The future of acoustic gw detectors

- “bars”
  how and what they (try to) detect

- coincidence search for short gw bursts
  the IGEC

- upgrades under way
  the reach out of the upgraded IGEC

- “ultimate bars”
  spherical resonators
  what they could detect
  reach out
Detection and Transduction

"quantum limit"

$K_{B} T_{H} \sim \frac{4}{3} \frac{4}{3}$

now:

$\sim 10^{4}$

soon:

$\sim 10^{5}$

Electromechanical Transducer tuned to the lowest longitudinal mode (max cross section)

Vibration Insulation

Final Amplifier

Signal Out

Low T

Bar

$\frac{K_{B} T_{H}}{Q_{\text{bar}}}$
bars on a great circle + parallel - DO OVERLAP OF ANTENNA PATTERNS

interferometers → INCOMPLETE ANTENNA PATTERN OVERLAP WITH OTHER INTERFEROMETERS IN DIFFERENT
AURIGA at LEGNARO (PADUA ITALY)

INFN National Laboratory

www.auriga.infn.it
noise

the g.w. "amplitude" $h$

the "detector spectral noise power" $S_h(f)$
(equivalent g.w. amplitude at input)
such that

$$\int_{\Delta f} S_h(f) \, df = h_{\text{rms}}^2$$

over the band $\Delta f$

"typical best" of bars in operation

$$S_h^{1/2}(930 \text{ Hz}) \approx 5 \times 10^{-22} \text{ Hz}^{-1/2}$$

$$\hbar_{\text{limit}} = 3 \times 10^{-19} \quad \leftrightarrow \quad \Delta E_{\text{dressed}} = 10^4 \text{ quanta of vibration}$$

$\tau_{\text{D}} = 10^{-4} M_\odot e G C$
 Auriga

$h_\nu \approx 7 \times 10^{-19}$

$\gamma$-ray outburst 08/27/98
1900+14 soft $\gamma$-repeater
$E \approx 5$ Kpc

"Loudest event" $\Rightarrow h_\nu \approx 3 \times 10^{-18} \Rightarrow \epsilon_{gw} \approx 2 \times 10^{-3} M_\odot$

"Similarly for any astronomical target over the whole 15 years period (June 1985 - June 2000)"
ALLEGRO NSF- Baton Rouge
AURIGA INFN - LNL
EXPLORER INFN- CERN,
NAUTILUS INFN- LNF
NIOBE ARC- Perth

5 "bars"

- of mass 1.5-2.3 tons at temperatures 0.1-4.2 K
- resonating at 700-950 Hz with 1 Hz bandwidth
- of similar "bursts" sensitivity $h_r \leq 5 \times 10^{-19}$
- located on and orthogonal to a great circle with parallel axis to maximize coincidences probability
  * short term, quasi-gaussian
  * for short gravitational wave bursts
- each group responsible to exchange list of candidate event under common protocol
- unanimous agreement to make public results
- open to any over g.w. data producing project

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Penn State Nov 8ᵗʰ 2001
THE BAR DETECTORS "OBSERVATORY"

in operation:
• reach out to 100 kpc: watching the Galaxy for g.w. bursts $\geq 0.05\ M_\odot$
• no correlations between pairs of detectors
• false alarm rates $<<1$/century for 3-fold coincidences
• operation with astronomical triggers: g.w. association with neutrinos, gamma bursts, etc.
• continuous sources and stochastic background

upgrades under way:
• reach out to the Local Group (observe x20 luminous mass)
• complement initial interferometers in the global network

future:
• "ultimate" bars (spheres and hollow spheres) would reach out to cosmological distances

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a useful exercise...

"typical best" $h_e \approx 3 \times 10^{-19}$

$\sim 1$ hour

↓

- thresholds @ $3 \div 5 h_e$
- quasi-stationary
- quasi-gaussian
- false alarm $< 1/cy$ (3 detectors on the air)

ACTUAL OPERATION

$h_e \geq 5 \times 10^{-18}$

duty cycle $\sim 10\%$ "on" time
$M = 23 \text{ ton}$

$T = 0.4 \Omega$

$L = 3 \text{ m}$

$q = 10^6$

$\omega = 930 \text{ Hz}$

$0.5 \text{ Hz} \leq \text{ Bandwidth} \leq 0.5 \text{ Hz}$

$\text{ Frames}$
Eugenio Coccia with mini.GRAIL.

The CuAl\textsuperscript{62} spherical detector

\( \phi 65 \text{cm} \) 1 ton 3200 Hz 10mK

at Giorgio Frossati lab in Leiden

Annette de Waard

Luciano Gottardi
BH-BH binaries
inspiral, merger and ringdown @ 1Mpc

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<thead>
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<th>Line</th>
<th>Description</th>
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<td>AURIGA 100 $h$</td>
<td></td>
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<tr>
<td>miniGRAIL SQL</td>
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SNR

Total mass 2M
(Solar Masses)
worth continuing for a while
- cope with non-stationarity of noise
- non-gaussianity of noise
- learn how to increase duty cycle
- $\times 100$ energy sensitivity
- in specific searches complement initial ifos
  - # poor signature signals (burst...):
    - DIFFERENT DETECTORS GET SAME SIGNAL
    - TEST TRACELESSNESS OF RIEMANN TENSOR
  - # STOCHASTIC BACKGROUND $\rightarrow$ ALLEGRO/160

then

$\Delta f \leq 10\% \, f$
$\Delta f \sim f$
Concept of the DUAL SPHERE gravitational wave acoustic wide-band detector

Livia Conti

Two nested spheres:

<table>
<thead>
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<th>Beryllium</th>
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<th>Beryllium- Molybdenum</th>
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<tr>
<td></td>
<td>ext</td>
<td>int</td>
<td>ext</td>
</tr>
<tr>
<td>diameter</td>
<td>4.0 m</td>
<td>2.4 m</td>
<td>4.0 m</td>
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<tr>
<td>mass</td>
<td>52 ton</td>
<td>14 ton</td>
<td>52 ton</td>
</tr>
<tr>
<td>$f$ (1$^{st}$ quadr.)</td>
<td>1100 Hz</td>
<td>2900 Hz</td>
<td>1100 Hz</td>
</tr>
<tr>
<td>$f$ (2$^{nd}$ quadr.)</td>
<td>2800 Hz</td>
<td>4700 Hz</td>
<td>2800 Hz</td>
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</table>

- omnidirectional (absorbed energy invariant under large cross-section)
- with $>5$ sensors at specified locations on sphere get excitation of $Y_2m(\theta,\phi) \Rightarrow$ RECONSTRUCT DIRECTION + POLARIZATION

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\[ h_{\text{min}}(f) = \sqrt{S(f) \Delta f} \]

BAR \(100 \text{ Hz} \quad 10^{-22} \quad \sigma \quad 900 \text{ Hz} \)

mini GRB1 \(10^{-23} \quad \sigma \quad 3200 \text{ Hz} \)

D-SPHERE BE \(10^{-24} \quad \sigma \quad 1200 - 2500 \text{ Hz} \)

D-SPHERE BeNo \(\sigma \quad 1000 - 1300 \text{ Hz} \)

\text{SNR} \approx 10

Bar formation \(1.4 \text{ Ms} \quad @ \quad 1 \text{ Mpc} \)

\[ H(f) \rightarrow f \approx 2500 - 3500 \text{ Hz} \quad (G. \text{Harry} 2001) \]

\[ \text{SNR}^2 = \int \frac{|H(f)|^2}{S_0(f)} \, df \]
BH-BH binaries
inspiral, merger and ringdown @ 100 Mpc

- Dual sphere Be-Mo SQL
- Dual sphere Be SQL
- GRAIL Be SQL

SNR

Total mass 2M
(Solar Masses)
detectability of stochastic background
(M. Maggiore, Phys. Reports 321 (2000))

\[ h_{\text{min}} (f) \propto (T \Delta f)^{-\frac{1}{4}} \left[ f S_e (f) \right]^{\frac{1}{2}} \]

the minimum detectable \( \tilde{N}_{\text{gw}} \) at SNR = 1

\[ \tilde{N}_{\text{gw}} (f) \geq \frac{2\pi^2}{3 H_0^2} f^2 h_{\text{min}} (f) \]

\[ \approx 10^{-6} \left( \frac{f}{1 \text{ mHz}} \right)^3 \left( \frac{100 \text{ Hz}}{\Delta f} \right)^{\frac{1}{2}} \left( \frac{10^{-23} \text{ Hz}^{-\frac{1}{2}}}{f^2} \right)^{\frac{1}{2}} \]

spheres \( \rightarrow \tilde{N}_{\text{gw}} (f \sim 2 \text{ kHz}) = 10^{-6} \)

advanced ifos \( \rightarrow \tilde{N}_{\text{gw}} (f \sim 100 \text{ Hz}) = 10^{-11} \)

notice! it is NOT the detector \( S_e \) but it is the frequency... at 2 kHz

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bars allow tests on incoming signal: tracelessness, c-vol.

almost "omnidirectional" poor signature (bursts) 

Reduction in the burst amplitude sensitivity of the network (initial ifos + 2 bars) in respect to best orientation

• 4 interferometers (LIGO1, VIRGO, TAMA, GEO)
• 2 bars (AURIGA+25°, LSU-30°)

Average on polarizations

$\psi=0$ polarization
GW searches with “ultimate” acoustic detectors

- potentially most sensitive @ 1-2 kHz for long duration chirps et similia
  γ-bursts ??? r-modes??? …???
- correlations with ifos for poor signature high frequency signals as bursts
- complement ifos in bh-bh searches for M ~ 5 – 20 solar masses
- stochastic background @ kHz frequencies

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