUTILUS
  AIGO - NIOBE


10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
h
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
frequency Hz
Black Hole Binary Coalescence
Black Hole Formation
Compact Binaries
Black Hole Binary, 10^{5} Solar mass
IWDB
Space Interferometer
10^{3} Solar mass BH - BH
Laser Interferometer Initial
rare Milky Way SN
Bar 95
Bar 99
Future Bar
Sphere Intiial
Laser Interferometer advanced
SN (Virgo) Collapse
Compact Birary Coalescence
Sphere QL