Characterizing ghost cavitation noise generated by marine air gun arrays

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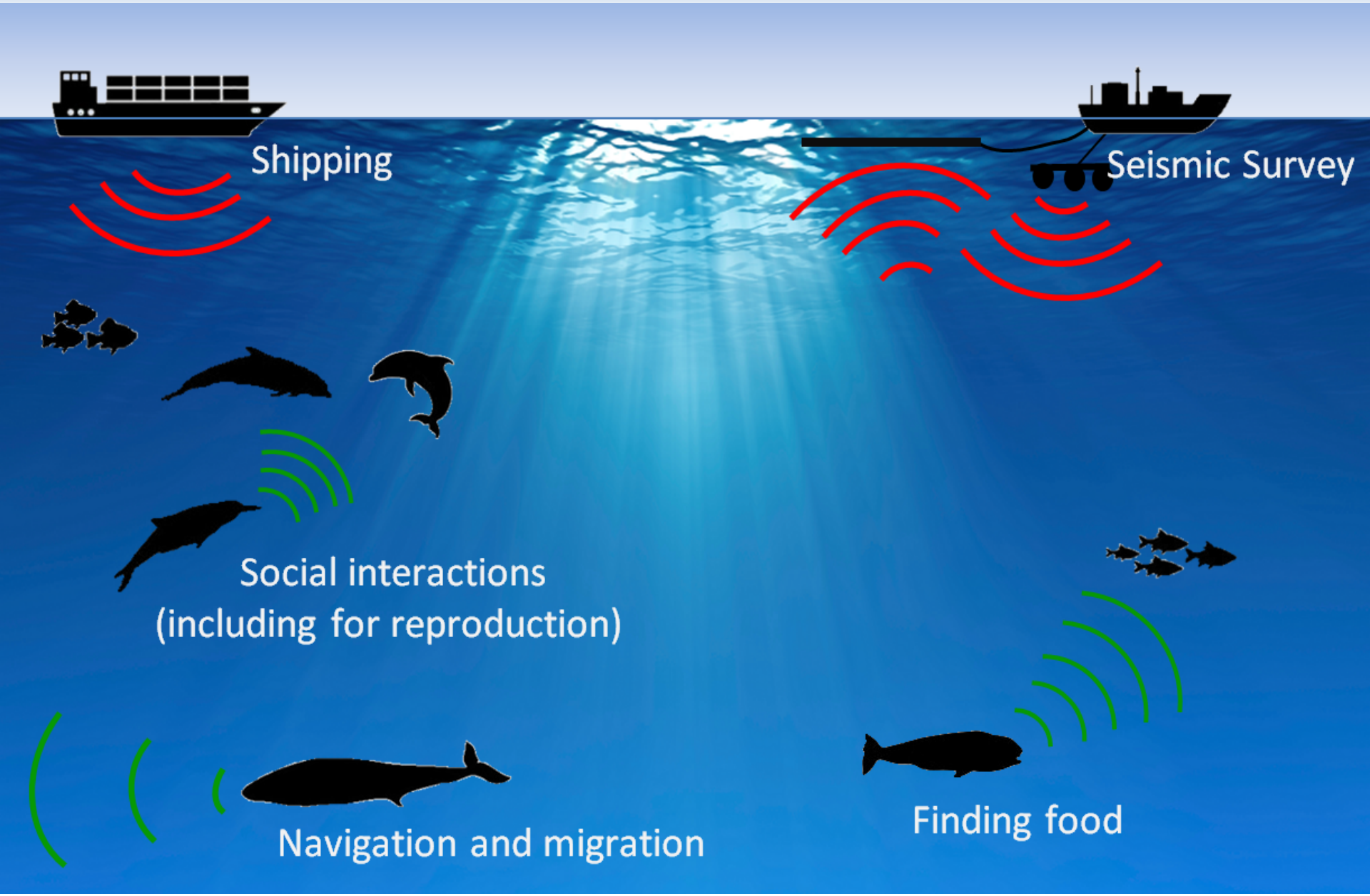
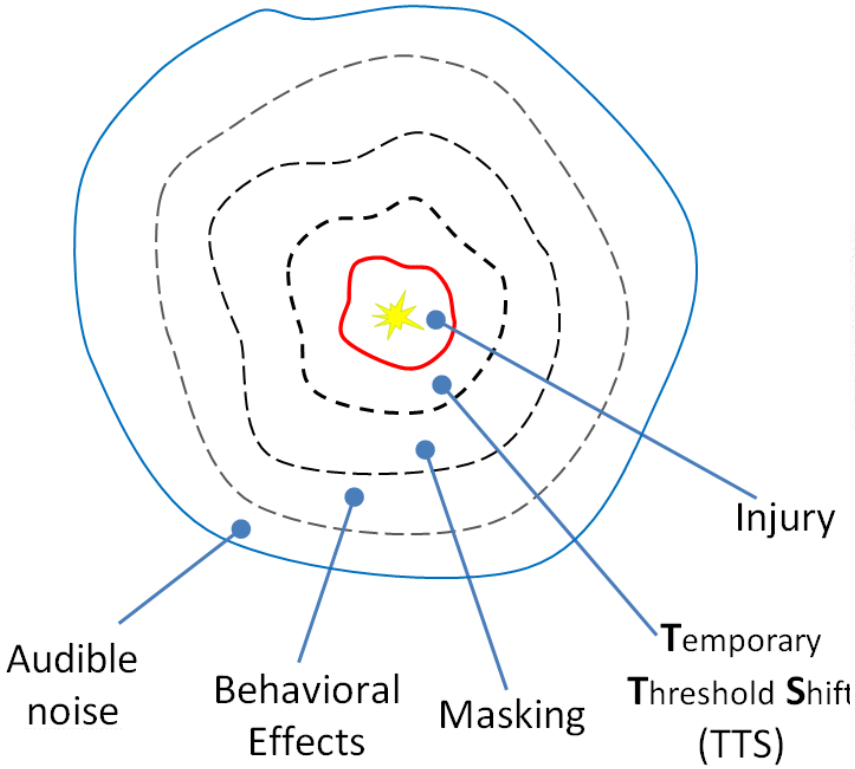
Trondheim

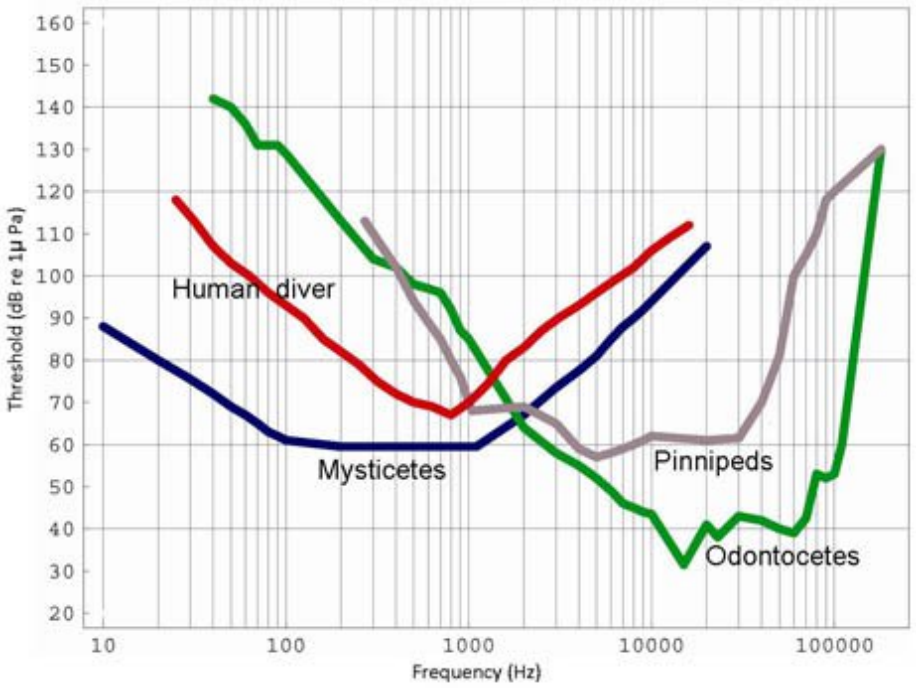
Marine life and sound



The impact on marine life



Hearing curves - audiogram



Landrø, Martin, and Lasse Amundsen. "Marine Seismic Sources Part V: The Hearing Of Marine Mammals."

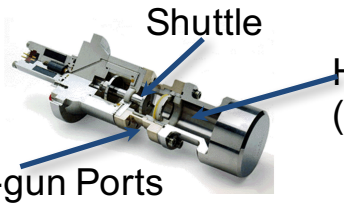
Loudness of sound depends on both its Amplitude and Frequency and is different for different species.

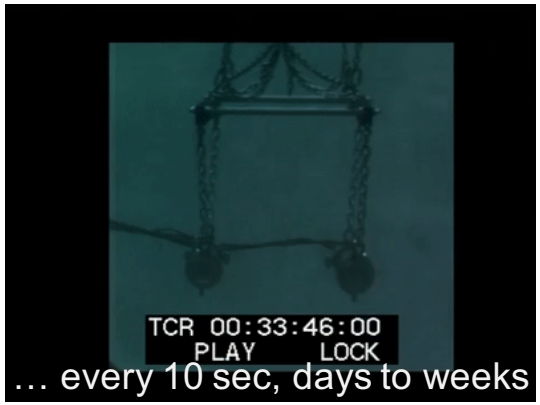
Various marine seismic sources

- Dynamite (pre 1960)
- Air-gun: 1960 Repeatability and safety
- Marine Vibrators (Mid 1960s)
- Low-level Acoustic Combustion Source (2009)
- Underwater tunable organ-pipe sound source (2007)

(Air-guns are used for **95**%)

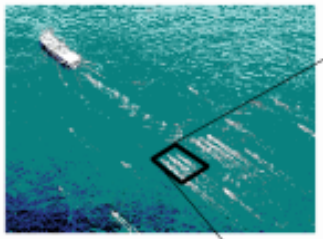
What are Airgun and Airgun Arrays?

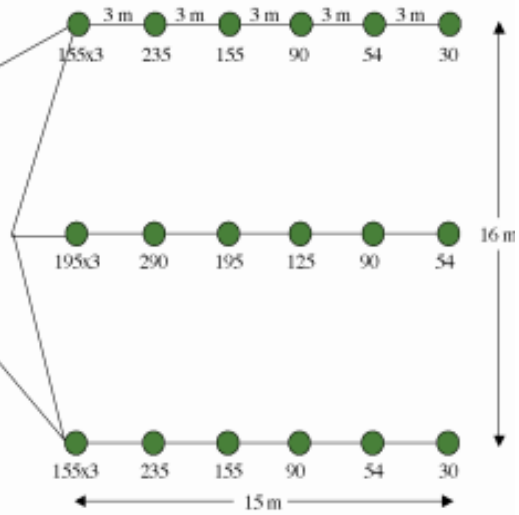




… every 10 sec, days to weeks

Airgun array

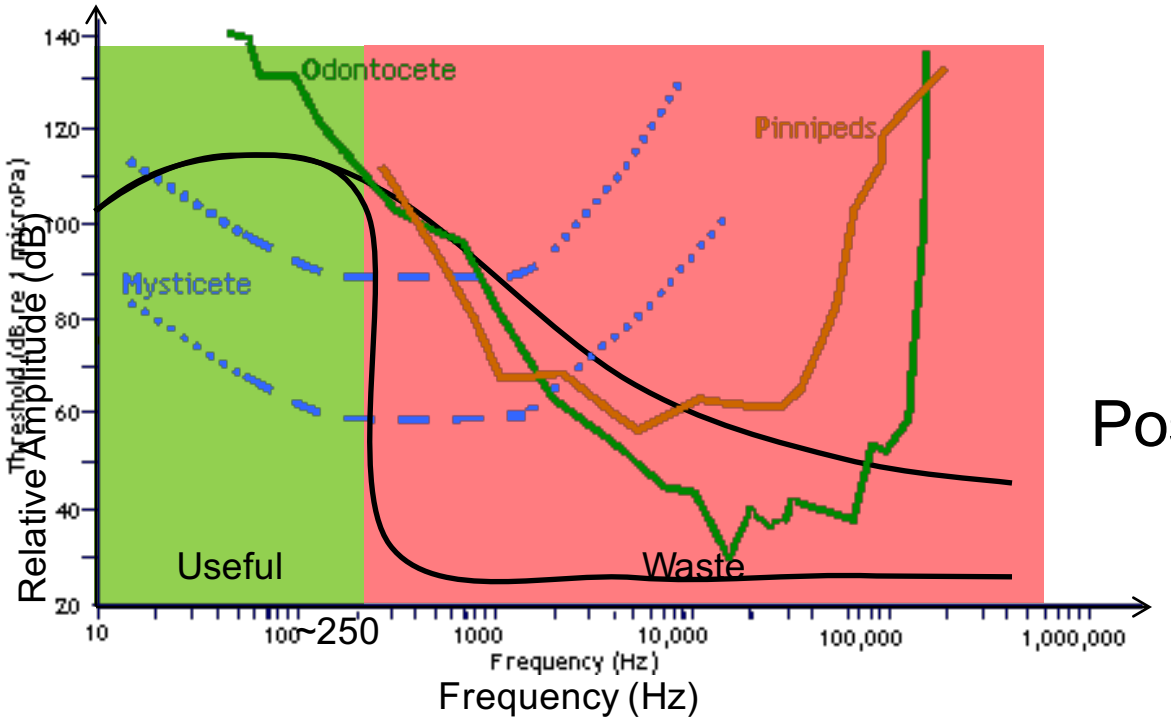




Airgun arrays:

- To reduce the bubble oscillations
- Increase the strength

Energy Spectrum of Airguns



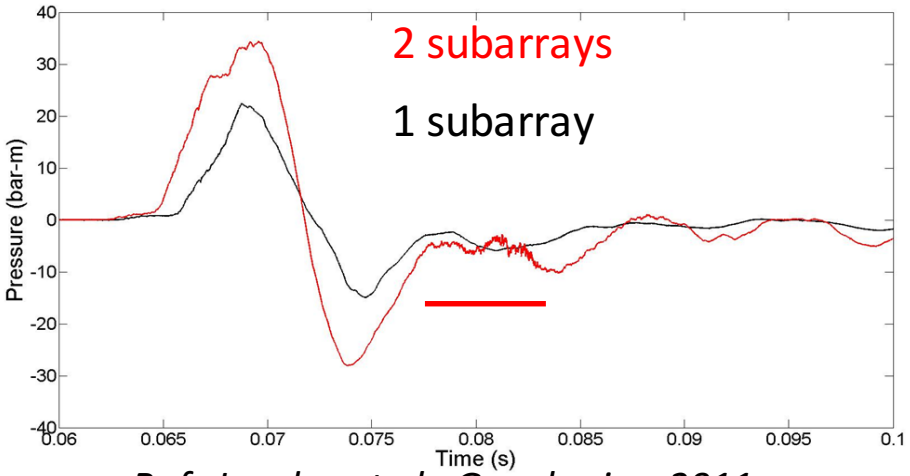
Possible?

Some of efforts to reduce high frequency contents of air-guns:

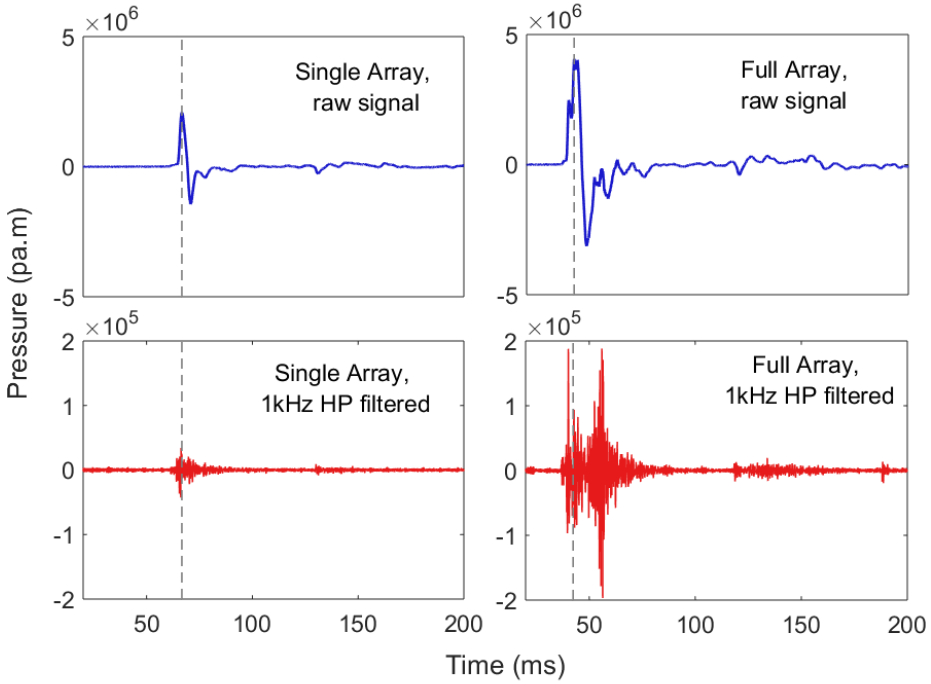
- Bolt/Schlumberger launched the eSource in 2014
- Airgun silencer (Nedwell et al, 2005)

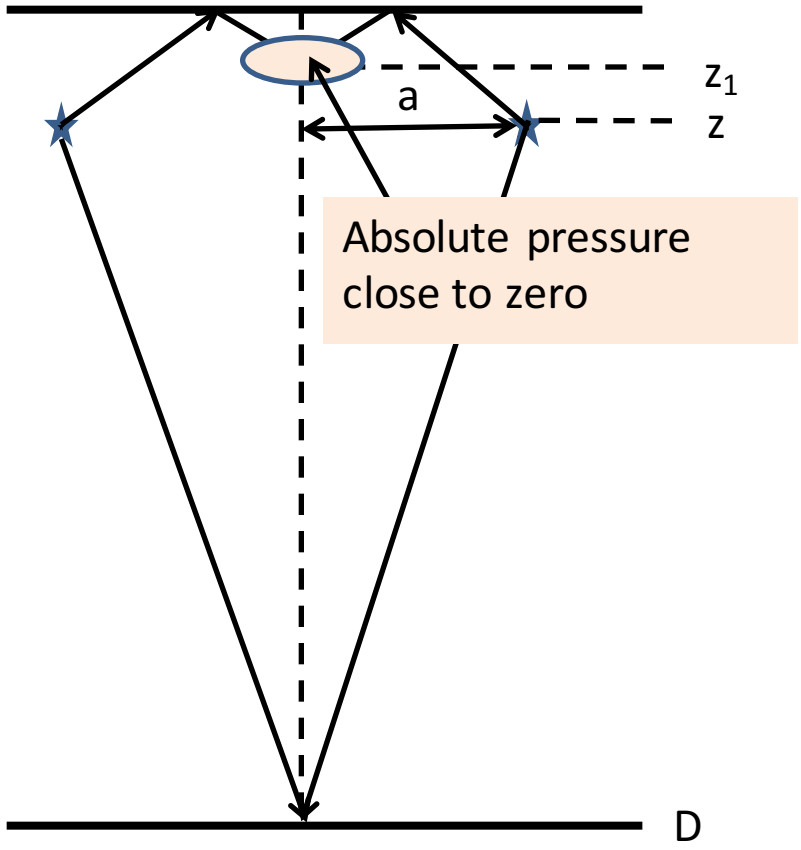
  maximum of 6 dB of attenuation (frequencies > 700 Hz) in 50 bar air guns

High frequency sound from air gun arrays: ghost cavitation



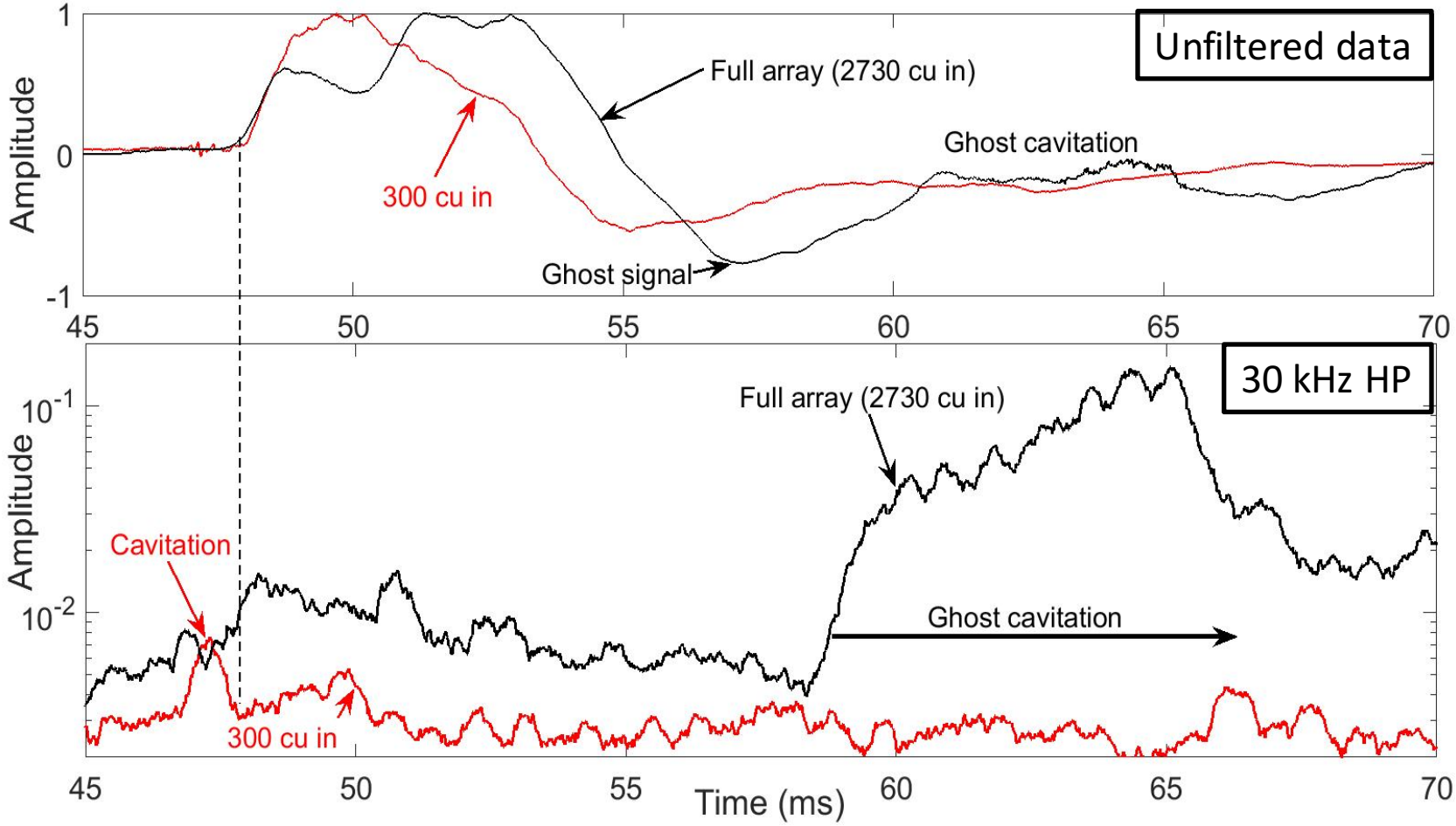
Ref.: Landrø et al., Geophysics, 2011





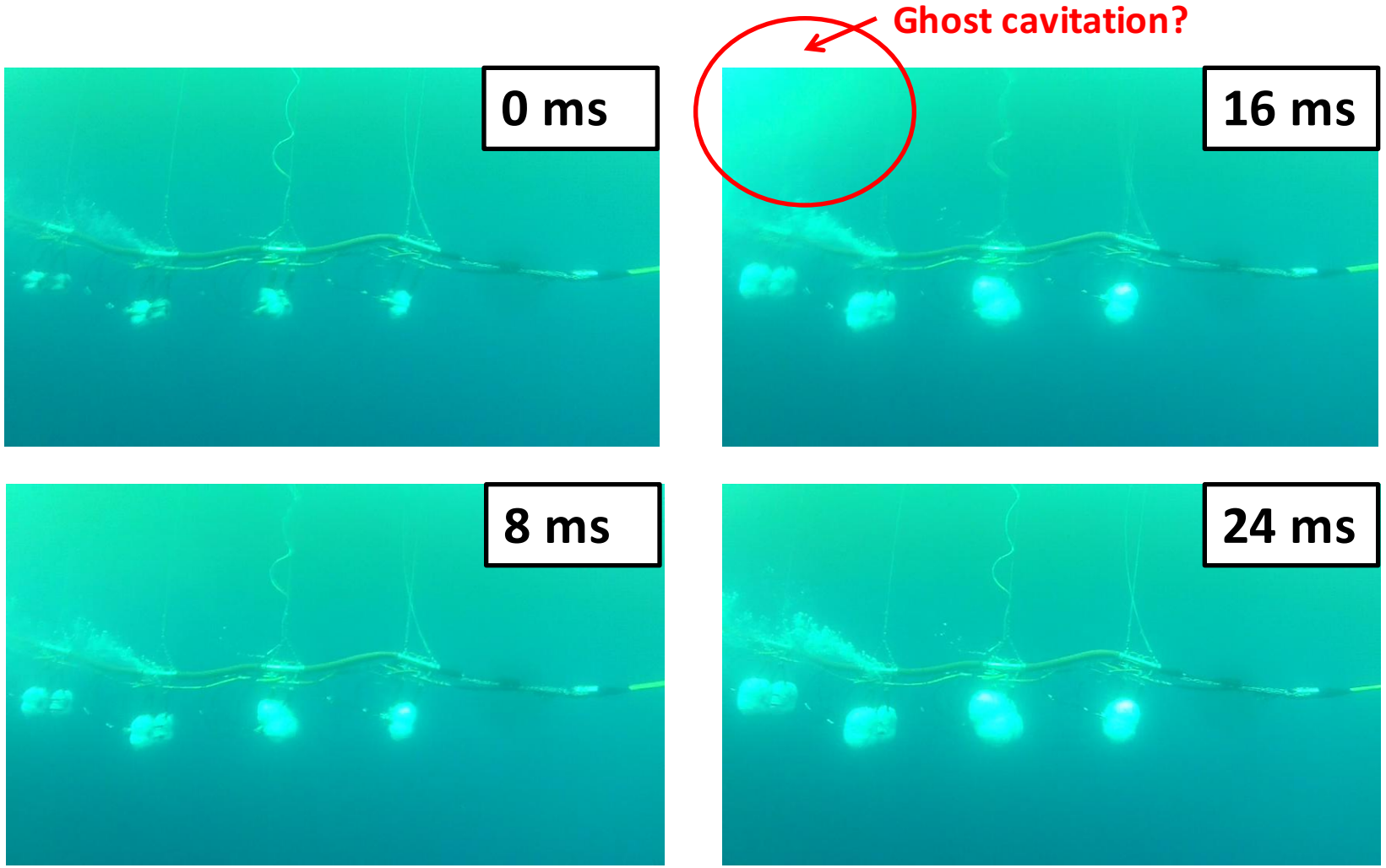
Absolute pressure close to zero

Comparison of single gun and large array



Landrø et al., 2016, Geophysics

Photos from high frequency experiment

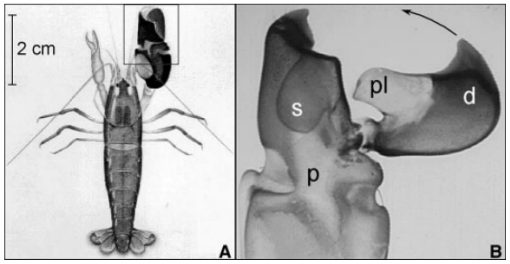


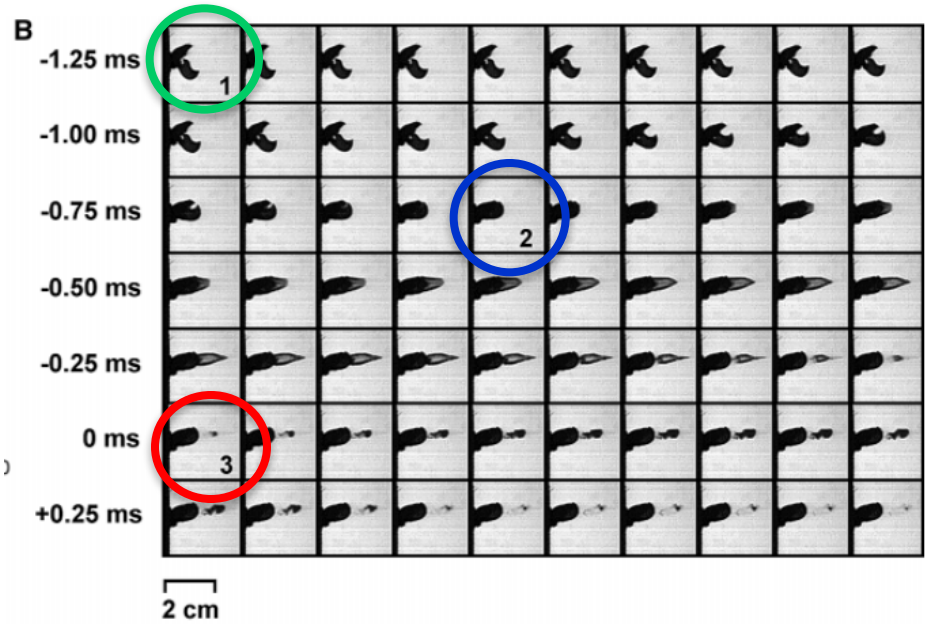
Landrø et al., 2016, Geophysics

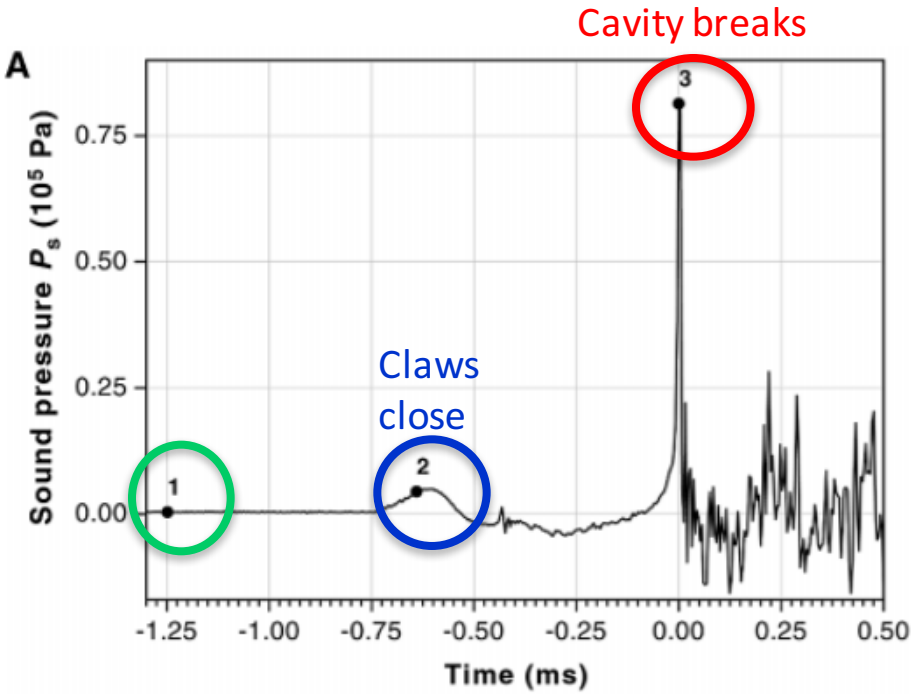
Expect cavitation between 7 and 14 ms, and close to surface

Nature's own cavity generator: The pistol shrimp

Pistol shrimp:







Versluis, M., et. Al.(2000). Science, 289(5487), 2114-2117.

Peak sound is not happened when full closure of the claw is achieved! **It is generated by cavitation!**

Field Test

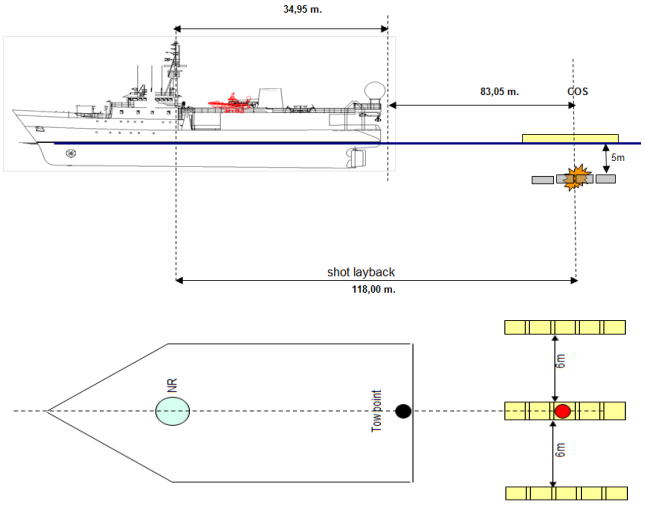
Black-sea offshore Turkey (2008)

Shooing Vessel: M/V Malene Ostervold

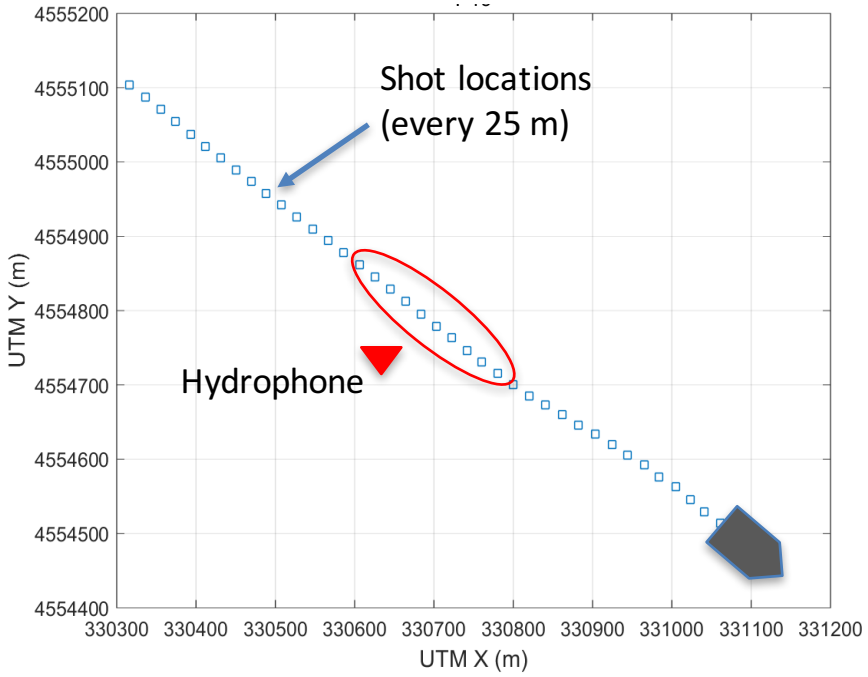
Several configurations of source array were tested:

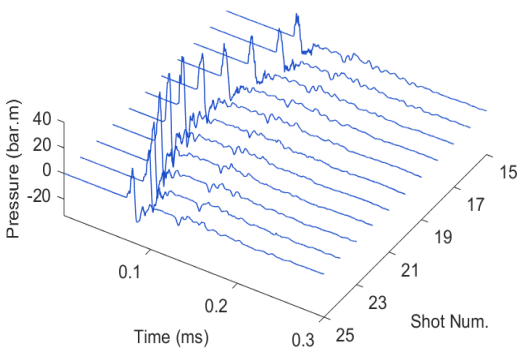
- Single gun
- Cluster
- Center Array
- Standad Array

Sampling Frequency: 125 kHz

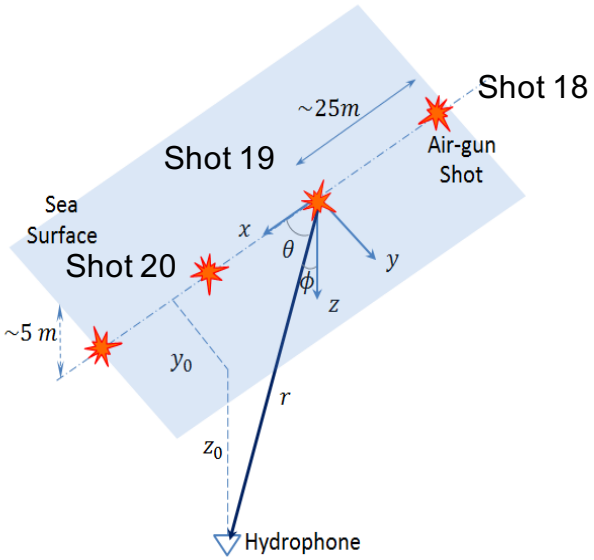


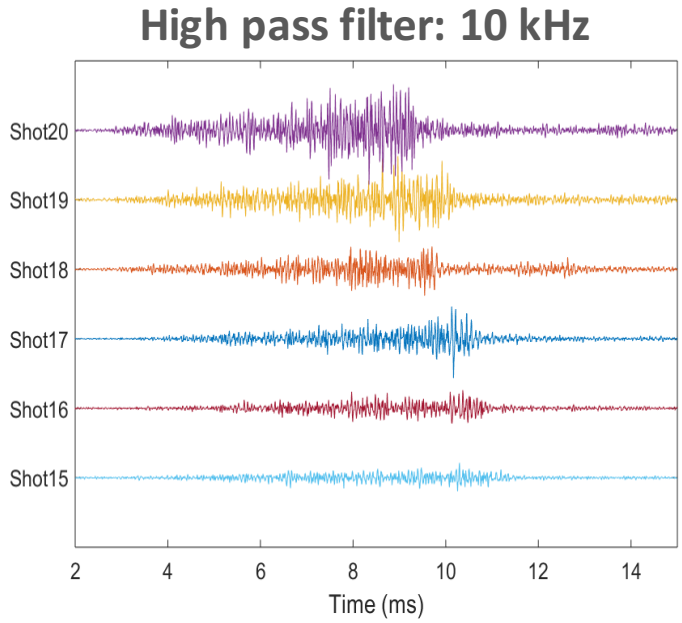
3 arrays of Airguns





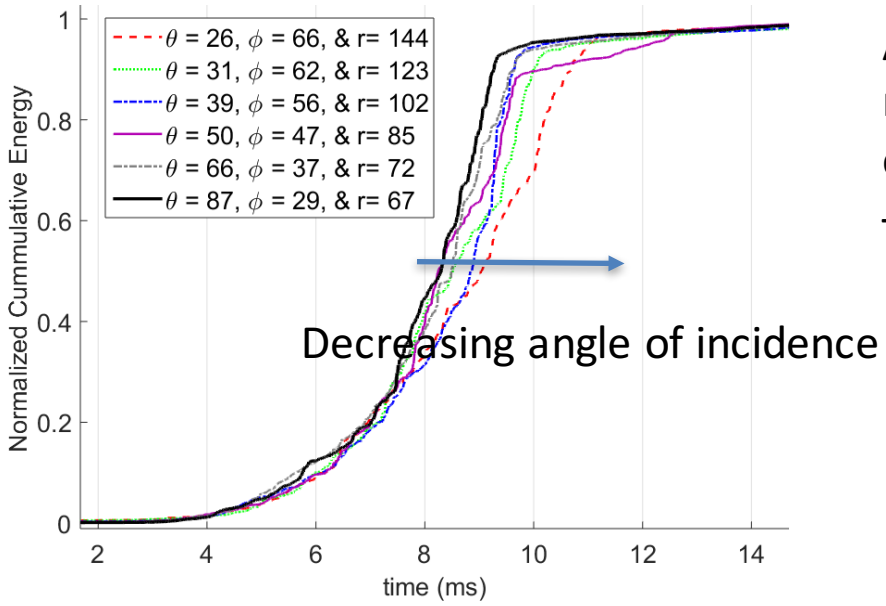
High frequency signal varies with angle





Variation in angle and distance

Cumulative energy for various incidence angles:



Decreasing angle of incidence

A spherical cavity cloud means identical energy curves (after normalization) – not observed

Cavity cloud is not spherical!

Can we determine the size and shape of the cavity cloud?

Modeling the ghost cavity signal:

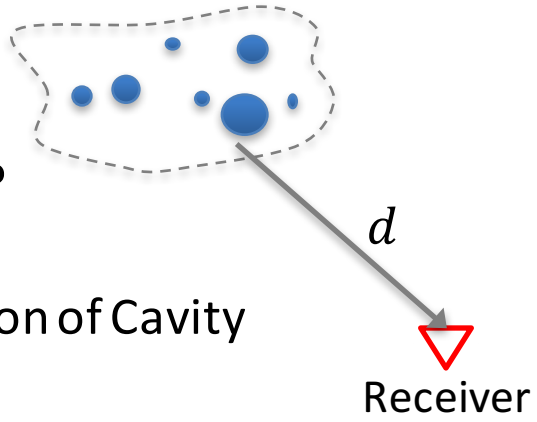
- Shape of Cavity Cloud (Spatial Distribution of Cavity bubbles)?

- Size of cavities?

- Number of cavities?

- Temporal Distribution of Cavity bubbles?

- Single cavity signature?



Different times from generation to record by hydrophone:

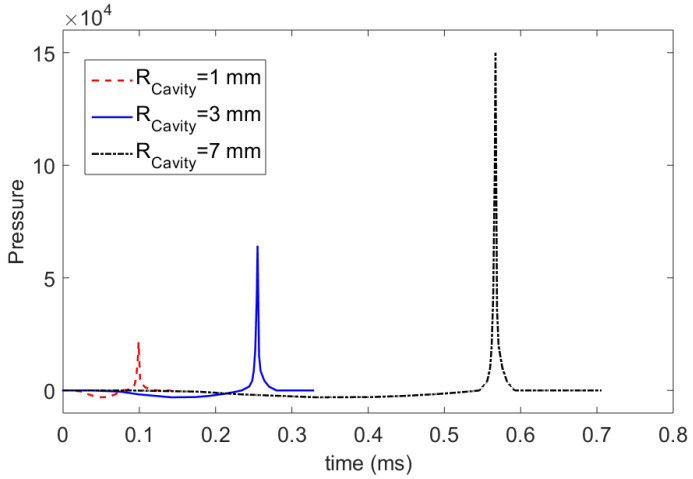
- Time of Formation of Cavity

- Time of traveling from cavity location to hydrophone: $t = \frac{d}{c}$

- Cavity collapse time (Rayleigh 1917)

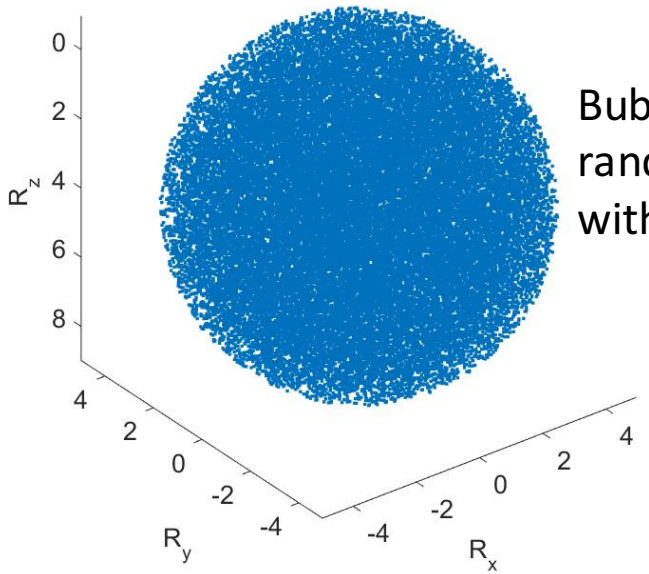
$$T = 0.915R\sqrt{\frac{\rho}{P_h}}$$

- R: Initial radius of cavity
- ρ : Density of water
- P_h: Hydrostatic pressure



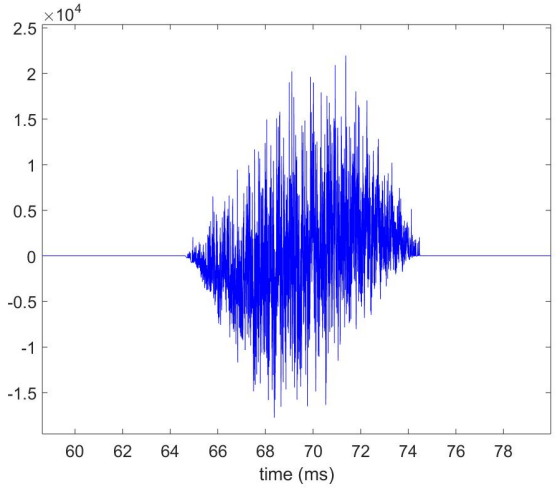
Larger the Cavity Bubble Radius, Longer the collapse time

Spherical Cloud



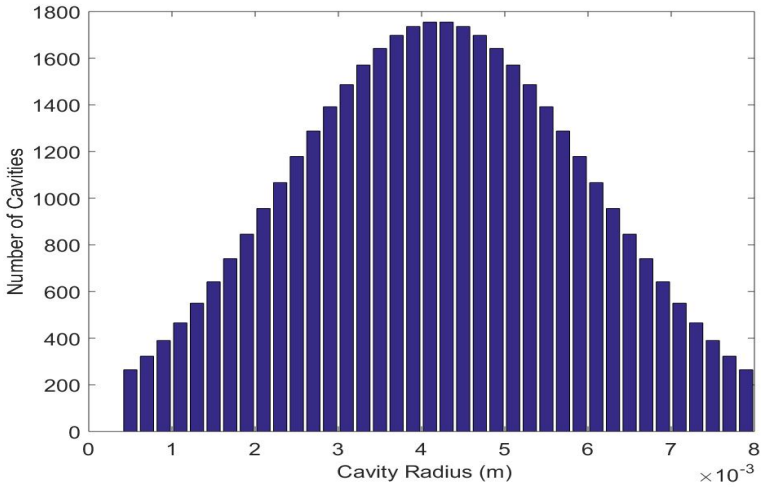
Bubbles Are randomly formed within **3 ms**

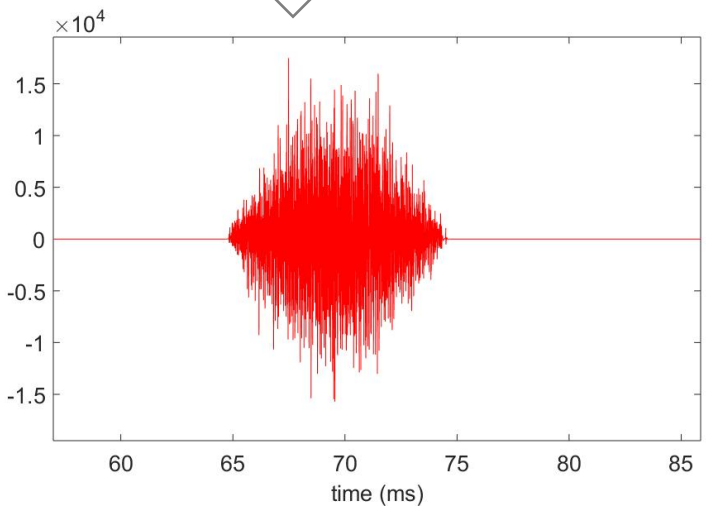
Raw Signal at receiver (shot 20):



10 kHz HP-filtered

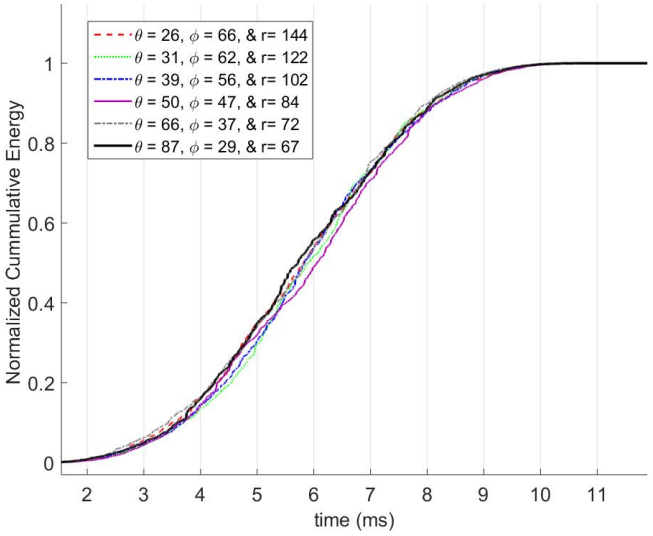
Distribution of Different Cavity bubble sizes:



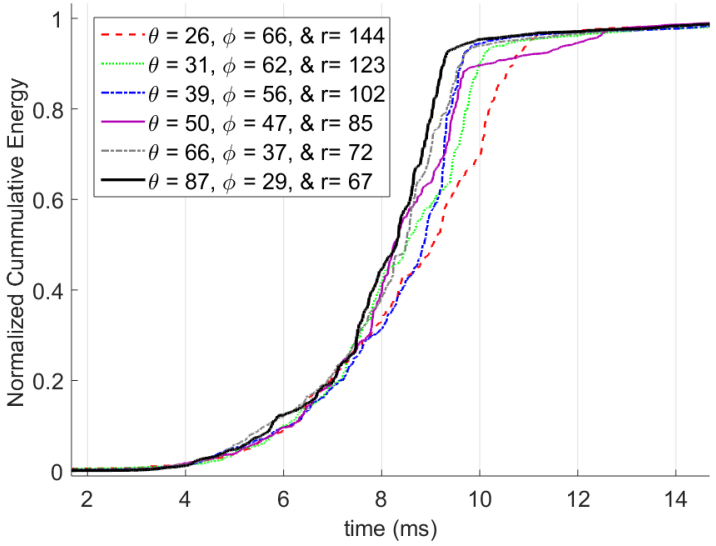


Spherical Cloud

Simulation

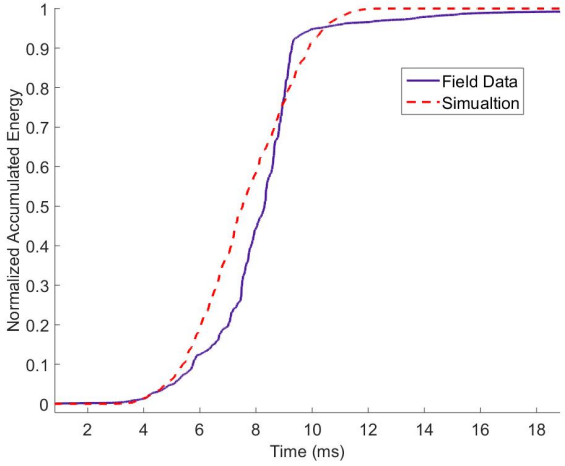


Filed Data



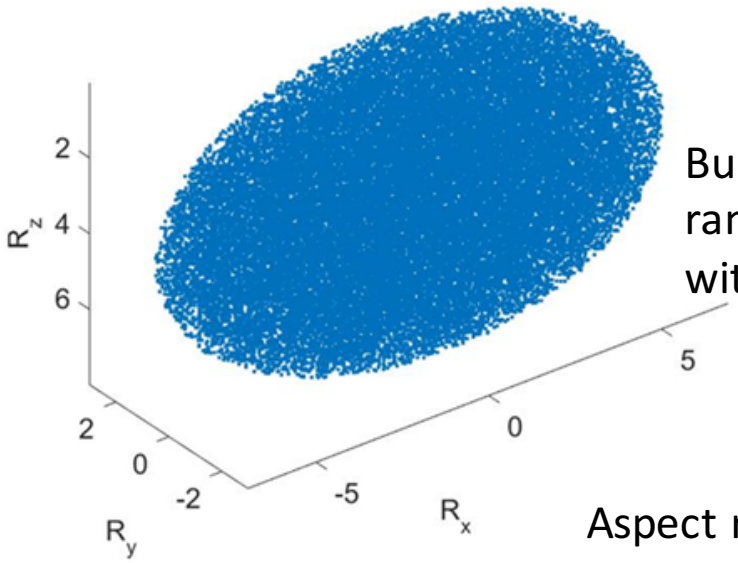
Normalized Accumulated Energy

(Comparison of Simulated and Measured Signal)



Assuming a spherical cloud does not work!

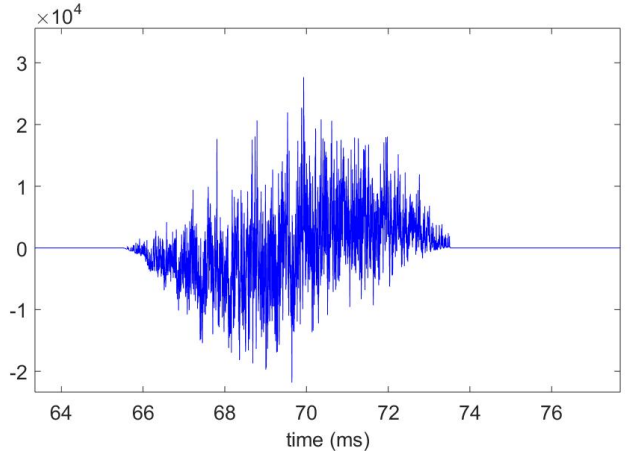
Ellipsoid shape cloud



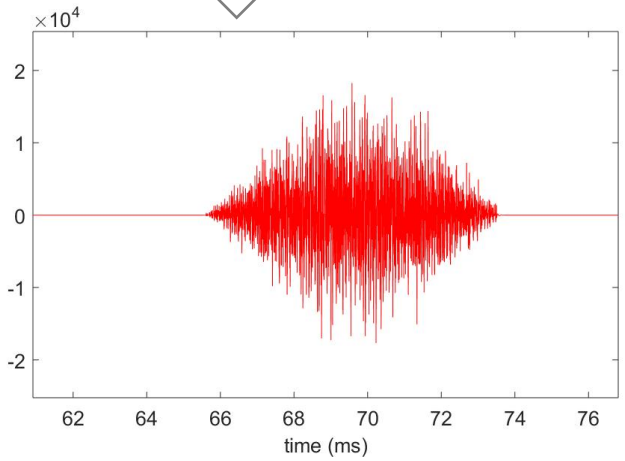
Bubbles Are randomly formed within **3 ms**

Aspect ratio: 2.3

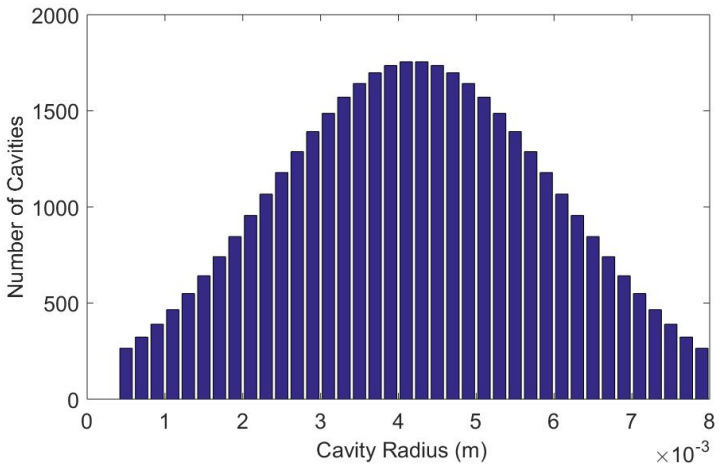
Raw Signal at receiver (shot 20):



10 kHz HP-filtered

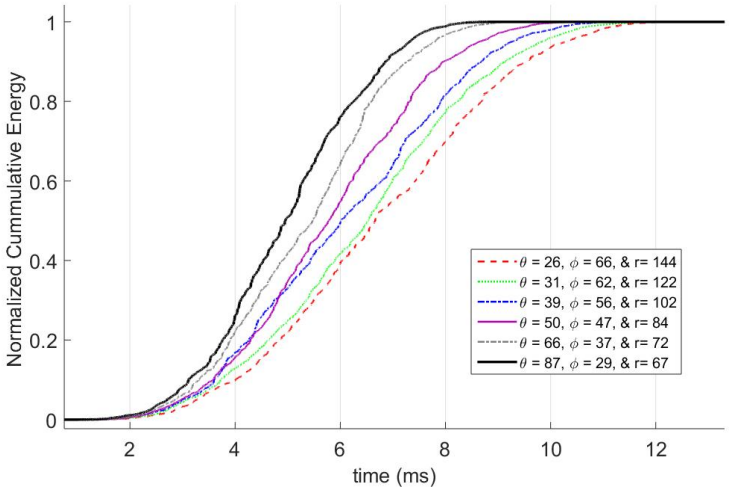


Distribution of Different Cavity bubble sizes:



Ellipsoid shape cloud

Simulation



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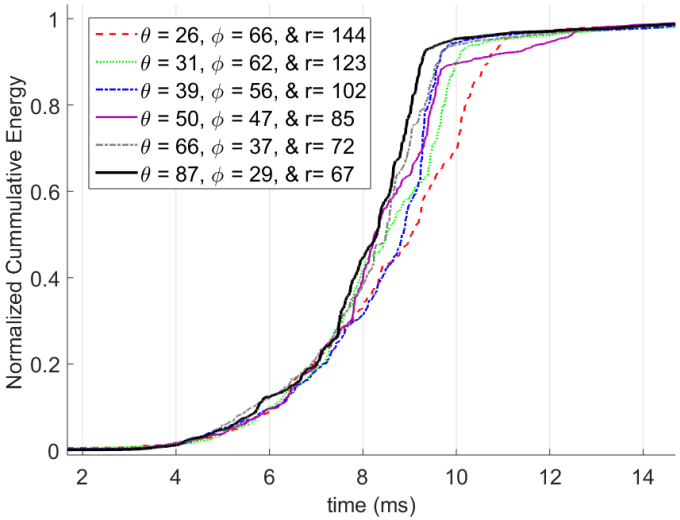
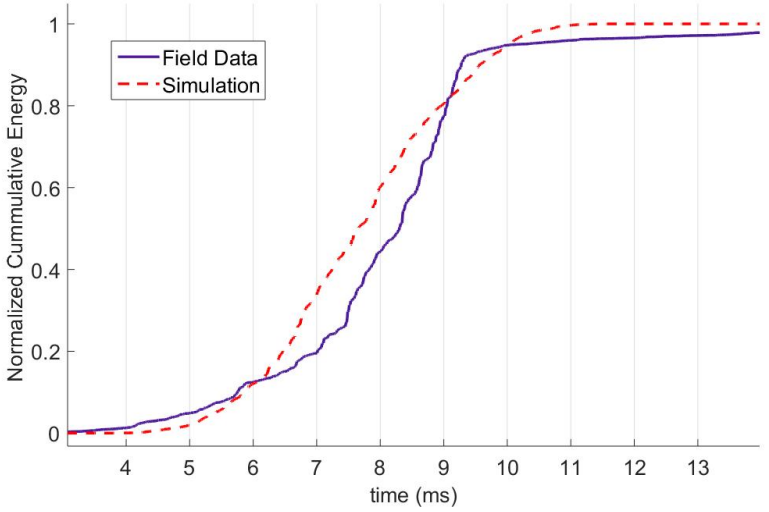


Normalized Accumulated Energy

(Comparison of Simulated and Measured field Signal)

Ellipsoid shape cloud is better than spherical, But still not doesn't capture the field data!

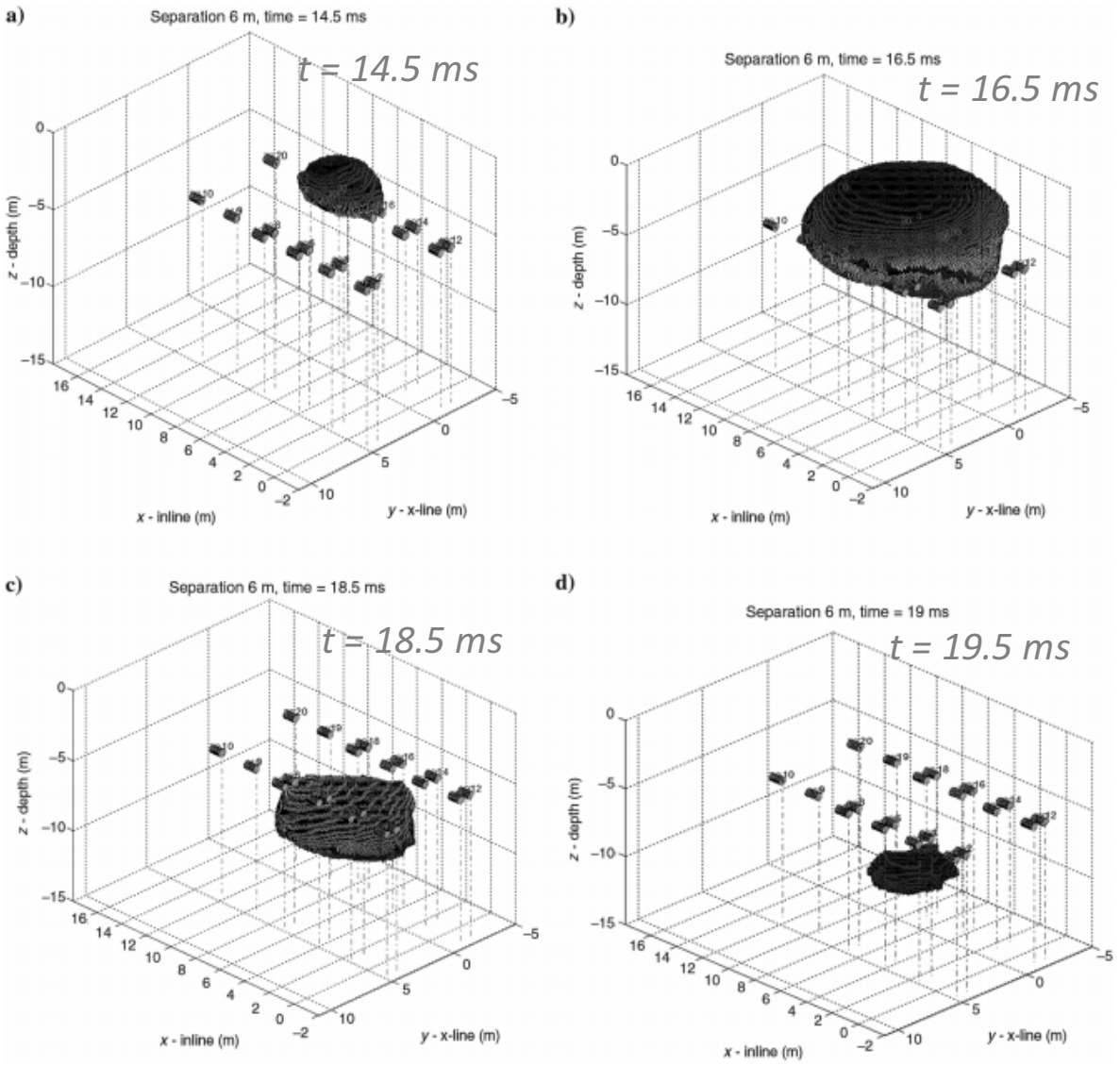
There should be a progressive Formation of the cloud!



Ghost cavitation cloud predicted by source modeling software

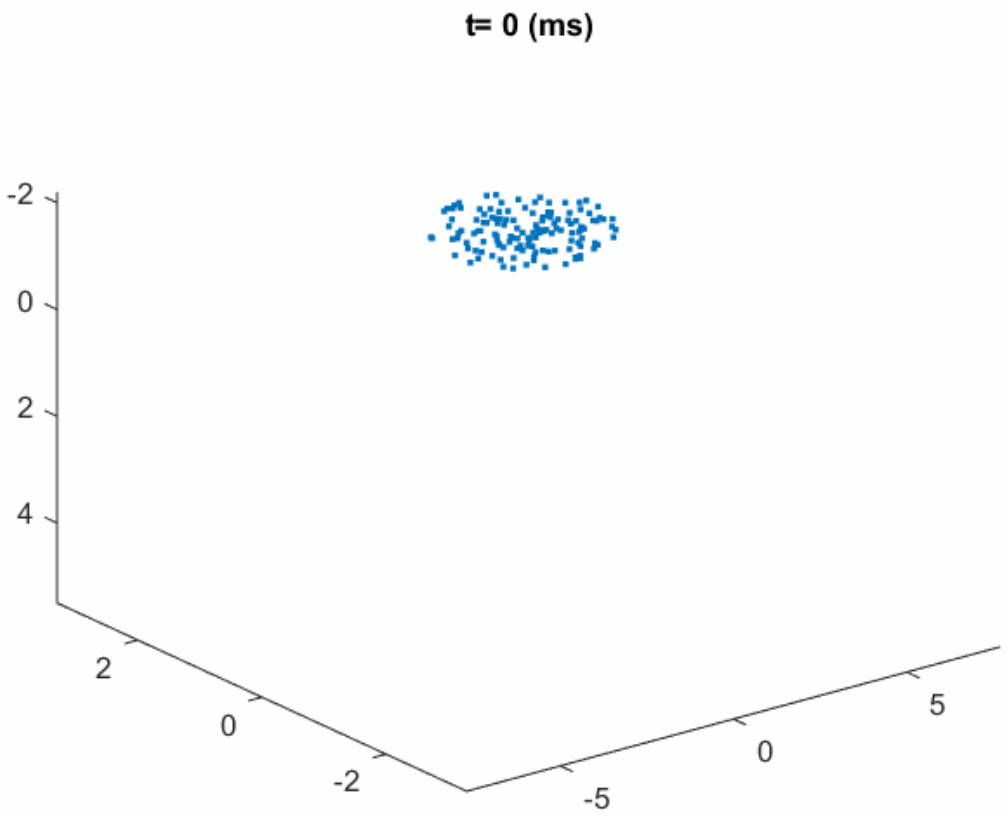
Ghost Cavitation Cloud predicted by **NUCLEUS** (source modelling Software)

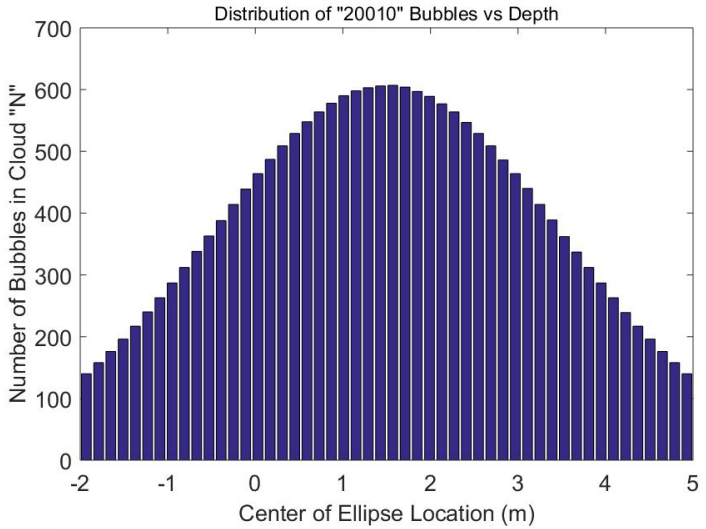
The results from NUCLEUS shows progressive formation of the Ghost cavitation cloud.

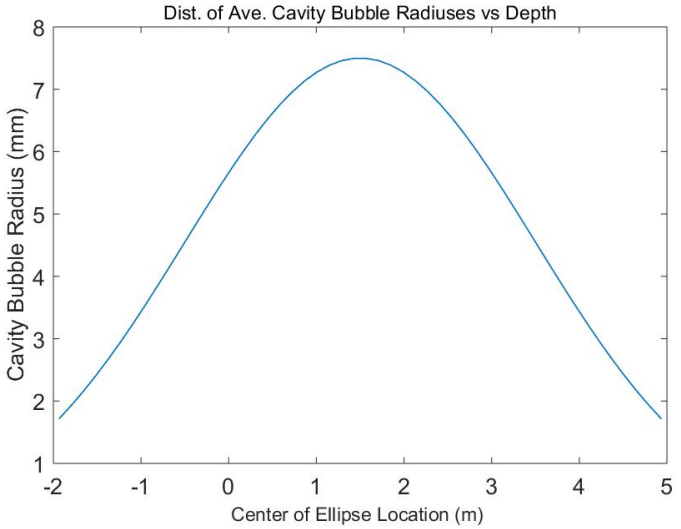


Landrø et al., 2016, Geophysics

Modeling Progressive Formation of the Ghost cavitation cloud:



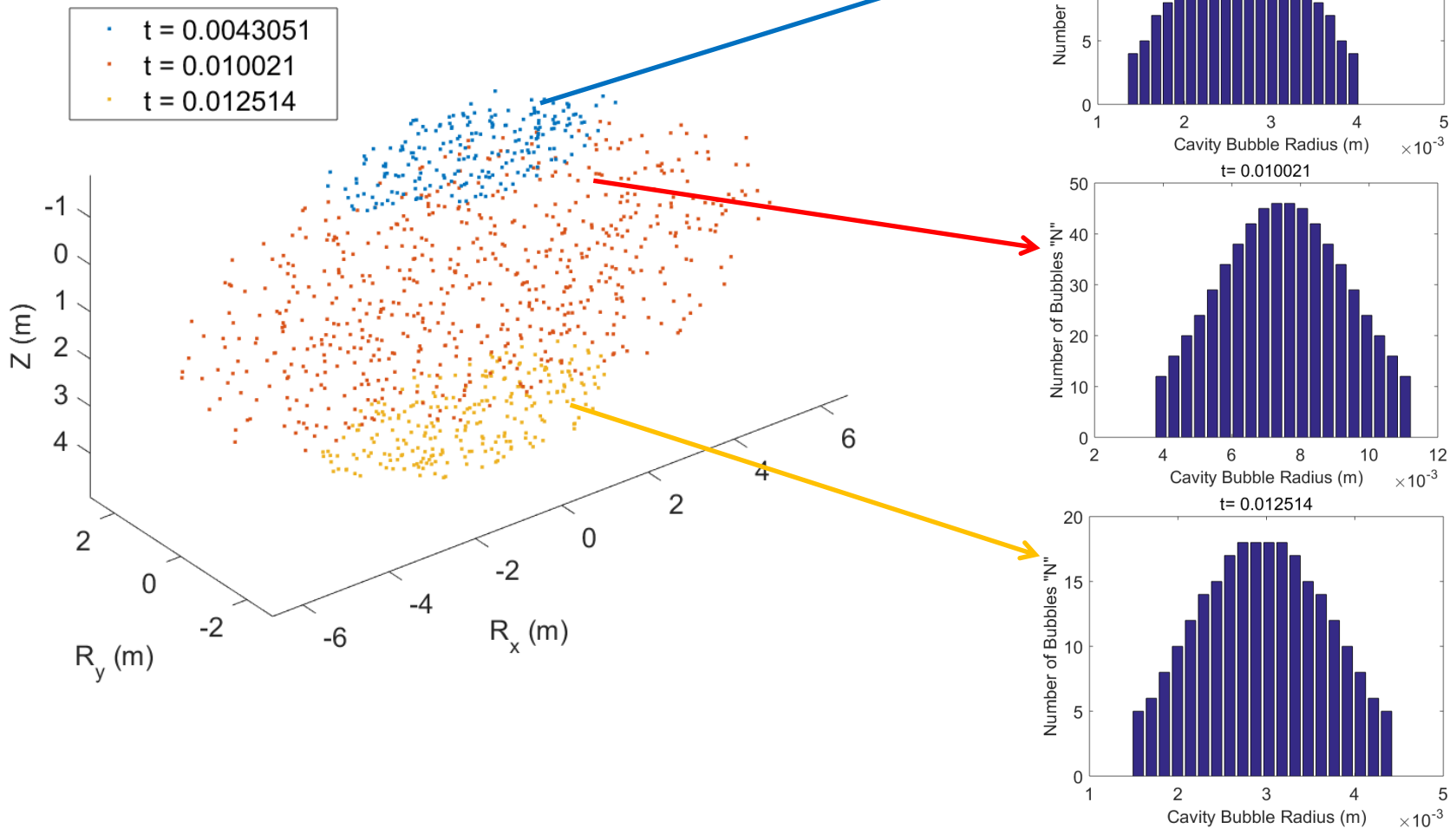




Gross aspect ratio for the cavity cloud: 2.3

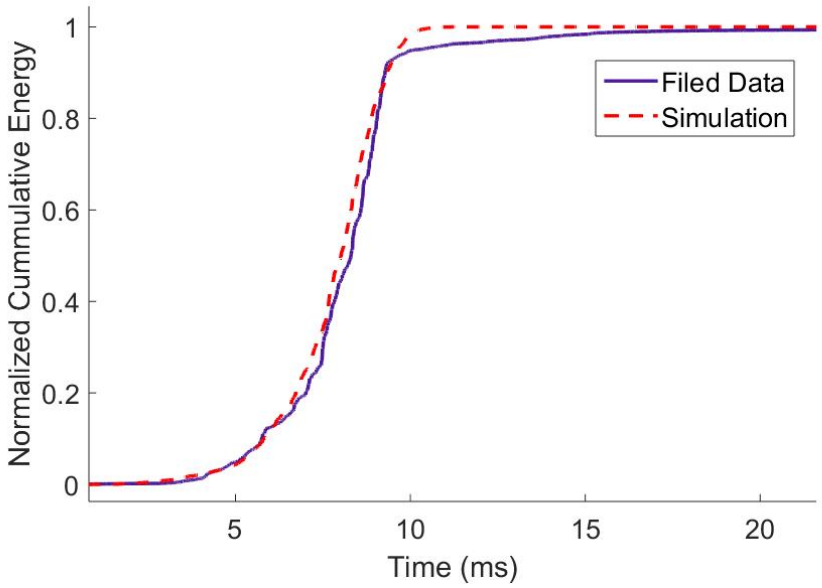
Modeling Progressive Formation of the Ghost cavitation cloud:

Distribution of cavitation bubbles' radiuses at each time:

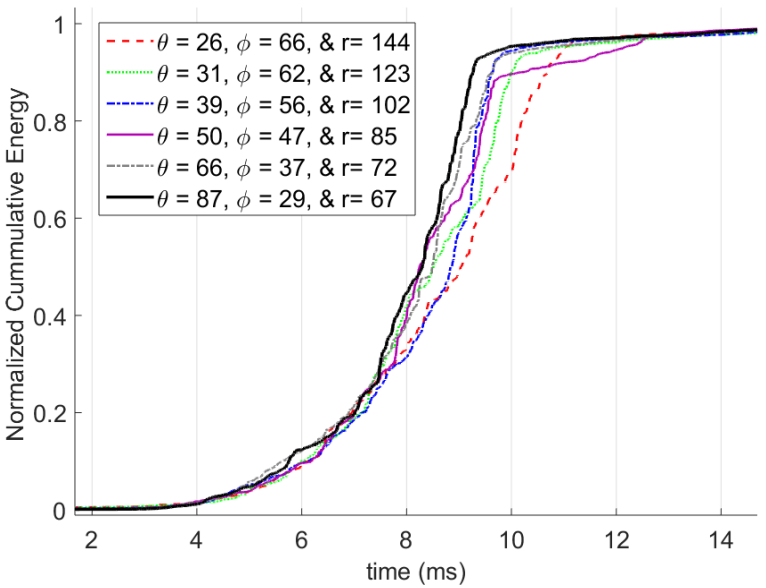


Results of Progressive Formation of the Ghost cavitation cloud:

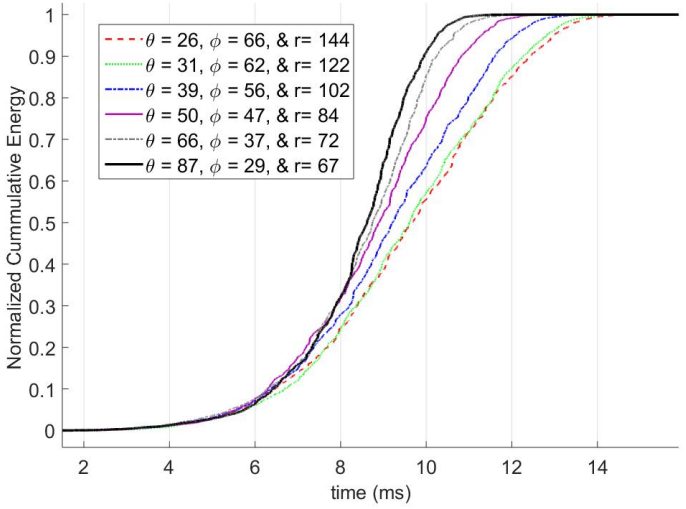
Normalized Accumulated Energy
(Comparison of Simulated and Measured field Signal)



Filed Data



Simulation



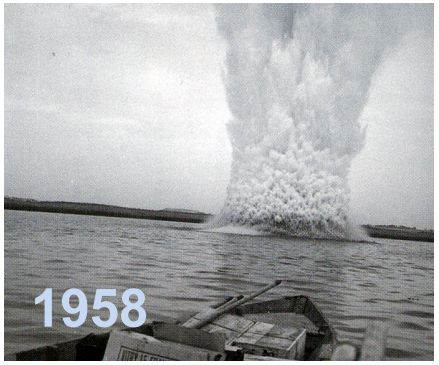
Conclusions

- The ghost cavitation hypothesis is confirmed by comparison between modeled and measured high frequency data
- There should be a progressive creation of cavity bubbles
- The rate of cavity creation should be non-uniform!
- Possible to reduce the amount of cavitation noise by increasing the distance between airgun subarrays

Various marine seismic sources

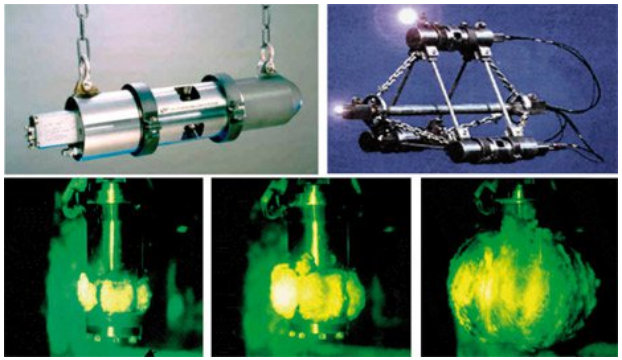
Impulsive:

Pre-1960: Dynamite



http://www.cgg.com/

Air gun: 1960 Repeatability and safety

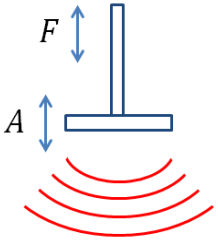


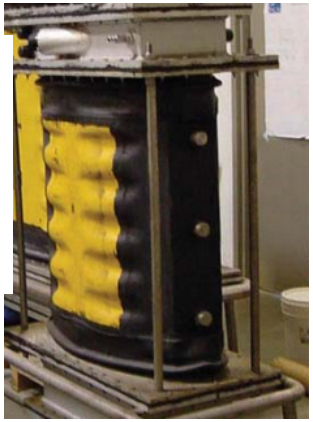
http://www.geoexpro.com/articles/2010/01/marine-seismic-sources-part-i

- Air gun used for **95**%

Alternatives:

Marine Vibrators (Mid 1960s)



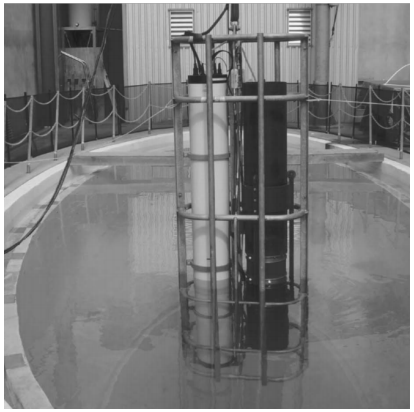


R. Tenghamn (2006). Exploration Geophysics, 37(4), 286-291.

Low-level Acoustic Combustion Source

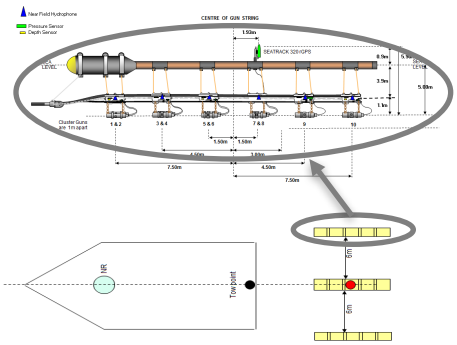
Askeland, B., et .al. (2009). *J of Appl. Geop.*, *67*(1), 66-73.

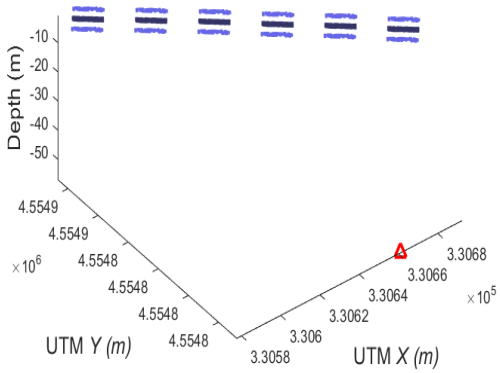
Underwater tunable organ-pipe sound source



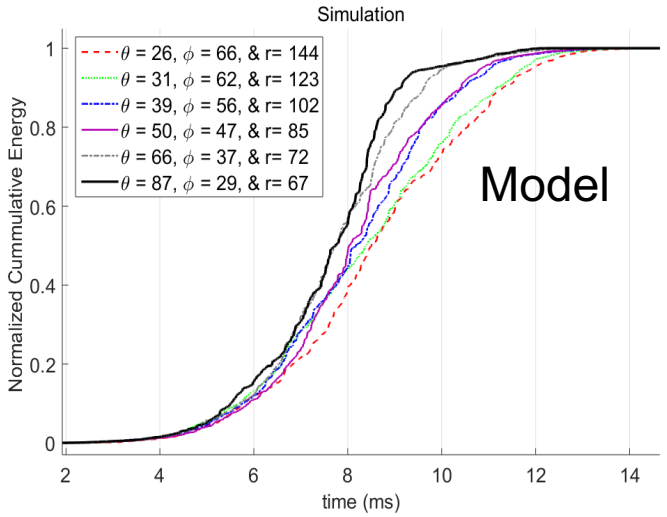
Morozov, A. K., et al.(2007). *The J of the Acoust. Soc. of Am.* , *122*(2), 777-785.

Ghost Cavitation – Cavitations around structure

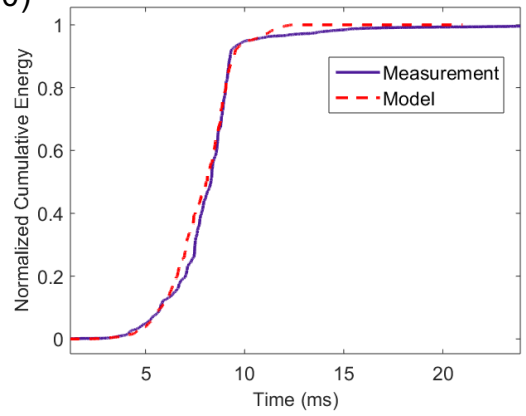


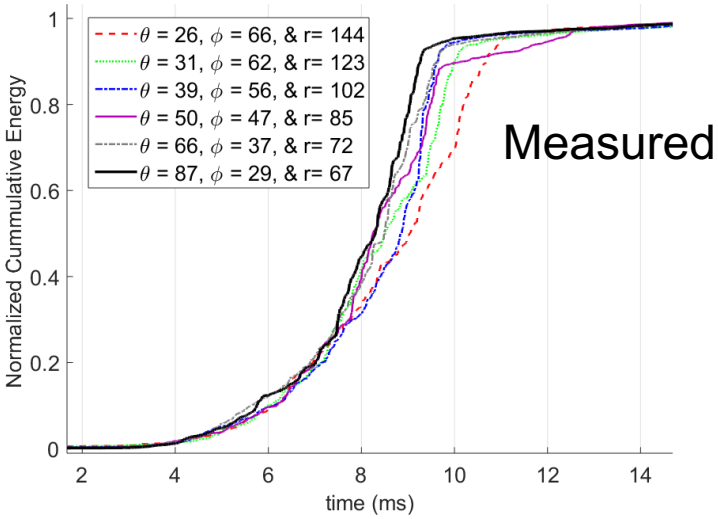


Accumulated Energy of simulated signal for shots 15 to 20

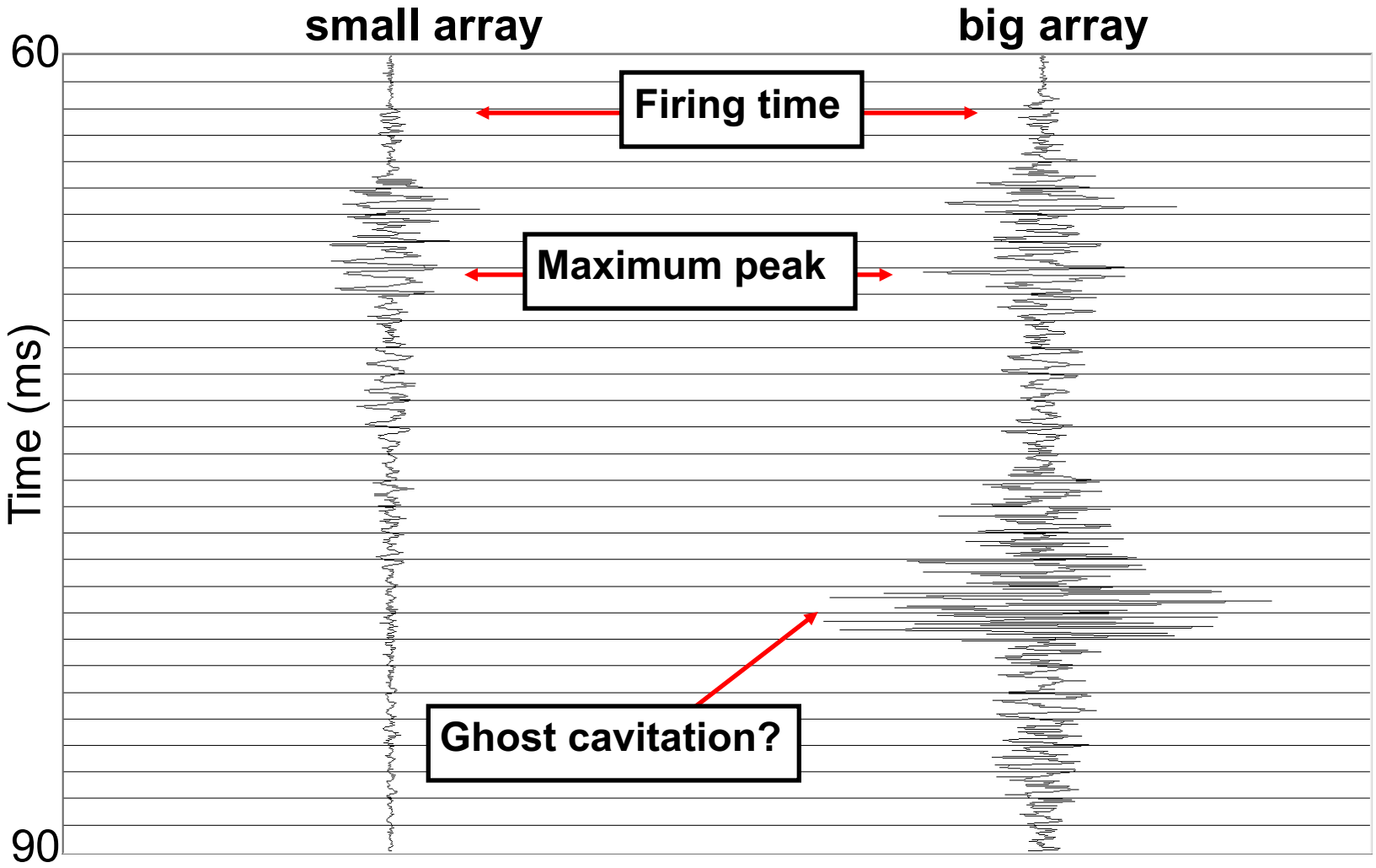


Accumulative energy of simulation and measurement for the nearest shot (No. 20)

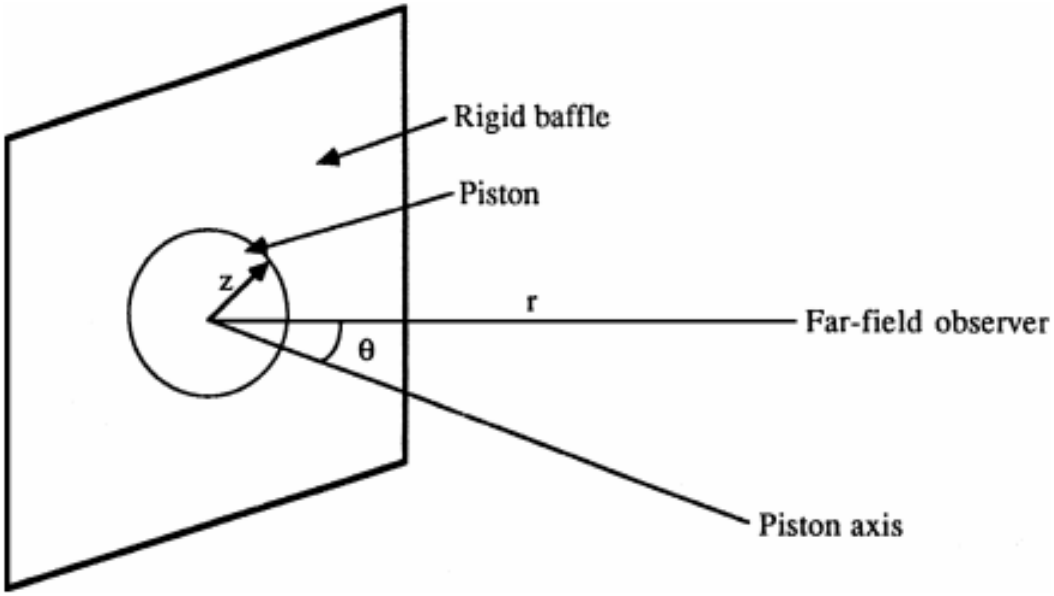


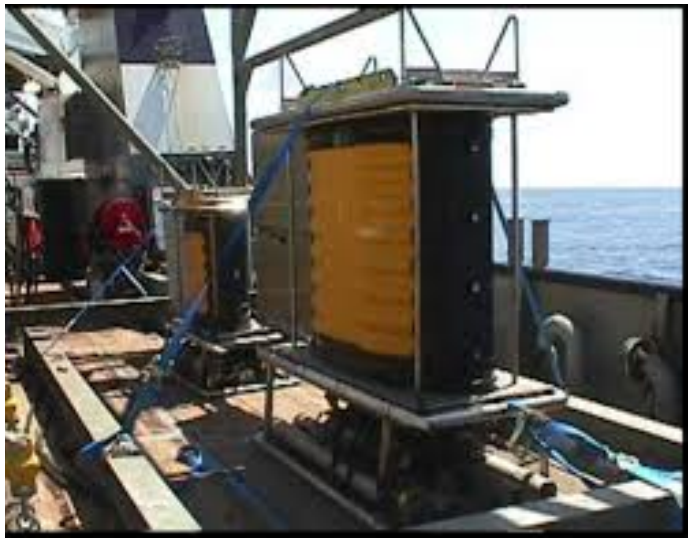


1 kHz high pass filter



Airgun is still the preferred marine seismic source - what about marine vibrators?





- Need a big piston to create low frequencies
- Marine vibrators become large and impractical
- Long sweeps are challenging for marine acquisition