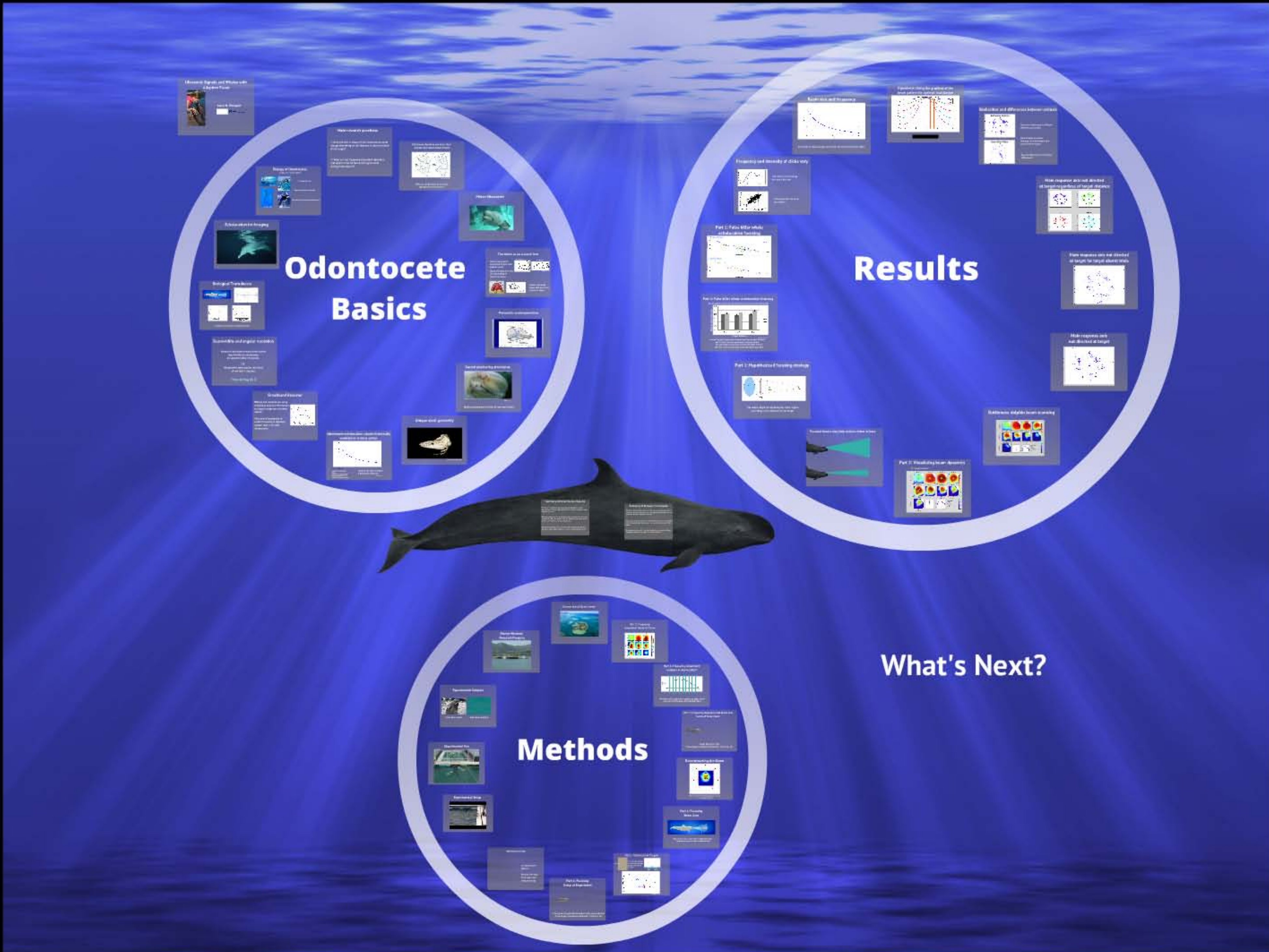
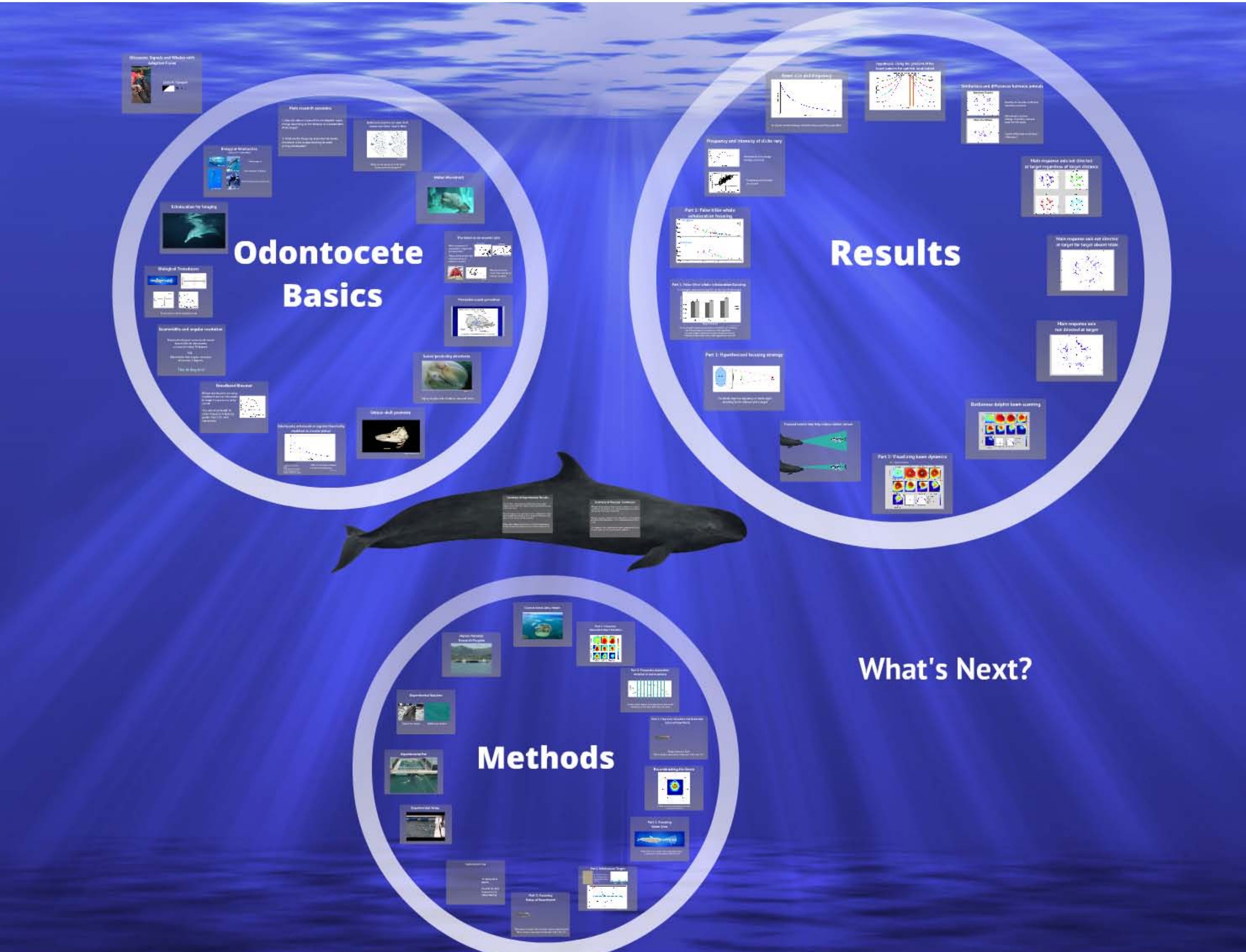

Odontocete
Basics
Results
Methods
What's Next?

Ultrasonic Signals and Whales with Adaptive Focus

Laura N. Kloepper

BROWN UMass | Dartmouth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Laura N. Kloepper
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The melon as an acoustic lens
Muscles surround melon that may act to control its shape
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Produce short, intense, broadband clicks
Pneumatic sound generation
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How do they do it?
Sound producing structures
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Whales and dolphins are using broadband spectral information to image in ways we currently cannot.
The ratio of bandwidth to center frequency is typically greater than 1 for most odontocetes
Unique skull geometry
Odontocete echolocation signals historically modeled as circular piston
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Summary of Experimental Results
Summary of Biosonar

Biology of Odontocetes

Odontocete = Toothed Whale

Sperm whale

Bottlenose dolphin

False Killer Whale

Killer whale

72 known species

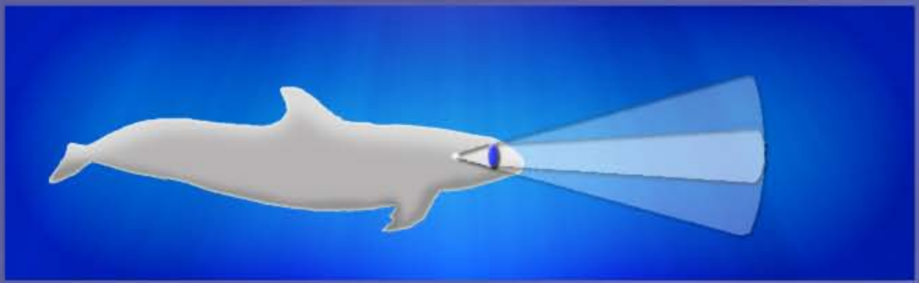
Sound generator in forehead

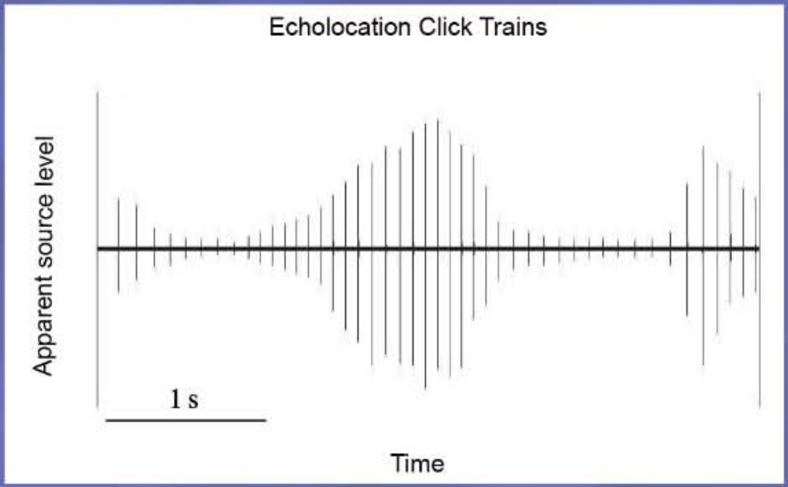
Uses fat filled melon as acoustic lens

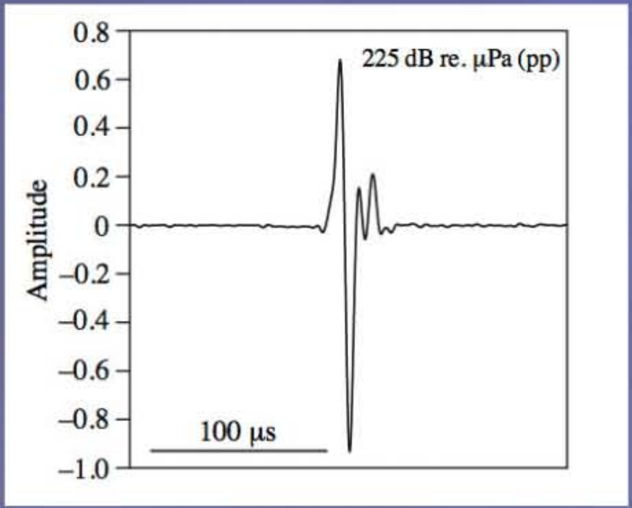
Echolocation for foraging

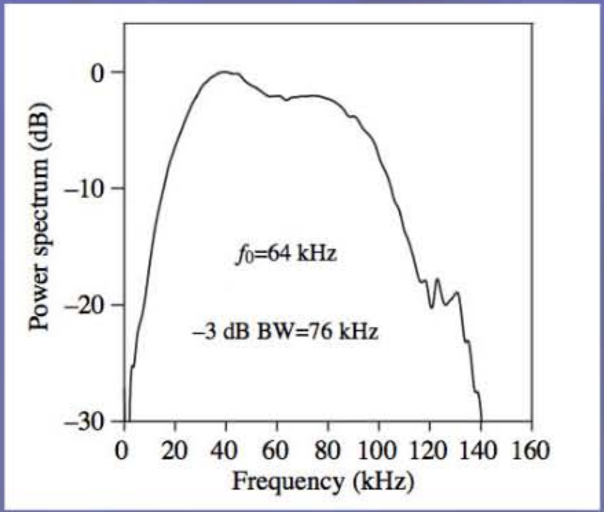
Echolocation for foraging

Biological Transducers









From Madsen et al., 2005

Produce short, intense, broadband clicks

Beamwidths and angular resolution

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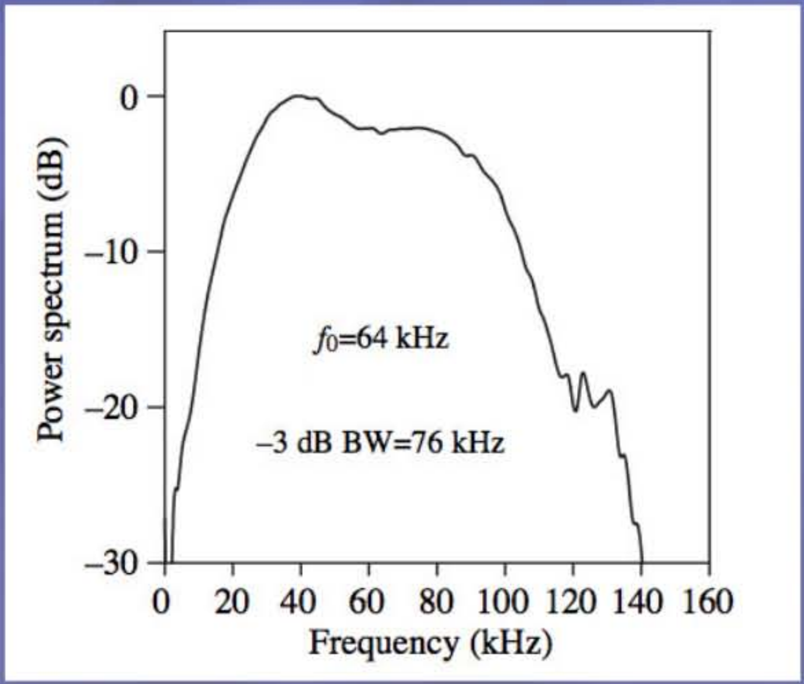
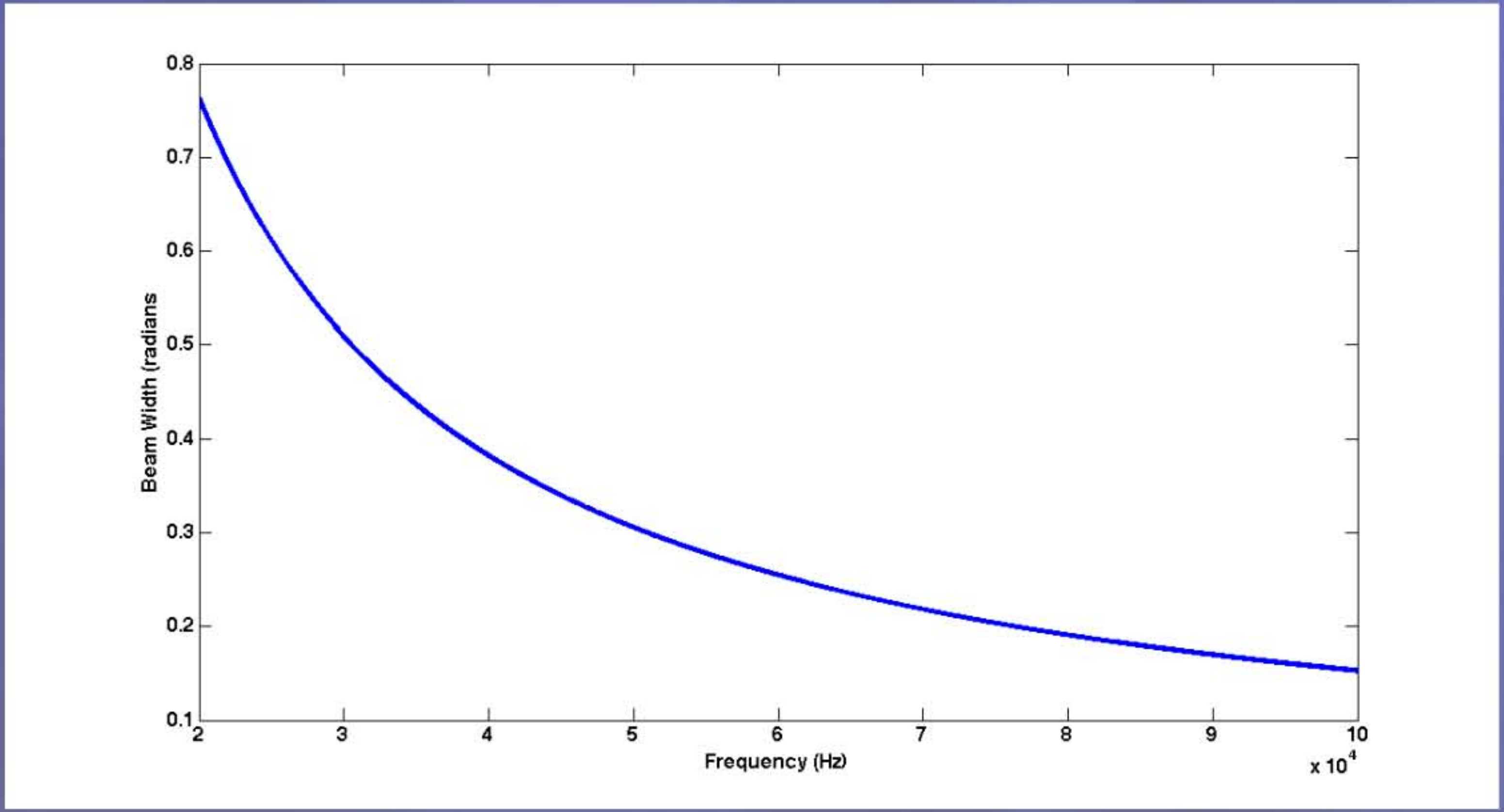


Odontocete echolocation signals historically modeled as circular piston



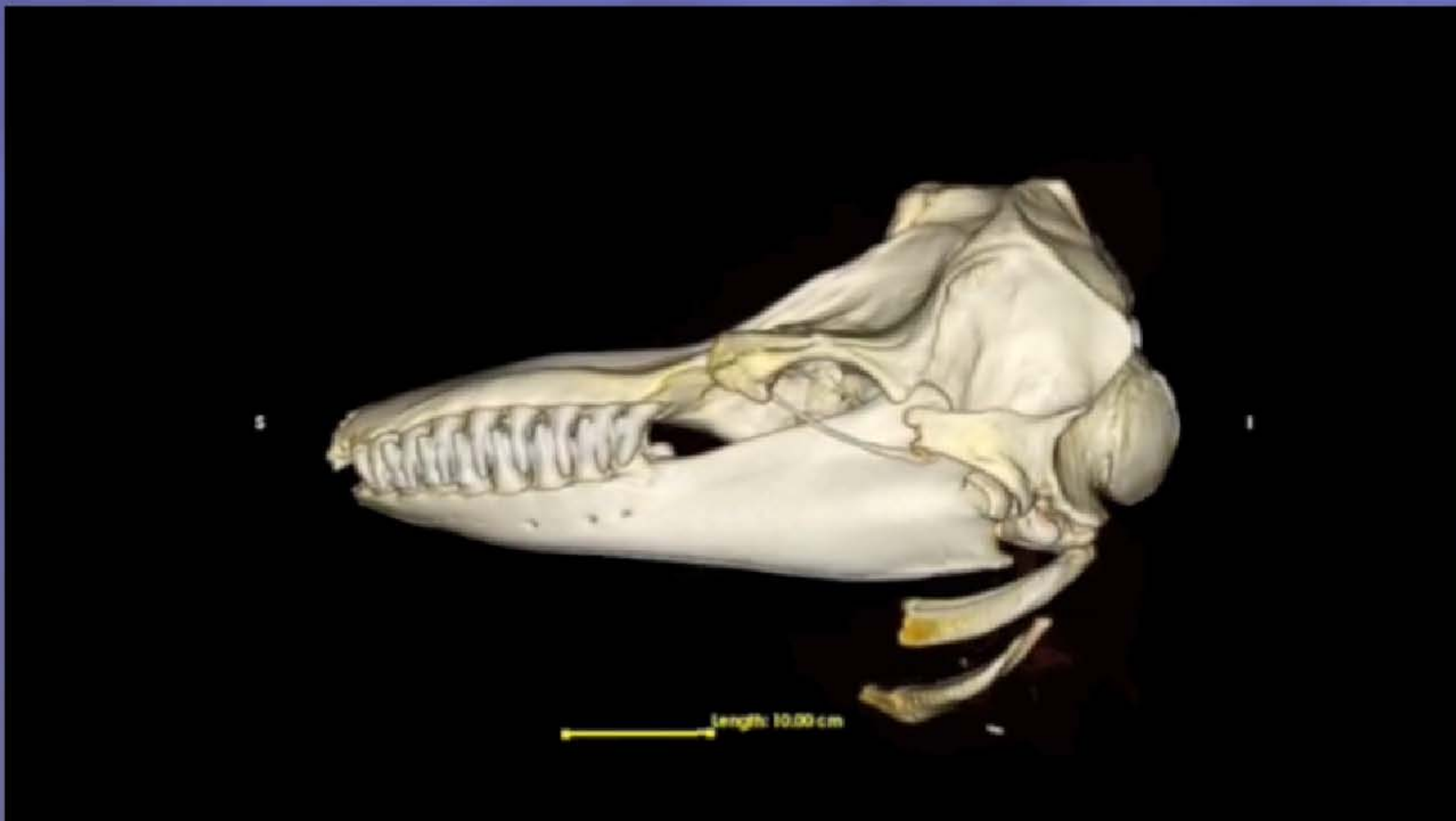
$$\Theta = 3.2/(\pi d/\lambda)$$

Assuming a circular piston
Where
Theta= Beam Width (radians)
d= size of aperture (10 cm)
lambda= wavelength of signal

Width of the beam is always a function of frequency

From Au, 1978

Unique skull geometry



Courtesy Darlene Ketten, WHOI

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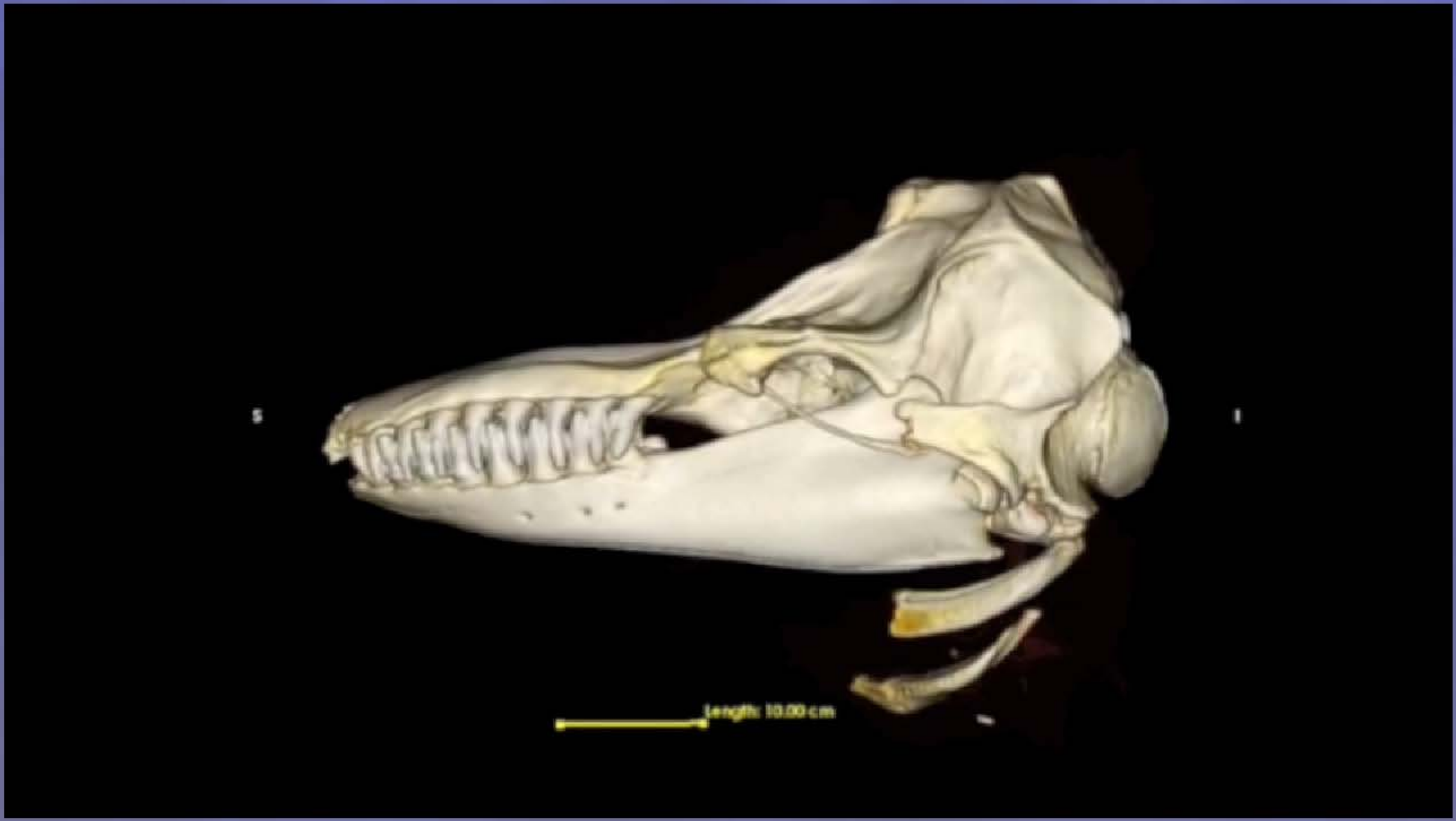


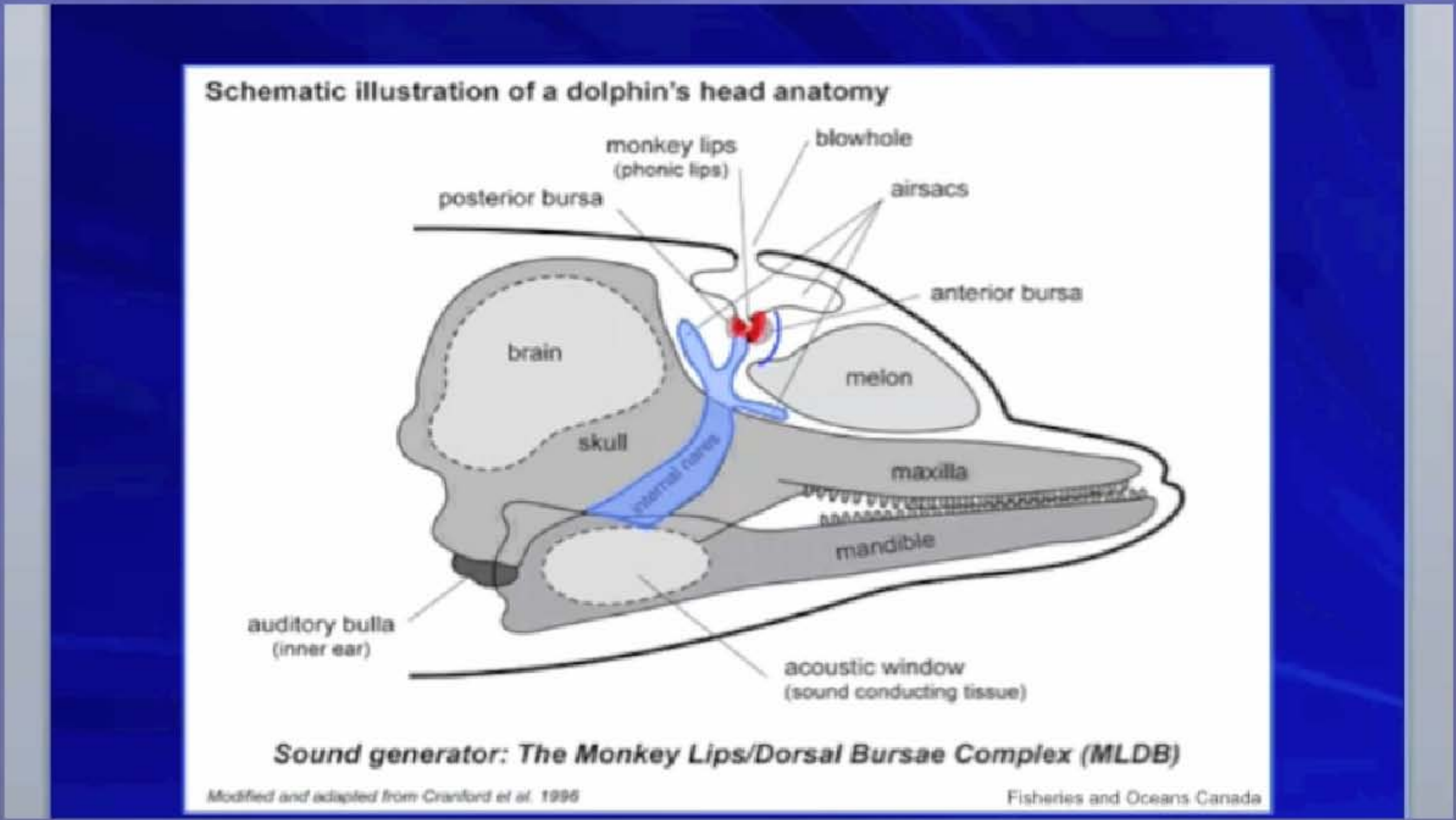
Courtesy Darlene Ketten, WHOI

Sound producing structures

Cranford et al., 1996

Highly complex and include air sacs and melon

Pneumatic sound generation



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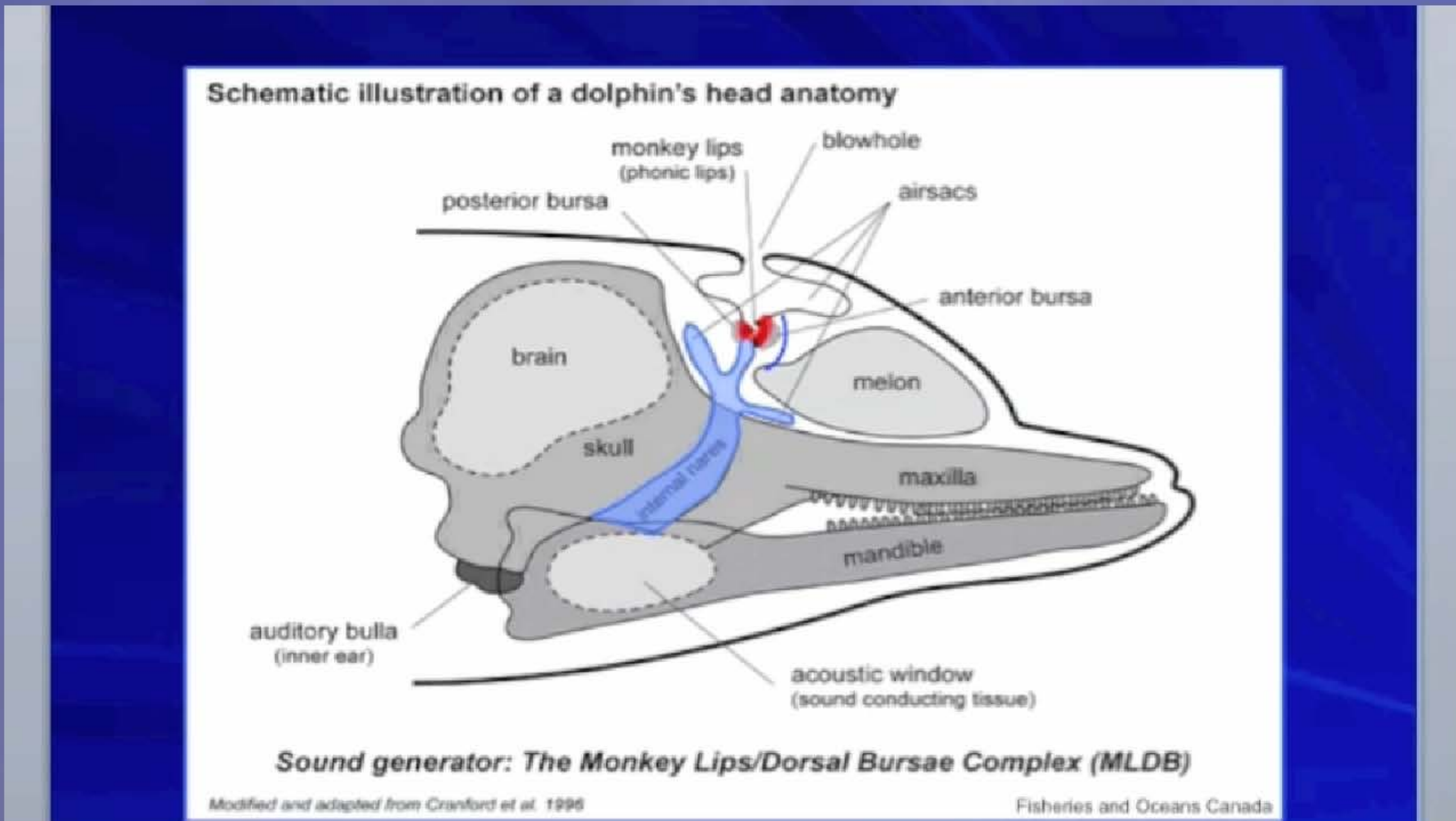
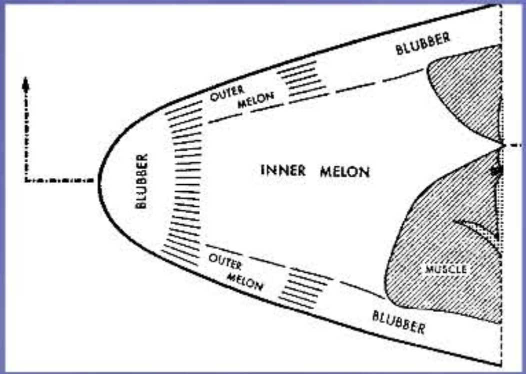


The melon as an acoustic lens

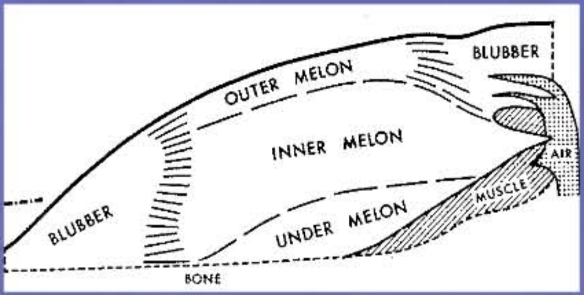
Melon composed of specialized triglycerides and wax esters

Shape and density of fats vary depending on location in melon

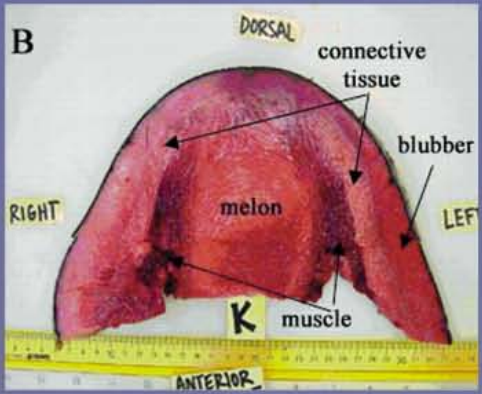
Transverse plane



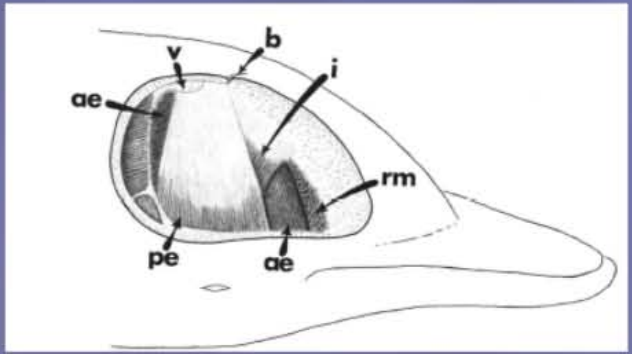
Sagittal plane



Litchfield et al., 1973



Soldevilla et al., 2005

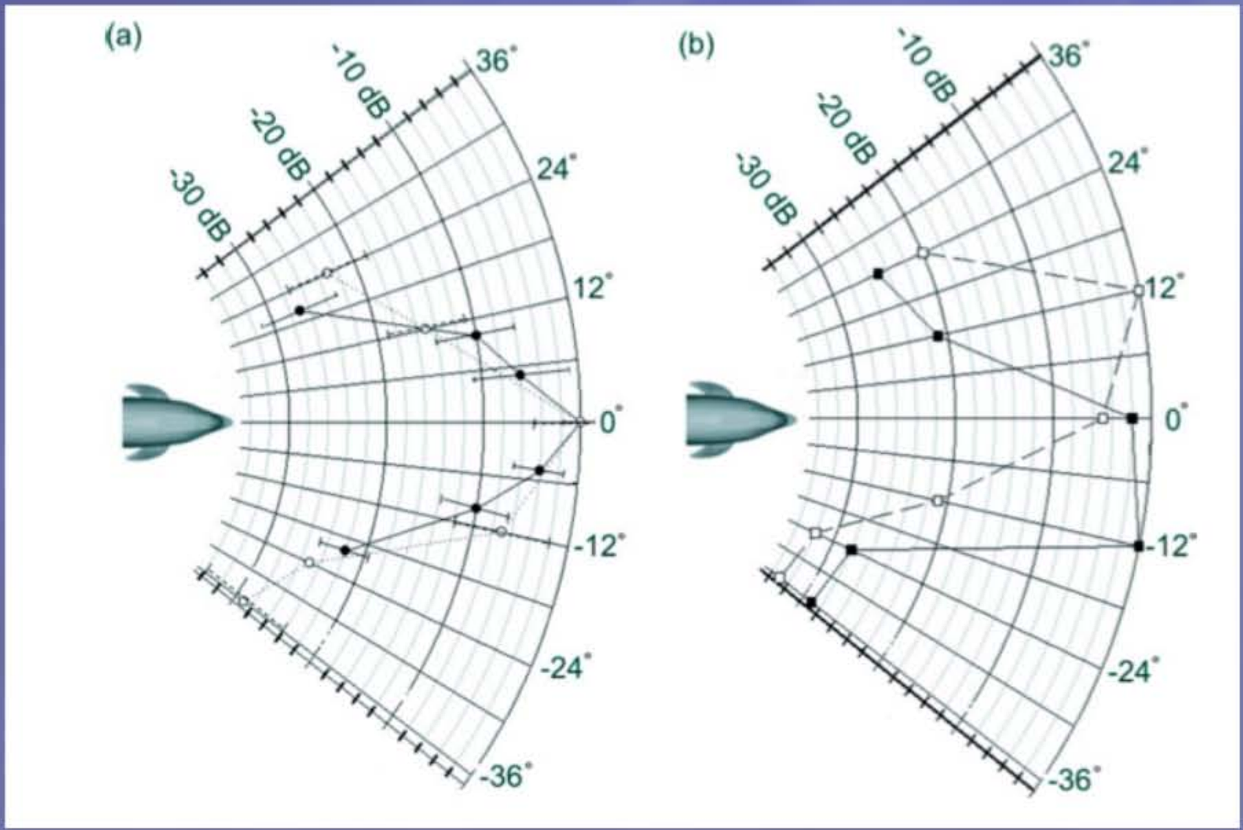


Mead, 1975

Muscles surround melon that may act to control its shape

Melon Movement

Bottlenose dolphins can steer their beams even when head is fixed



Moore et al., 2008

What are the dynamics of the beam during active echolocation?

Main research questions

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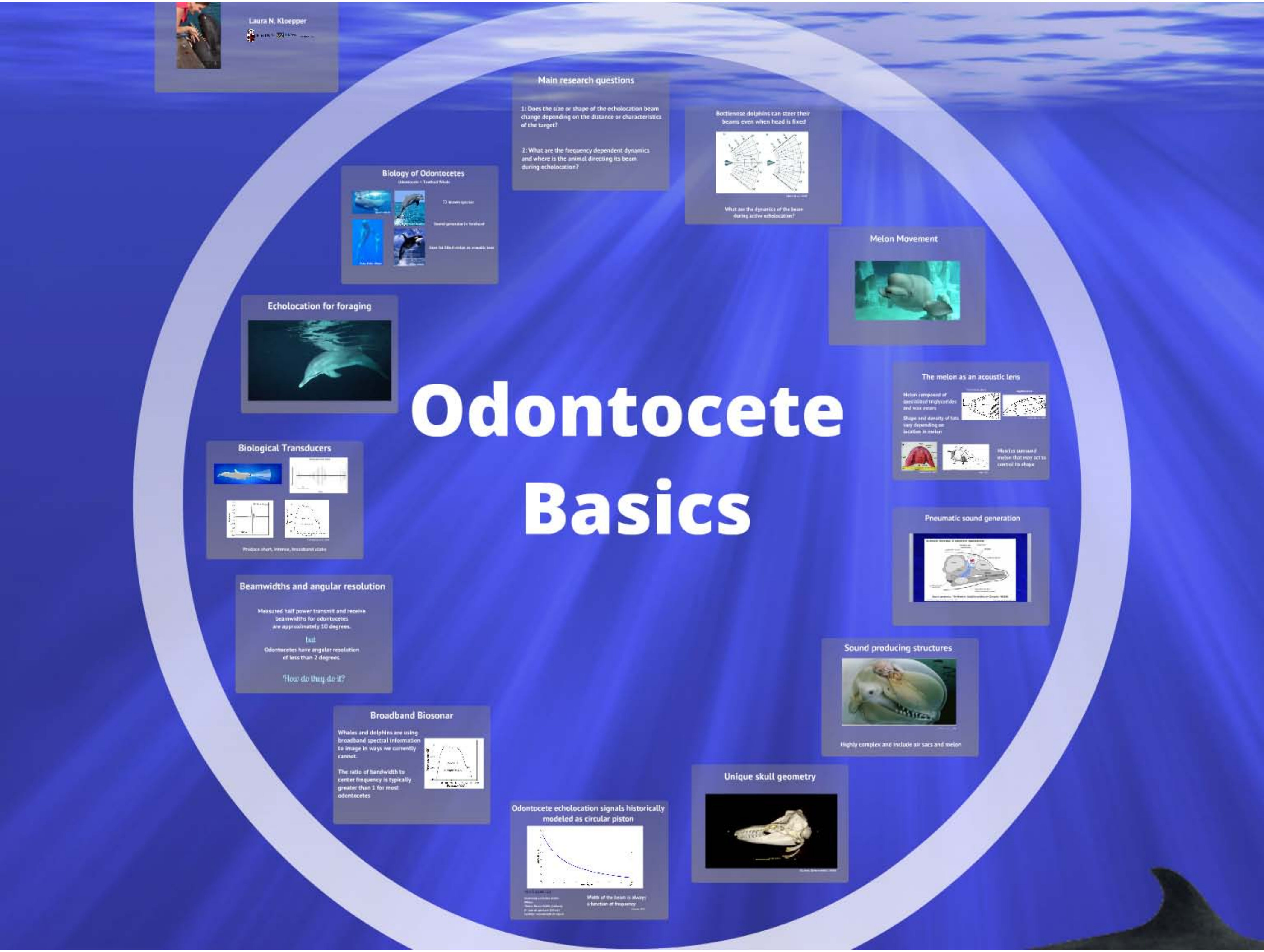
2: What are the frequency dependent dynamics and where is the animal directing its beam during echolocation?



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Coconut Island, Oahu, Hawaii
Marine Mammal Research Program
Part 2: Frequency Dependent Beam Variation
Part 2: Frequency-dependent variation in beam pattern
Experimental Subjects
False killer whale
Bottlenose dolphin
Part 2: Frequency Dynamics and Beam Aim Setup of Experiment
Target Detection Task
Three target presentation distances: 2.5m, 4m, 7m
Experimental Pen
Reconstructing the Beam
Experimental Setup
Part 1: Focusing Beam Area
Hydrophone Array
16 hydrophone system
Records the data from each click independently
Part 1: Echolocation Targets
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Two types of target discrimination tasks: easy and hard
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Experimental Subjects

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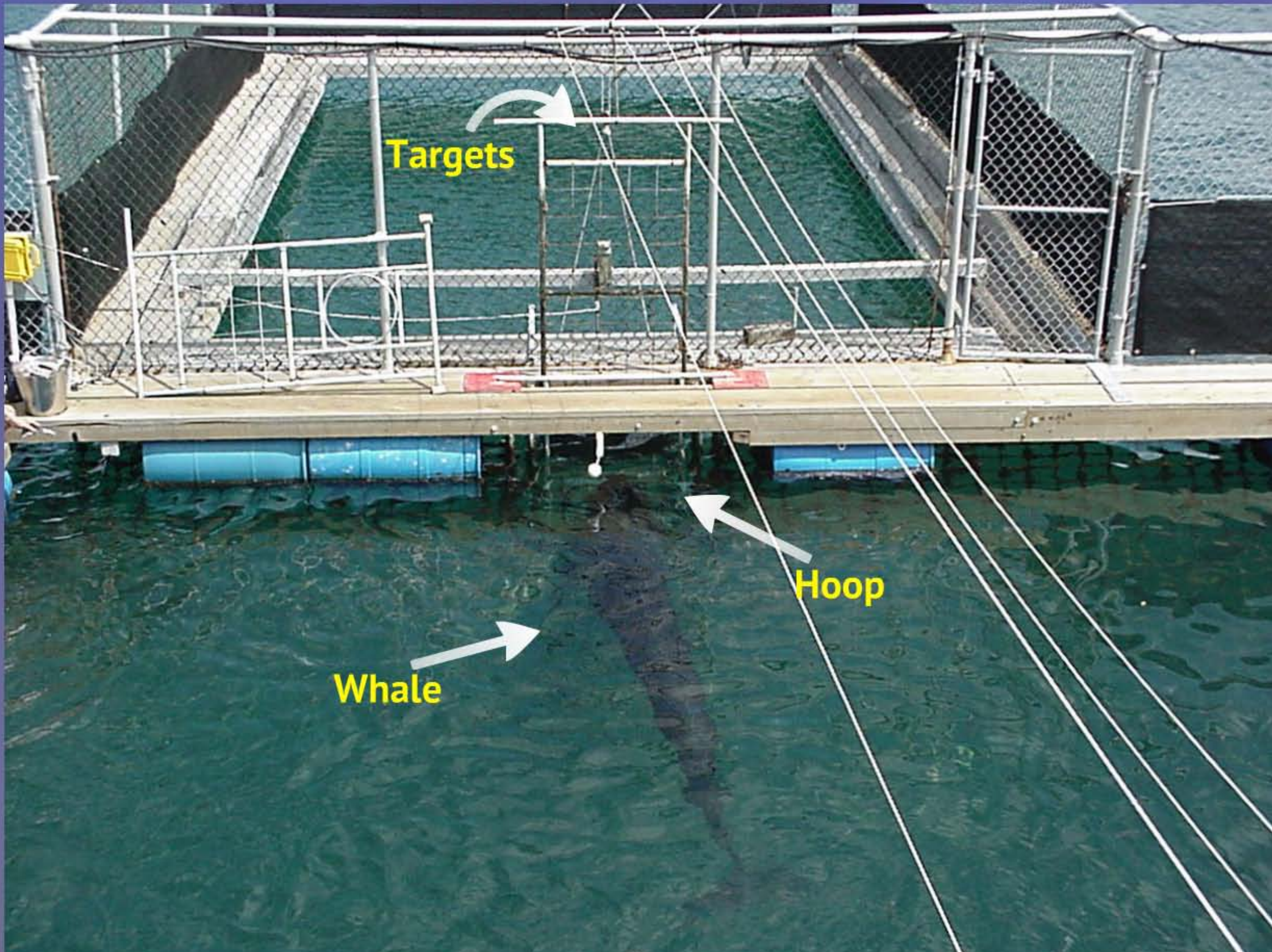


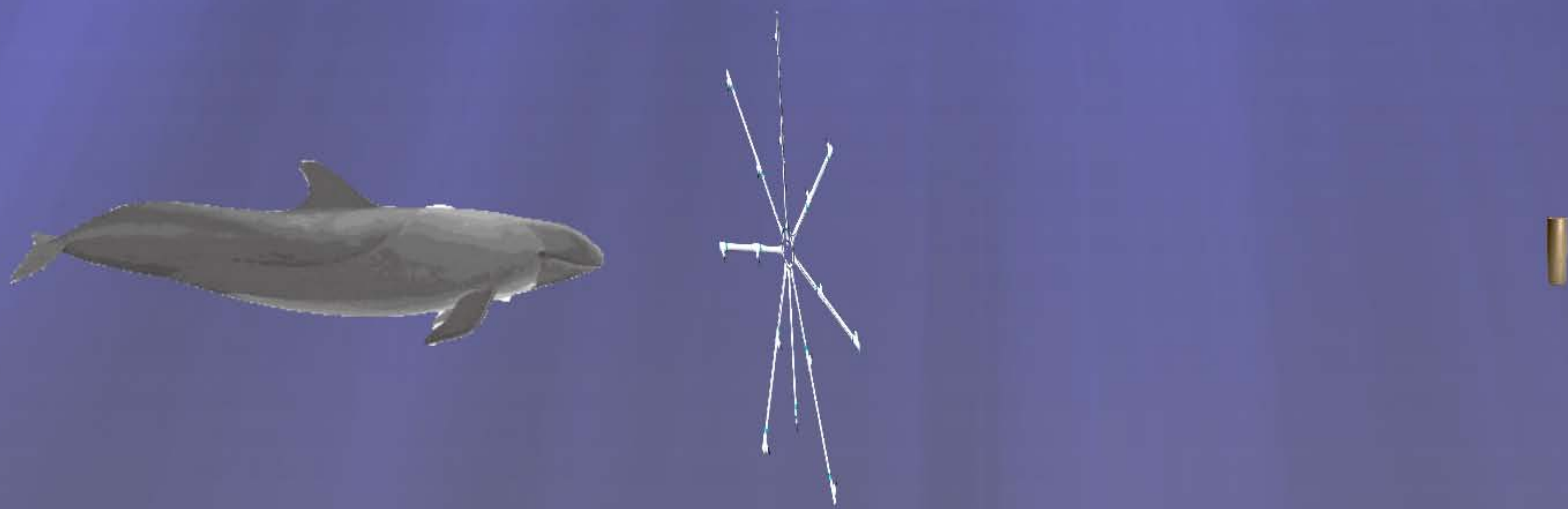
Experimental Setup

Hydrophone Array

16 hydrophone system

Records the data from each click independently

Part 1: Focusing
Setup of Experiment



Two types of target discrimination tasks: easy and hard
Three target presentation distances: 2.5m, 4m, 7m

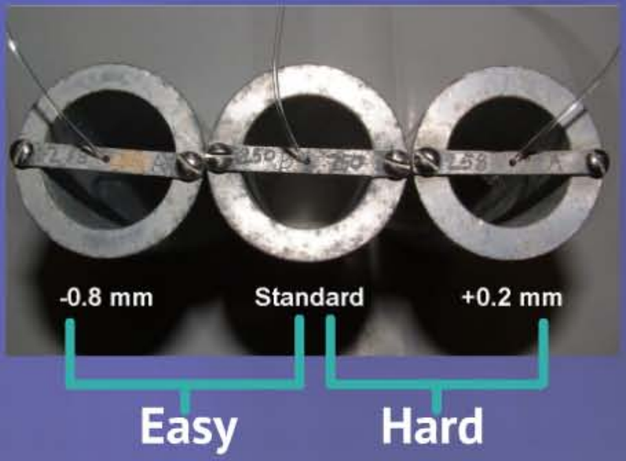
Part 1: Echolocation Targets

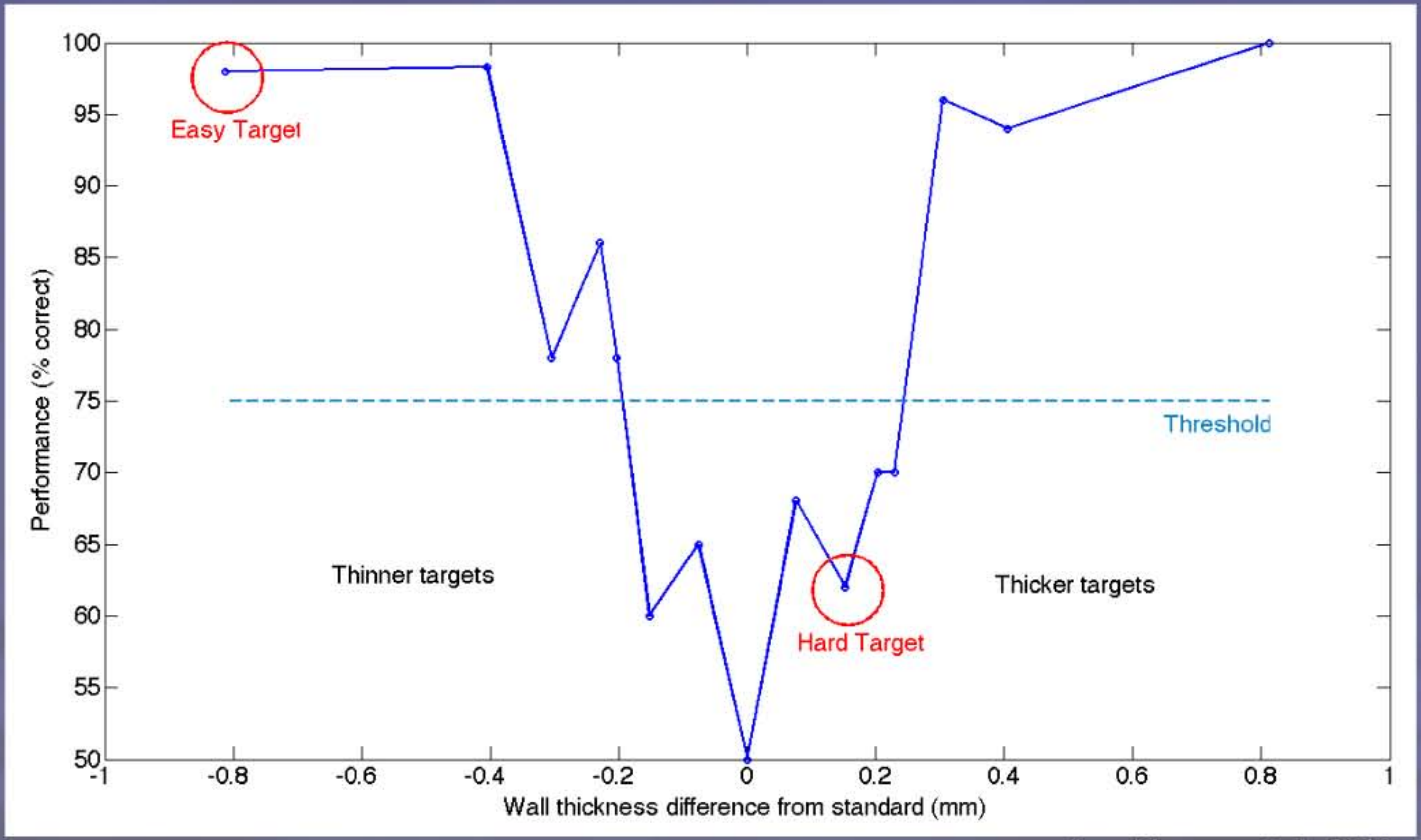
12.7 cm

37.85 mm outer diameter

25.15 mm inner diameter

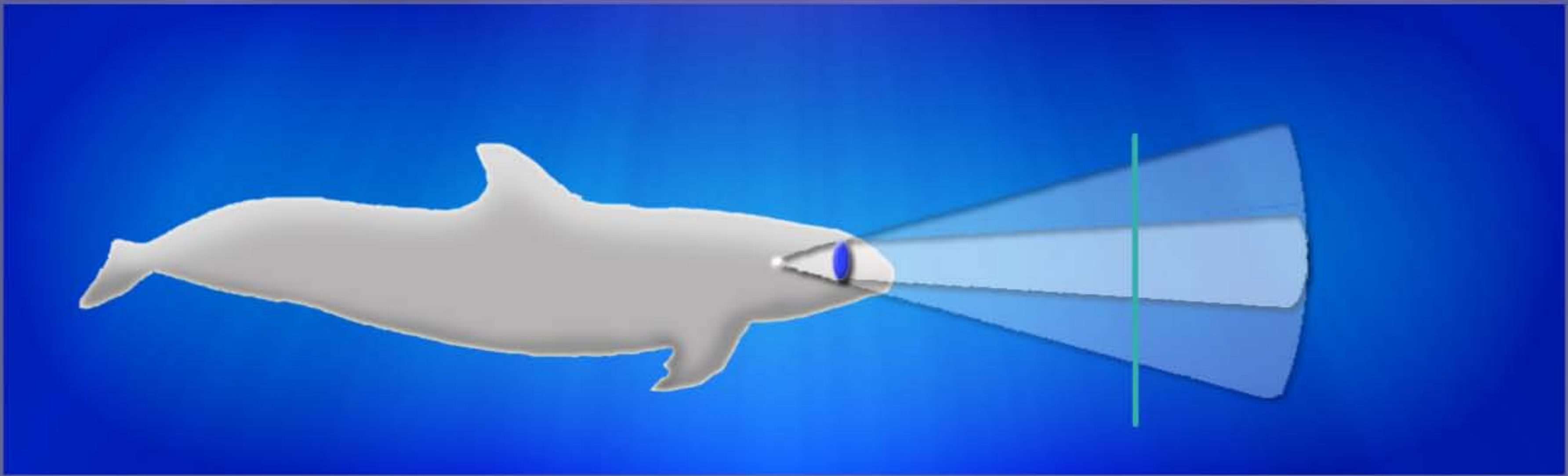
standard wall thickness
6.35 mm





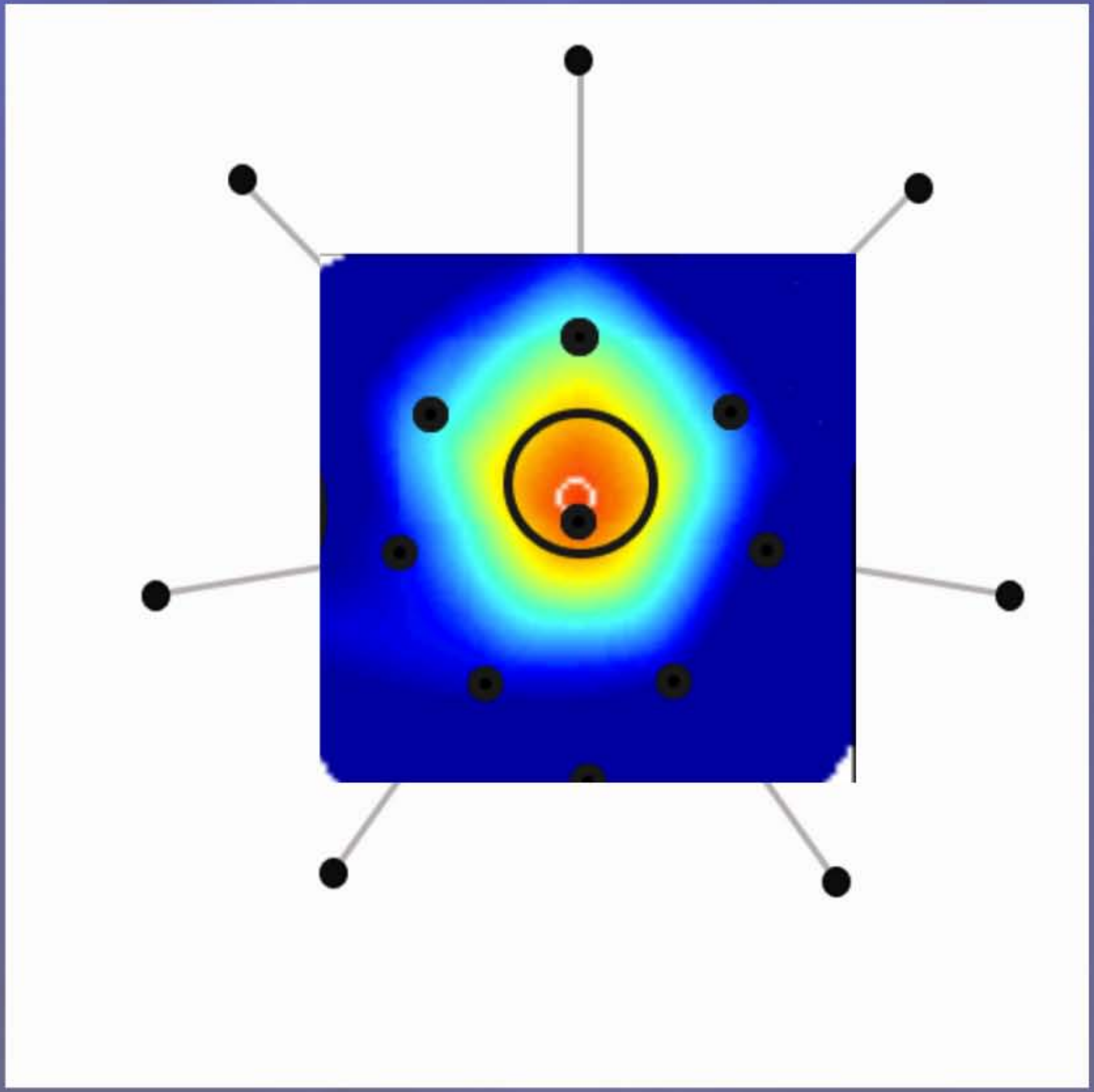
from Kloepper et al., 2010a

Part 1: Focusing
Beam Area



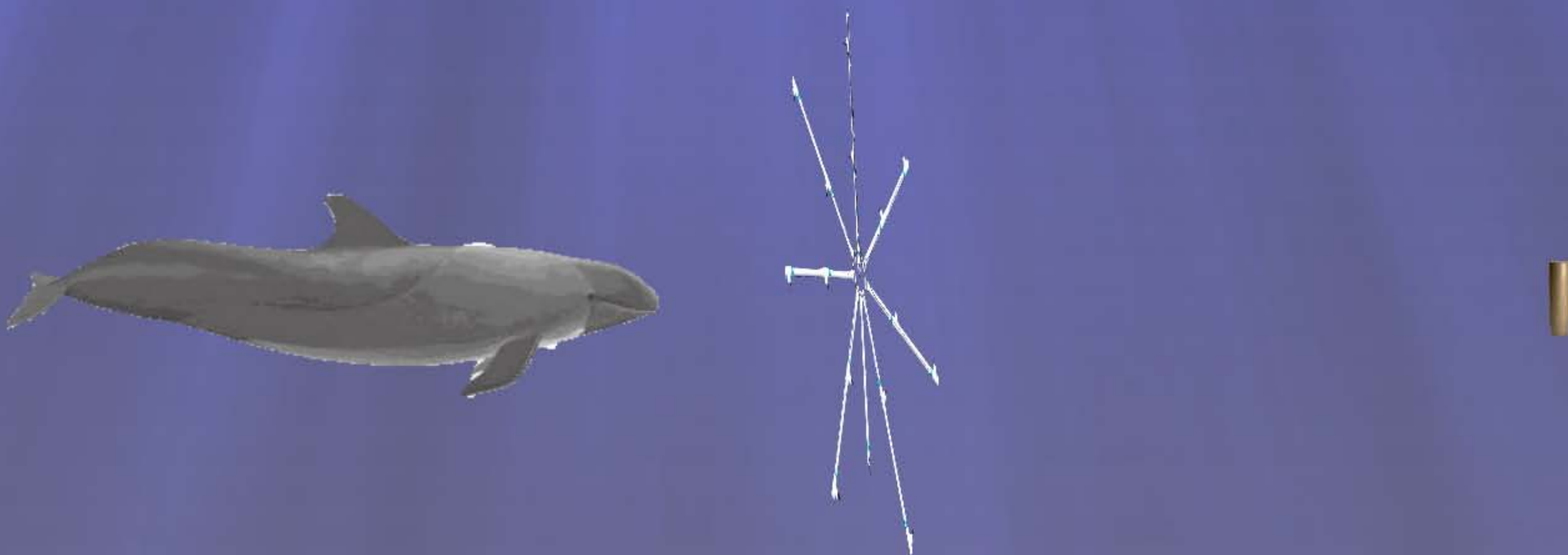
Beam Area= Cross section of the echolocation beam containing a set percentage of total intensity

Reconstructing the Beam



Beam areas determined by calculating a certain % of total click intensity

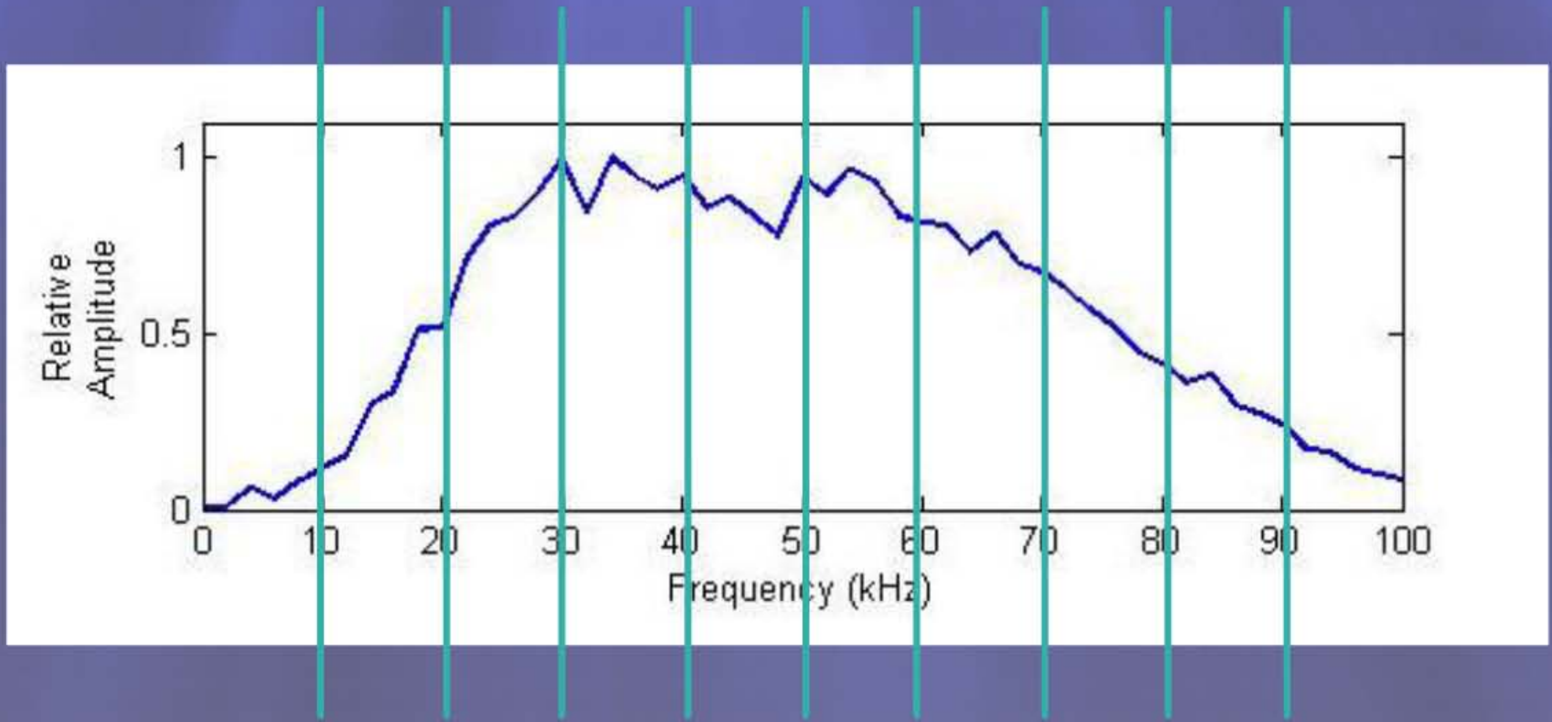
Part 2: Frequency Dynamics and Beam Aim
Setup of Experiment



Target Detection Task

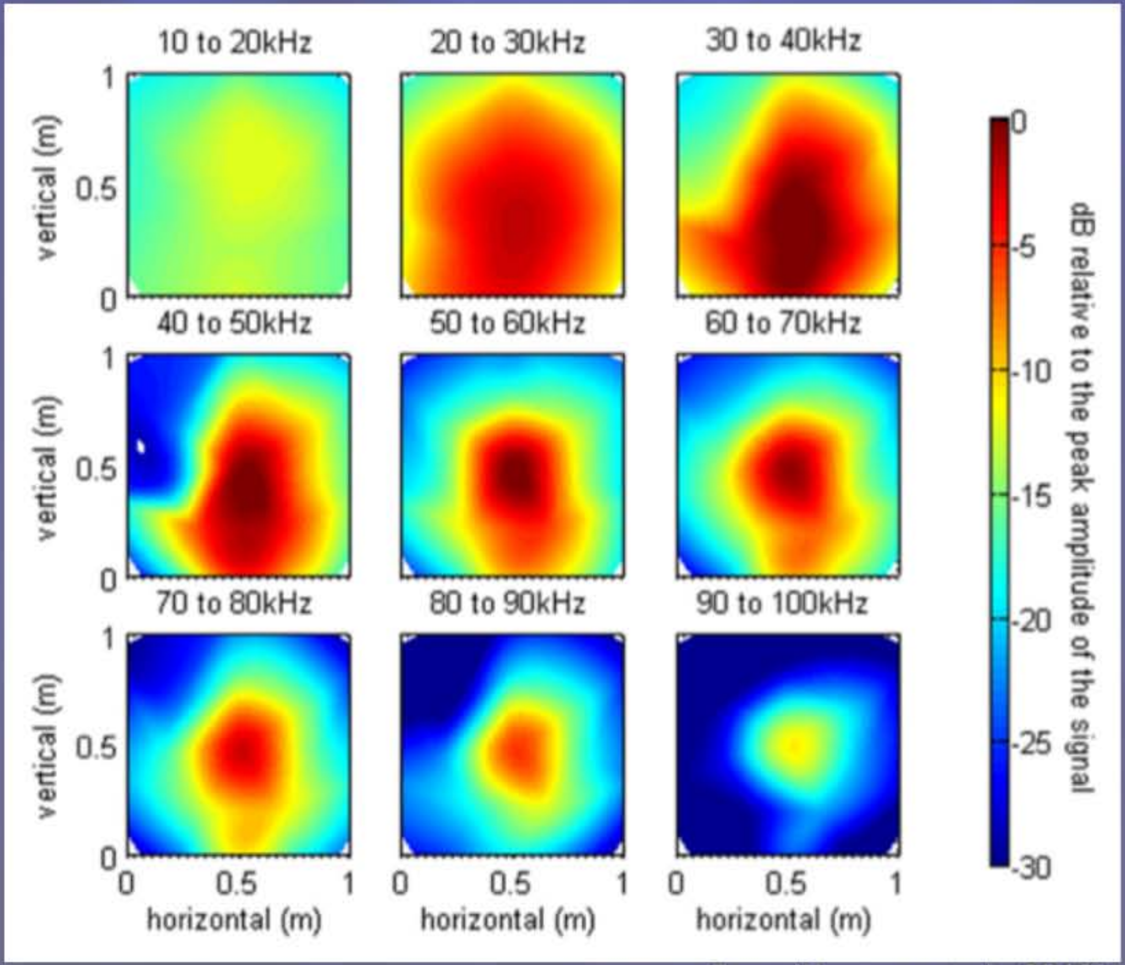
Three target presentation distances: 2.5m, 4m, 7m

Part 2: Frequency-dependent variation in beam pattern



Previous studies suggest some odontocetes shape certain frequencies of their beam differently than others

Part 2: Frequency Dependent Beam Variation



From Kloepper et al., 2012b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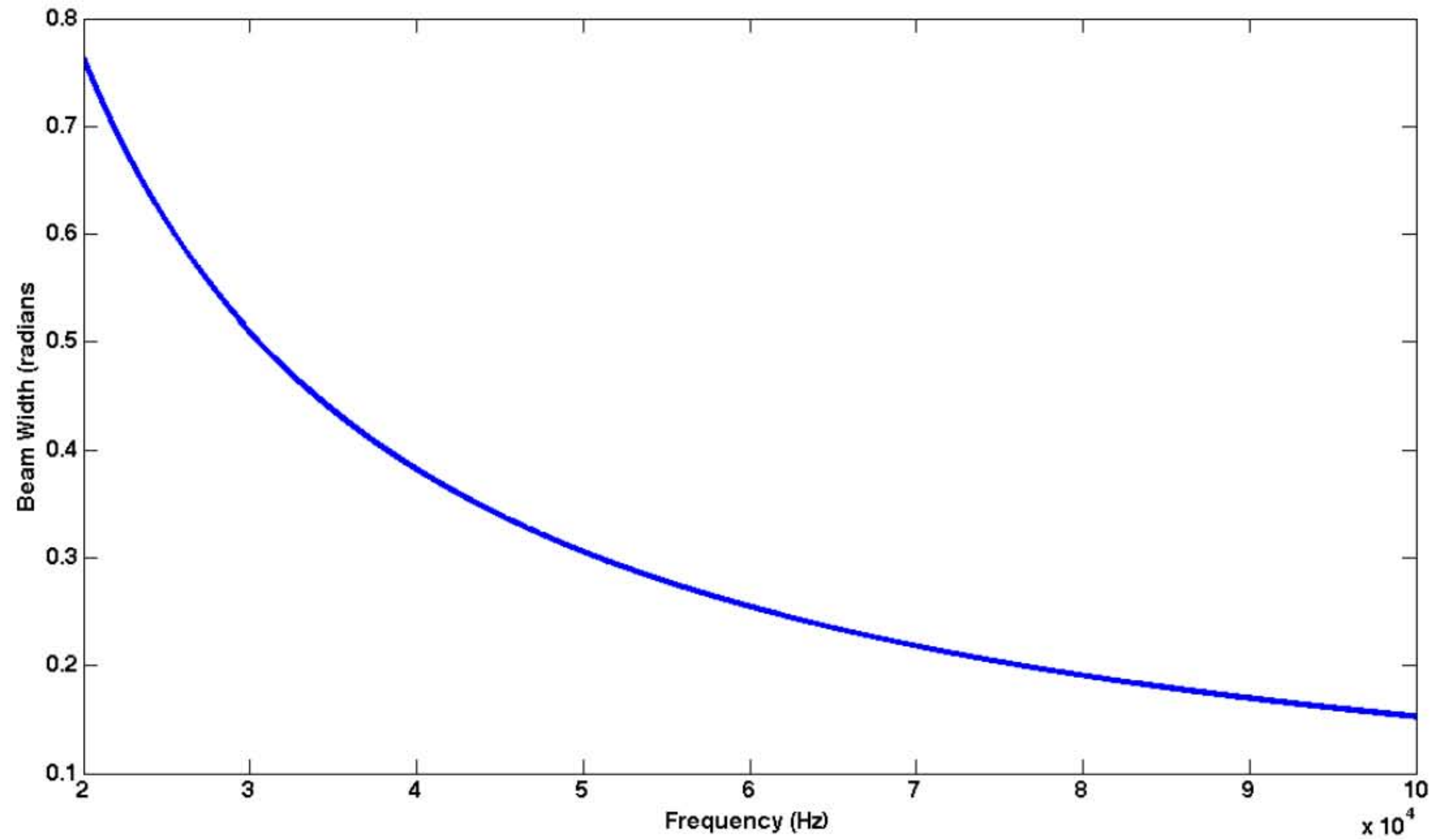
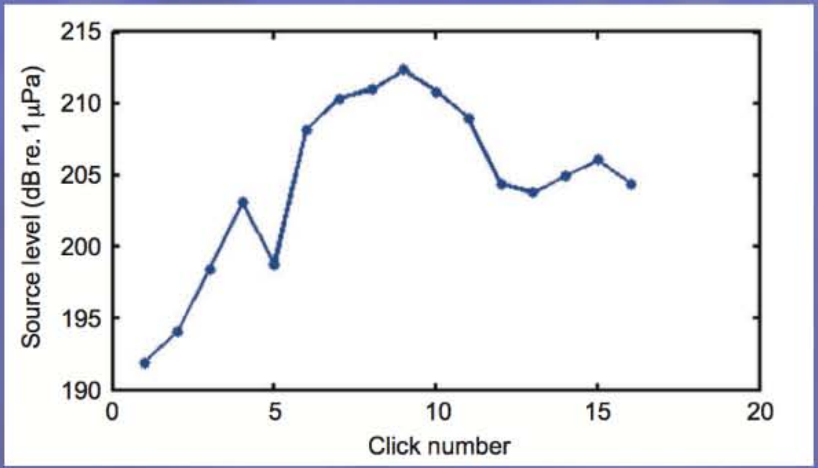
Results
Beam size and frequency
Hypothesis: Using the gradient of the beam pattern for optimal localization
Similarities and differences between animals
Bottlenose Dolphin
False Killer Whale
Frequency and intensity of clicks vary
Main response axis not directed at target regardless of target distance
Part 1: False killer whale echolocation focusing
Main response axis not directed at target for target absent trials
Part 1: False killer whale echolocation focusing
Target distance
Main response axis not directed at target
Part 1: Hypothesized focusing strategy
The whale might be adjusting her focal region according to the distance of the target
Bottlenose dolphin beam scanning
Focused beams may help reduce clutter echoes
Part 2: Visualizing beam dynamics
Summary of Biosonar Techniques

Beam size and frequency

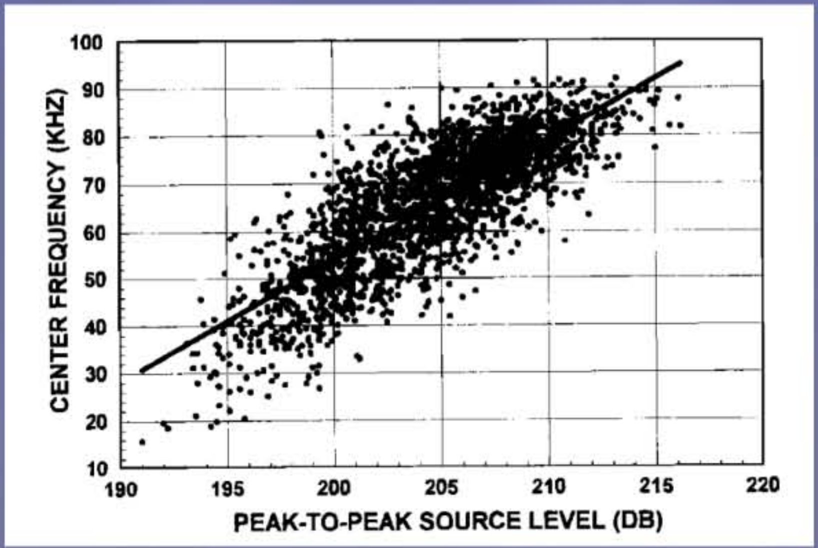


All studies on beam changes must take into account frequency effect

Frequency and intensity of clicks vary



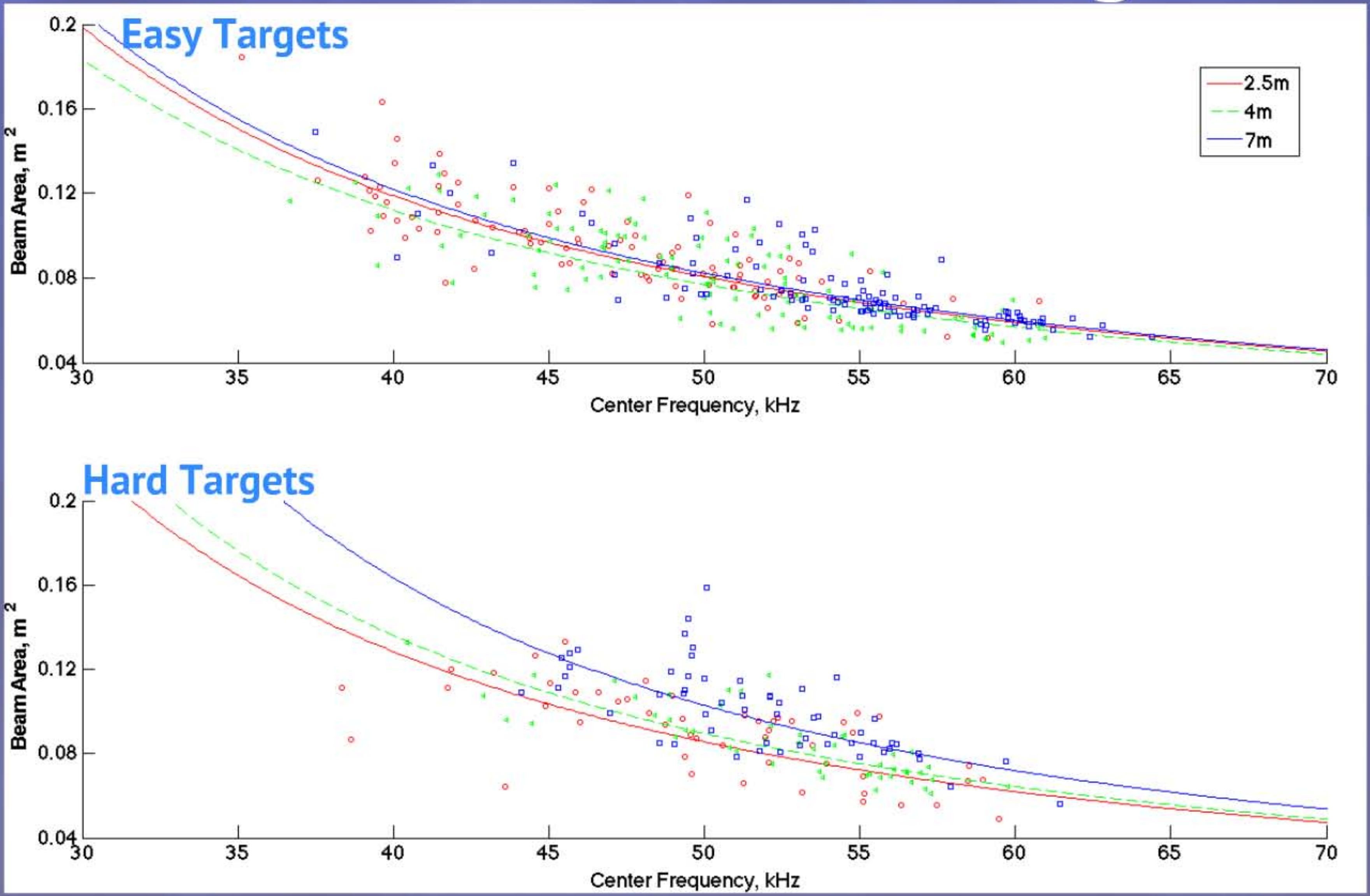
Intensity of clicks change during a click train



Au et al., 1995

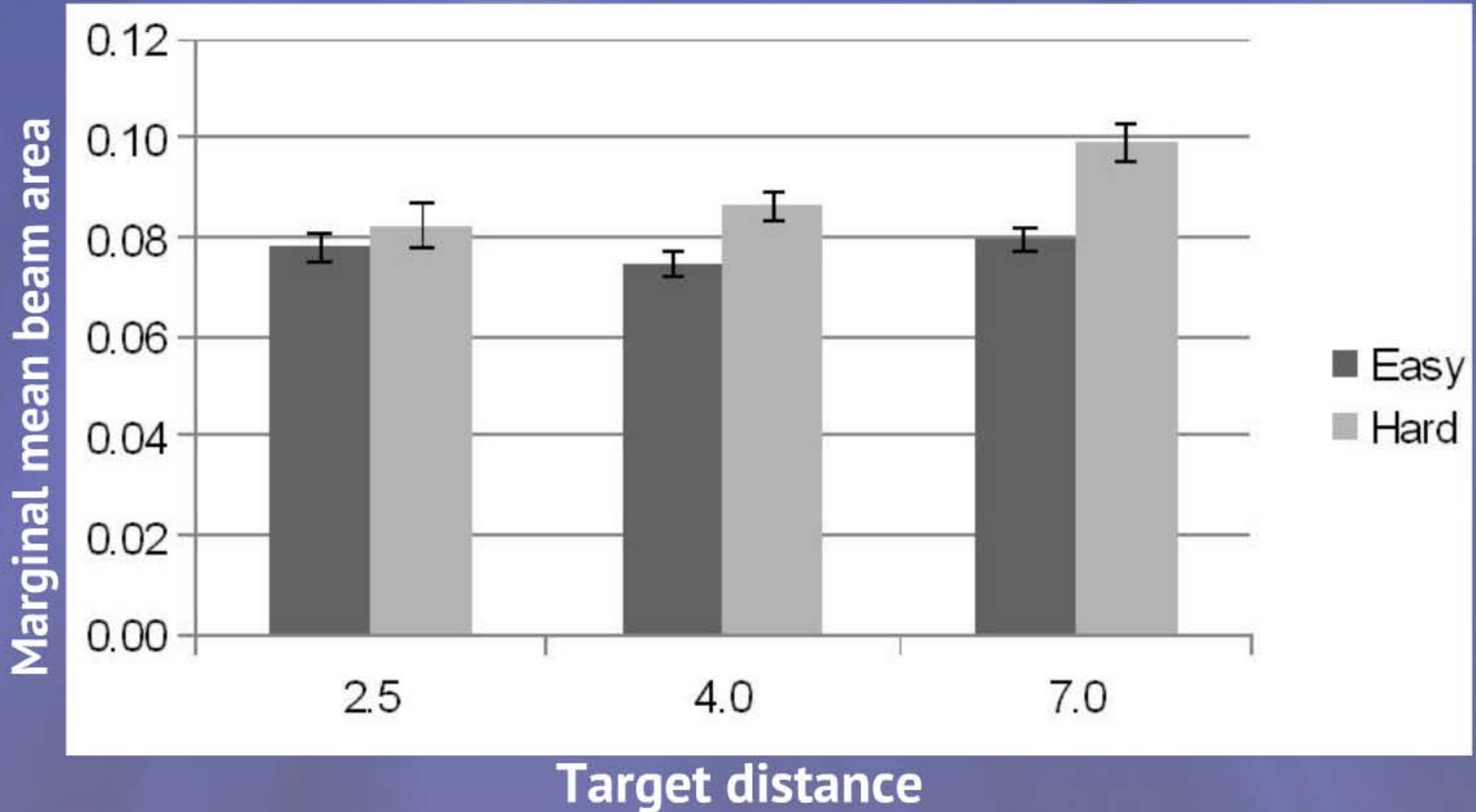
Frequency and intensity are related

Part 1: False killer whale echolocation focusing



Part 1: False killer whale echolocation focusing

For all targets, beam areas are larger for the hard than the easy targets

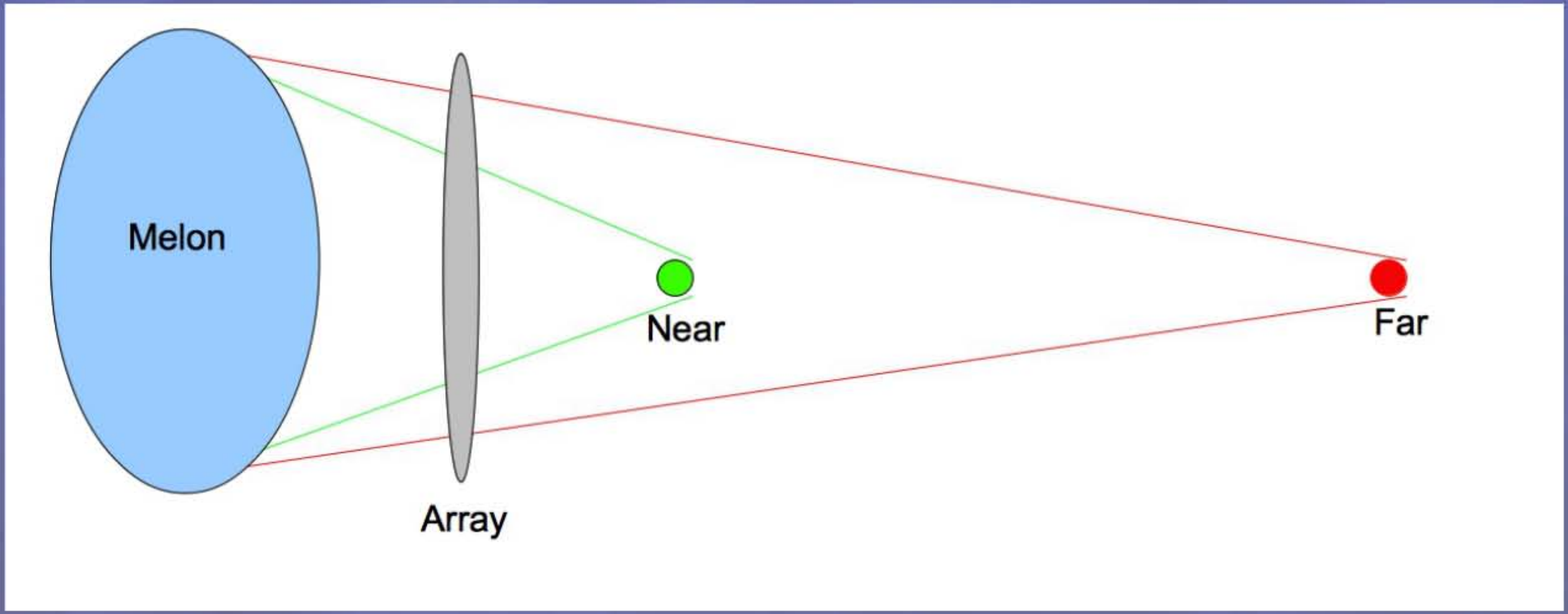


Kloepper et al., 2012

For hard targets, beam area increased consistently with distance, but 2.5 and 4.0m are statistically indistinguishable

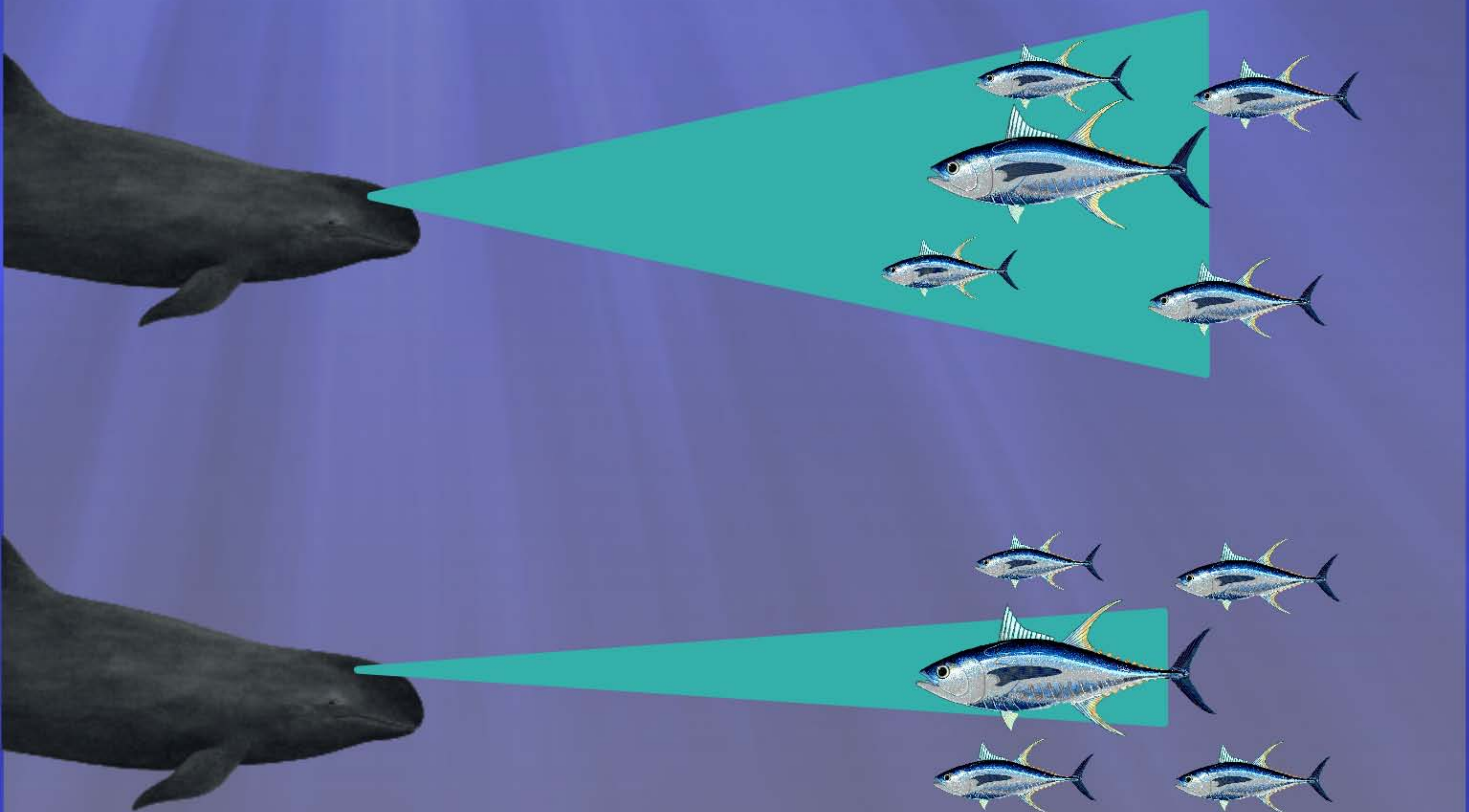
For easy targets, beam area increased between 4.0 and 7.0m but 2.5m is statistically indistinguishable from both

Part 1: Hypothesized focusing strategy



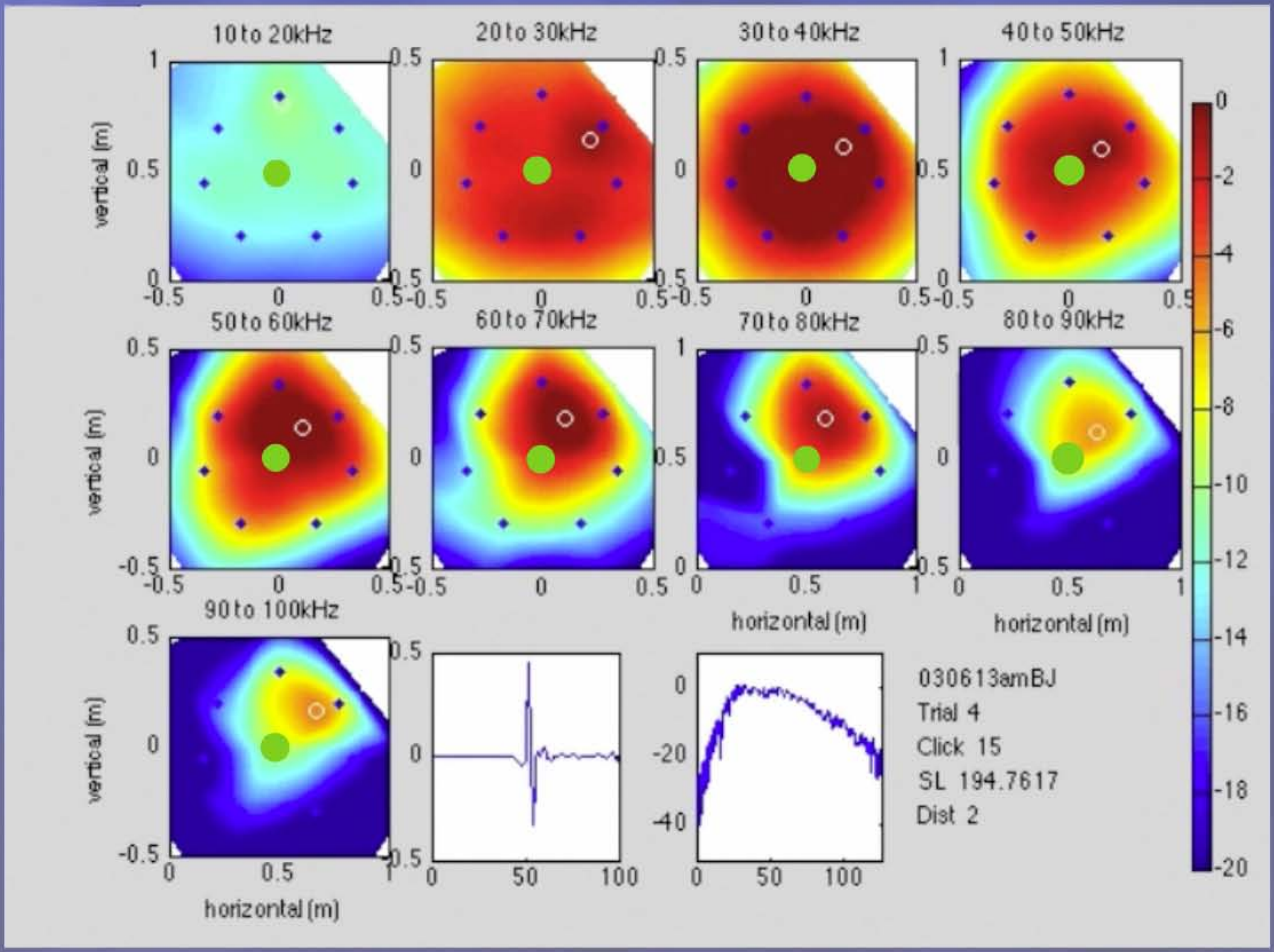
The whale might be adjusting her focal region according to the distance of the target

Focused beams may help reduce clutter echoes

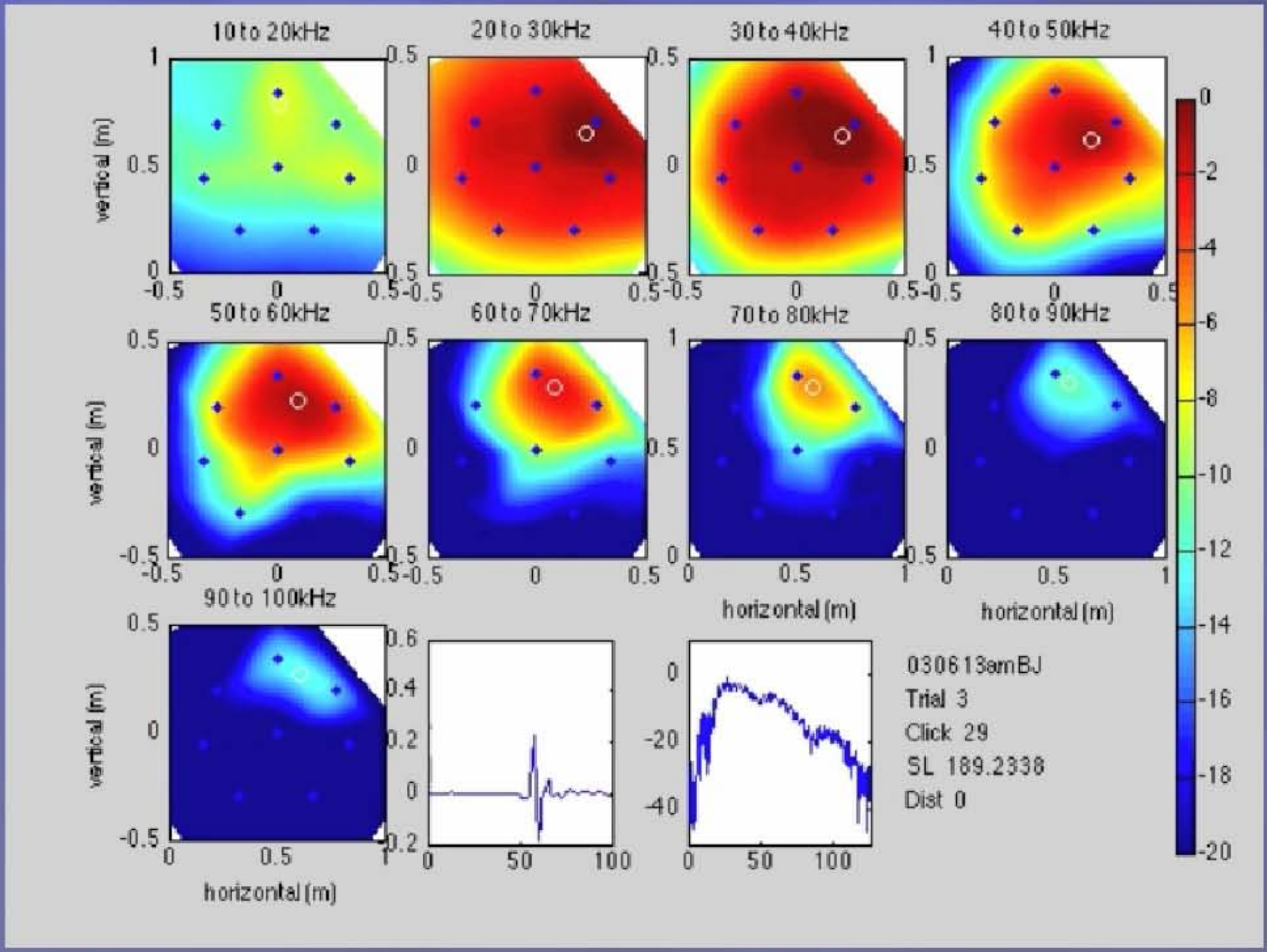


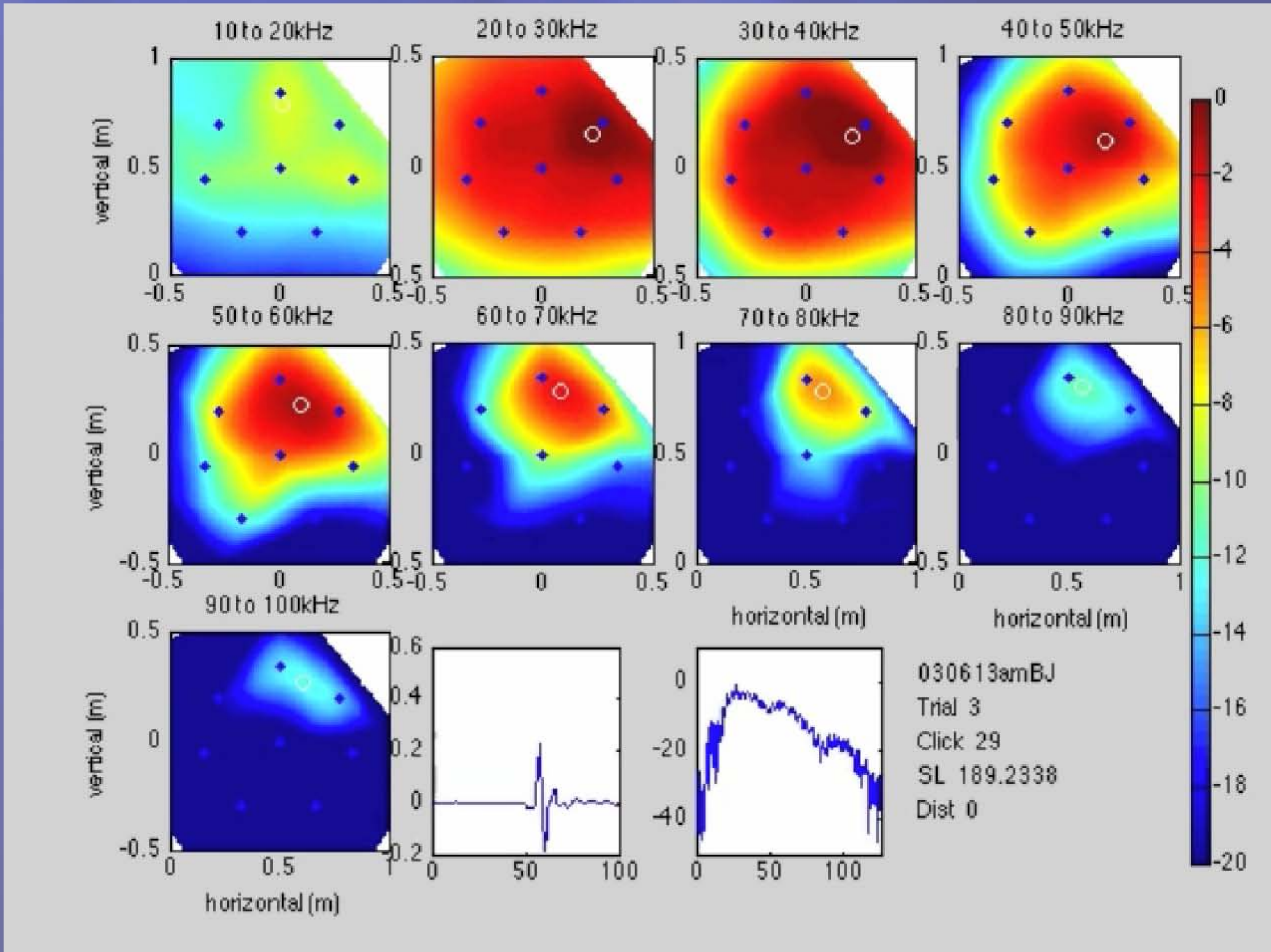
Part 2: Visualizing beam dynamics

● = target location

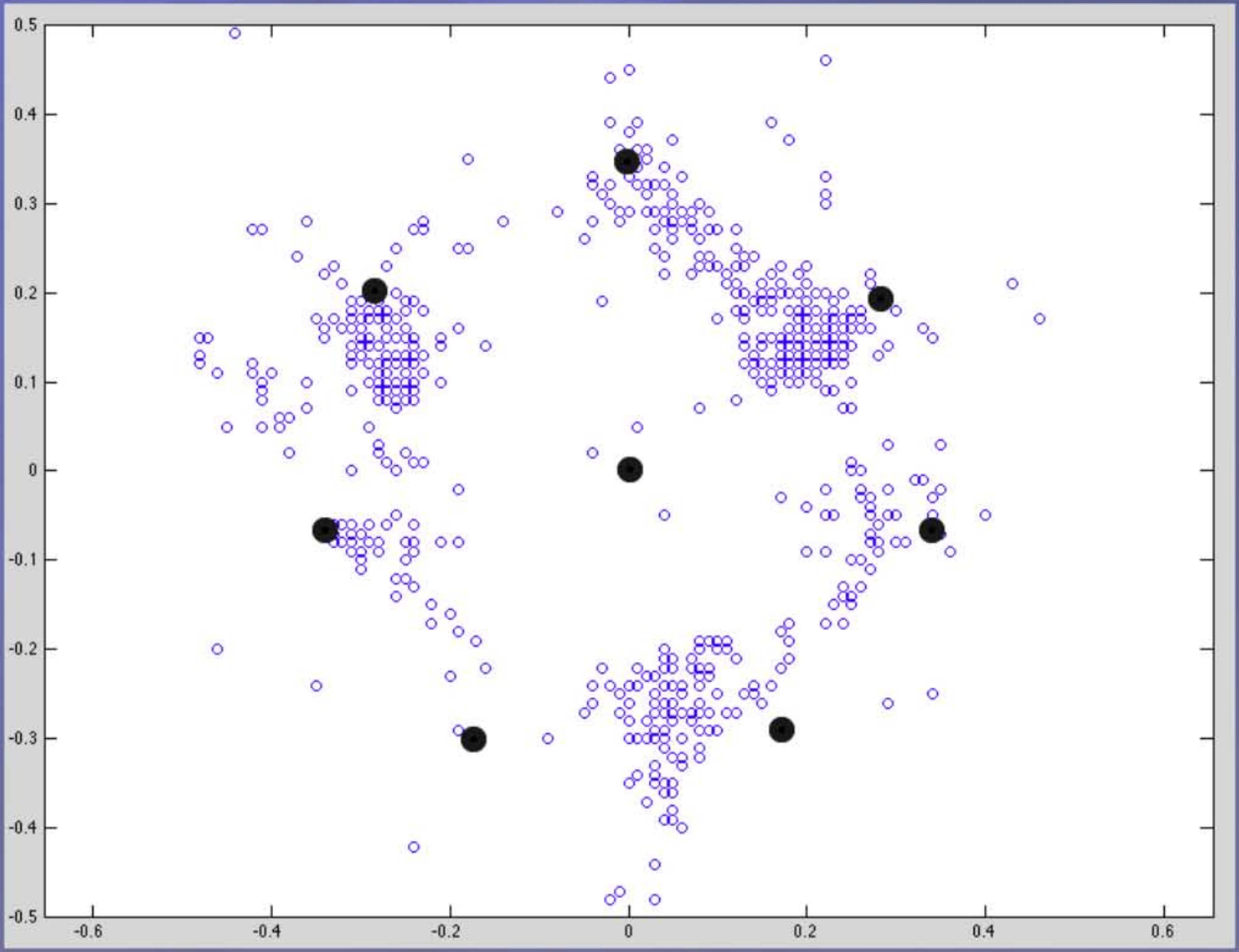


Bottlenose dolphin beam scanning

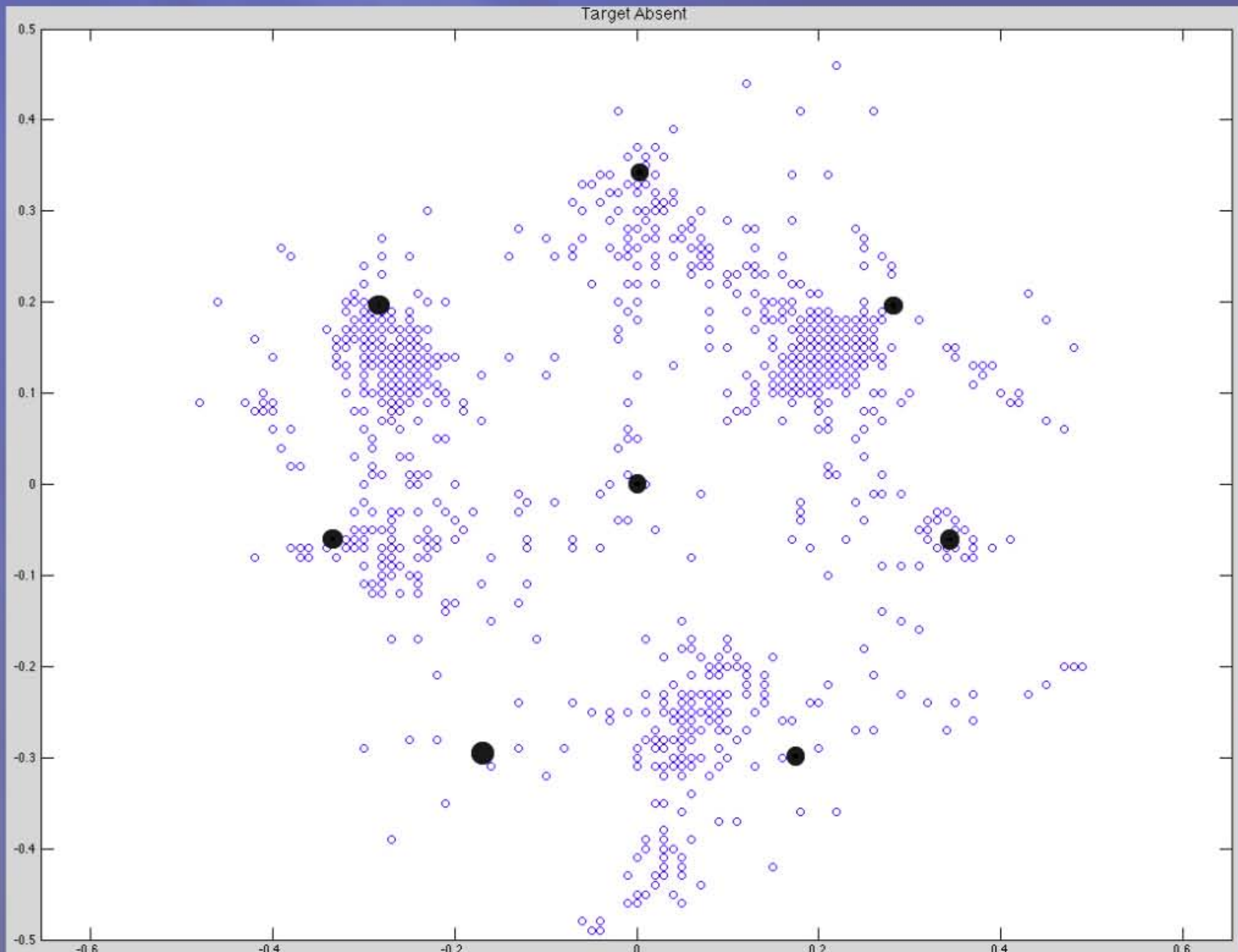



10 to 20kHz
20 to 30kHz
30 to 40kHz
40 to 50kHz
50 to 60kHz
60 to 70kHz
70 to 80kHz
80 to 90kHz
90 to 100kHz
vertical (m)
horizontal (m)
030613amBJ
Trial 3
Click 29
SL 189.2338
Dist 0

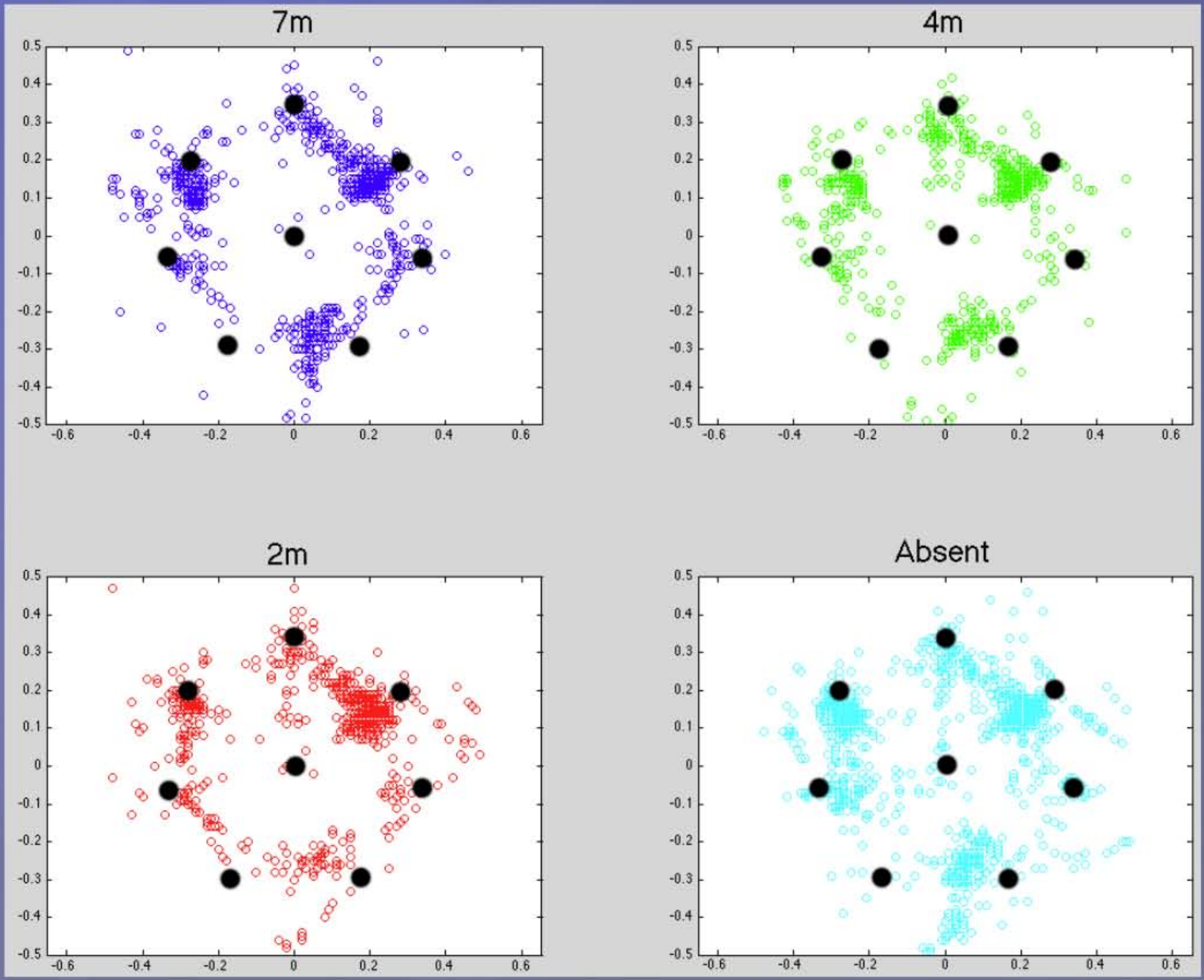
Main response axis not directed at target



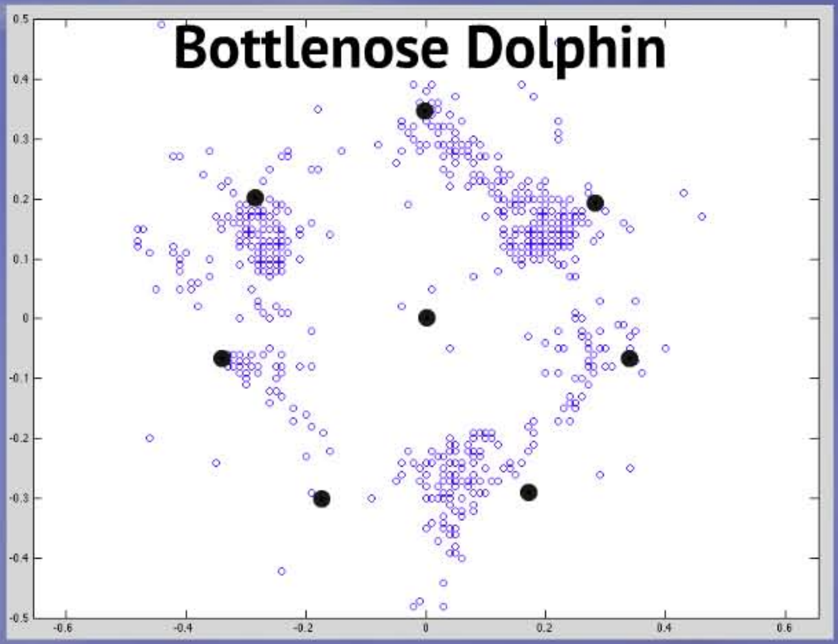
Main response axis not directed at target for target absent trials

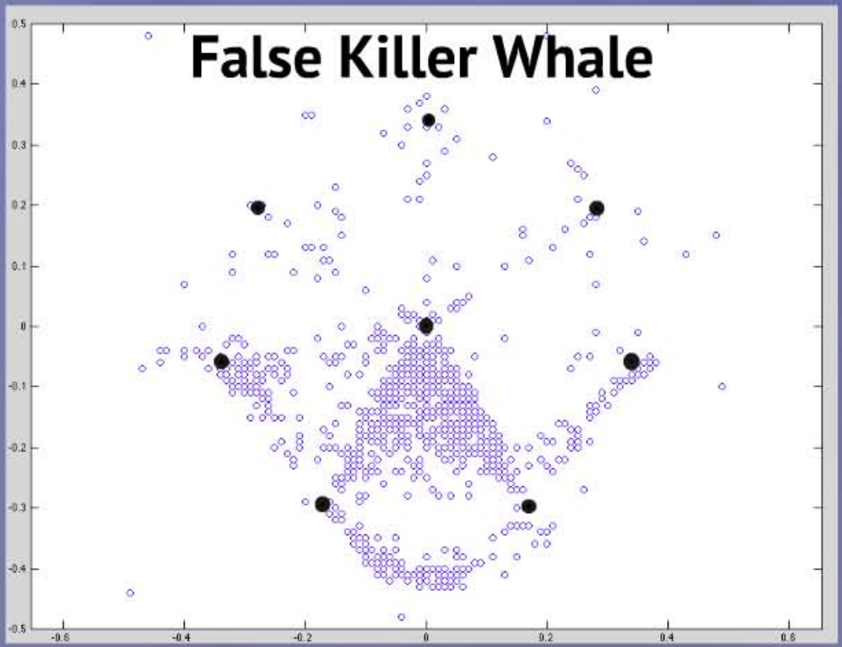


Main response axis not directed at target regardless of target distance



Similarities and differences between animals



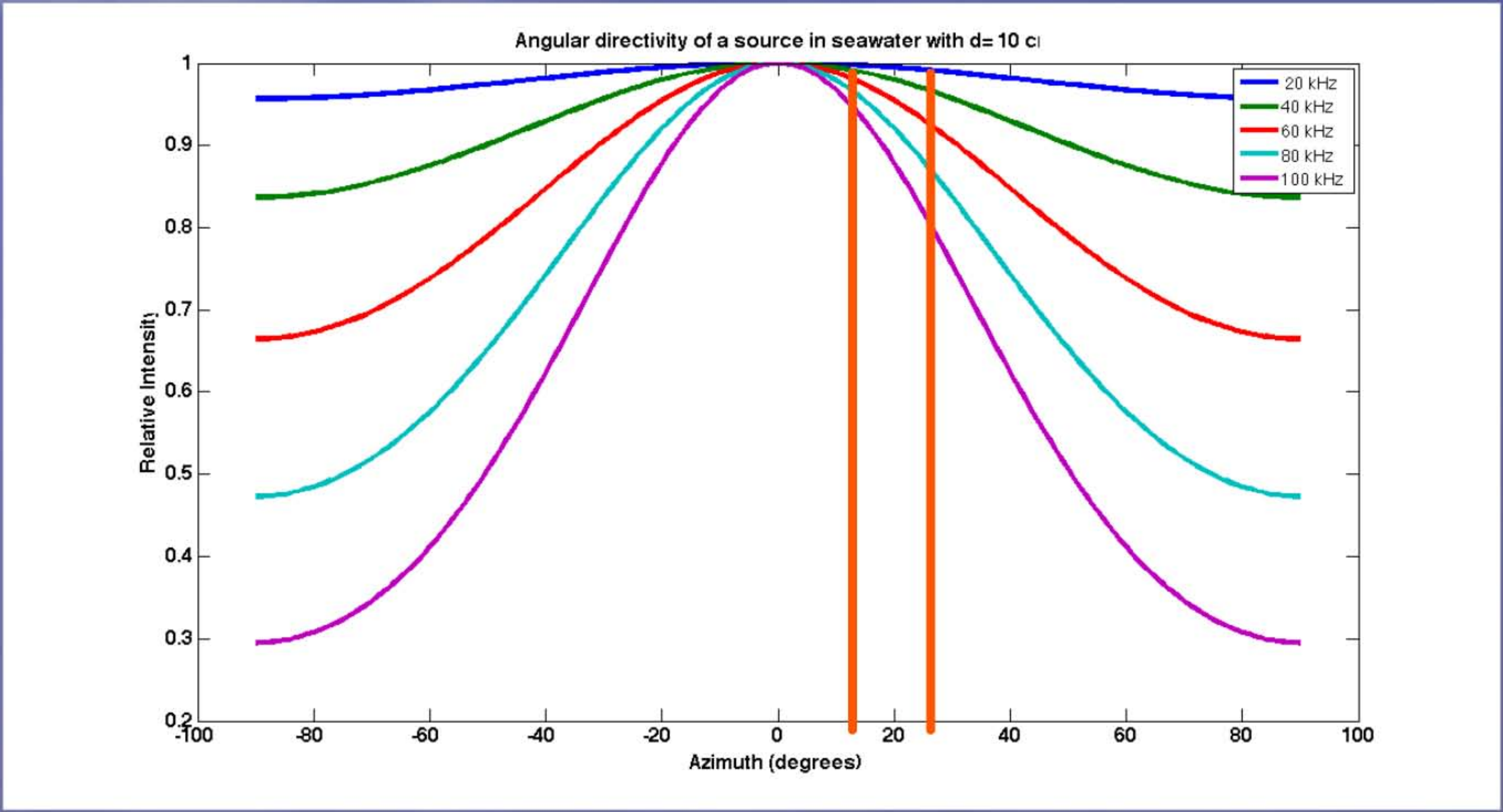


Direction of main axis is different depending on animal

Both animals use same strategy of pointing main axis away from the target

Species differences or individual differences?

Hypothesis: Using the gradient of the beam pattern for optimal localization



$$D_\omega(\theta) = \left(\frac{2J_1(\pi \frac{d}{\lambda} \sin\theta)}{\pi \frac{d}{\lambda} \sin\theta} \right)^2$$

Summary of Experimental Results

The size of the echolocation beam changes depending on target distance and difficulty, which might be a strategy of narrowing a focal region on the target

The main response of the sound beam is directed away from the target, which might allow the animal to use the frequency information on the gradient of the beam for optimal localization

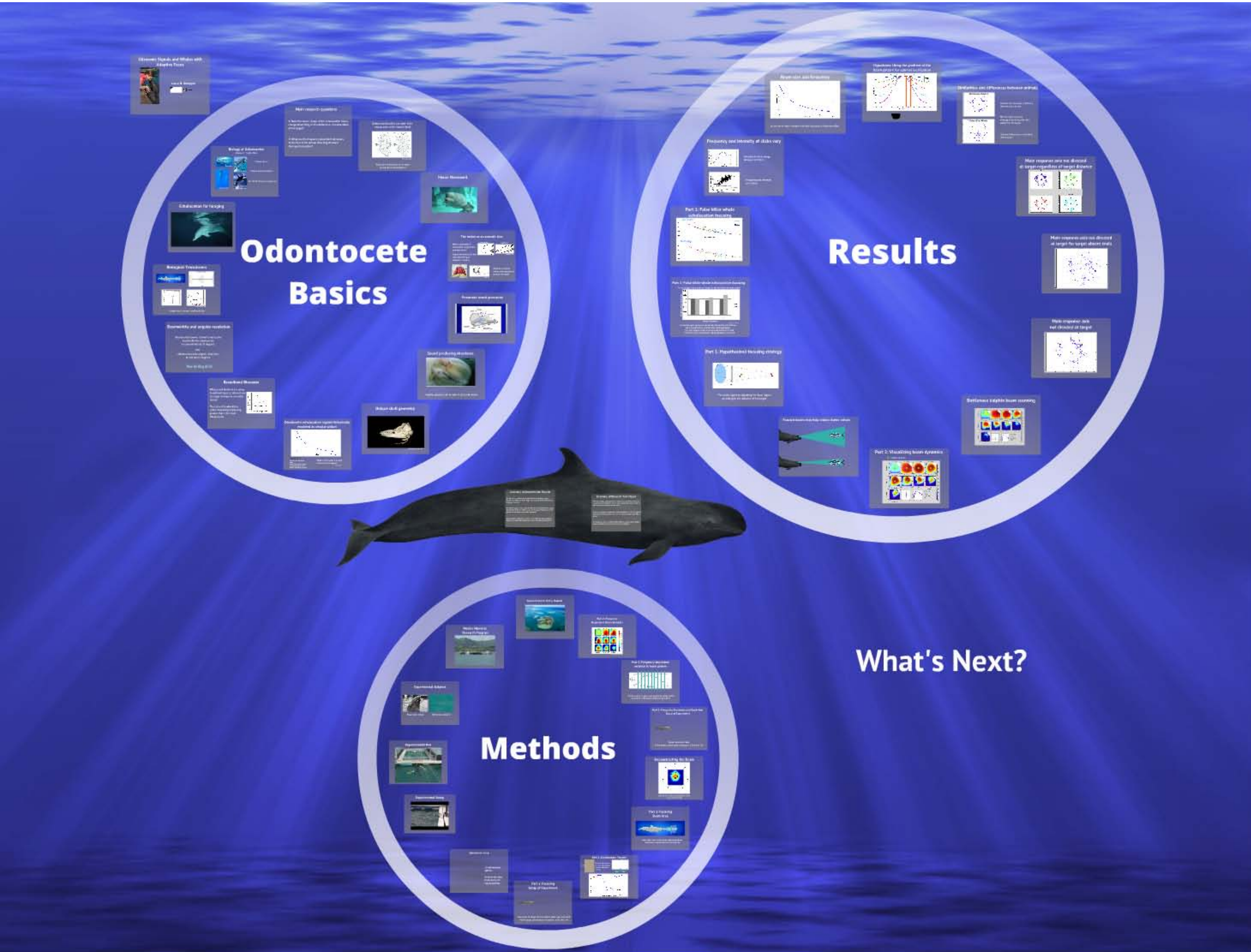
Small, dynamic adjustments occur on a click-by-click basis allowing animals to acoustically focusing on targets of varying characteristics

Summary of Biosonar Techniques

With just a single sound generator, odontocetes can achieve levels of resolution and performance greater than conventional devices with the same aperture and frequency constraints

Odontocetes produce signals with a high bandwidth to center frequency ratio and mechanically focus the emitted signals through a lipid filled melon.

The signals are directed off axis which might be a strategy of utilizing frequency gradients in the beam for target localization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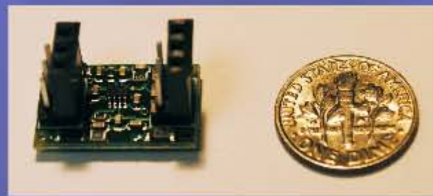
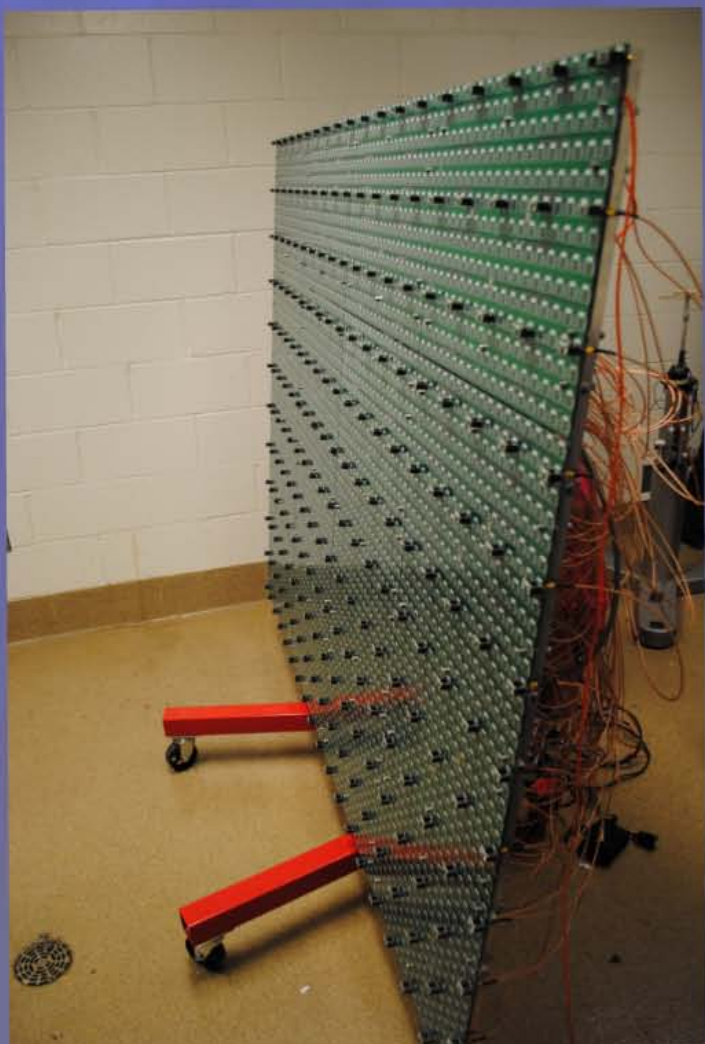
What's Next?

Large array for measurements of bat echolocation signals



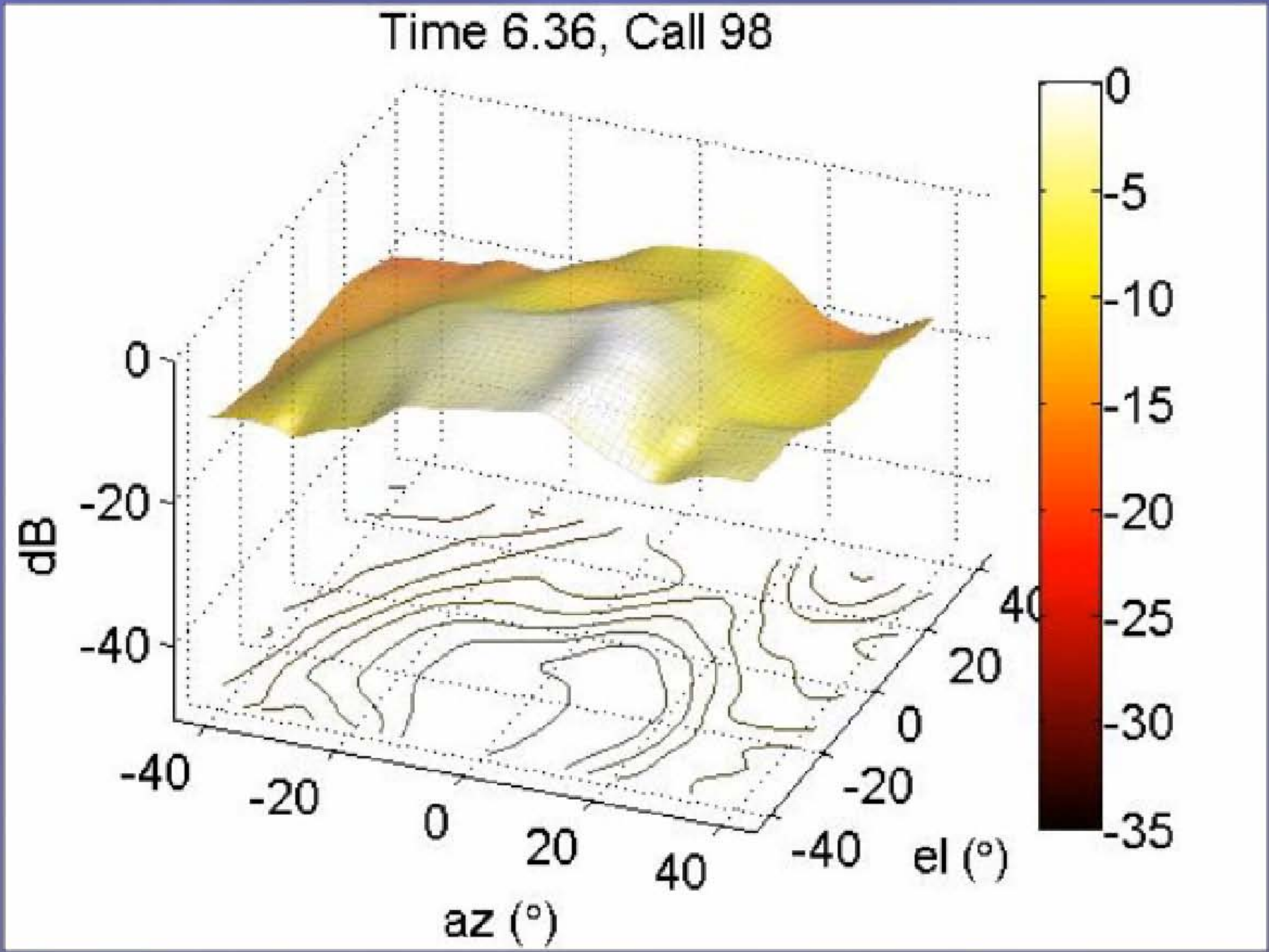


224 element microphone array

composed of low cost MEMS microphones and custom analog and digital electronics

allows for fine scale, independent, variable frequency measurements of the beam

Visualizing the beam of echolocating bats



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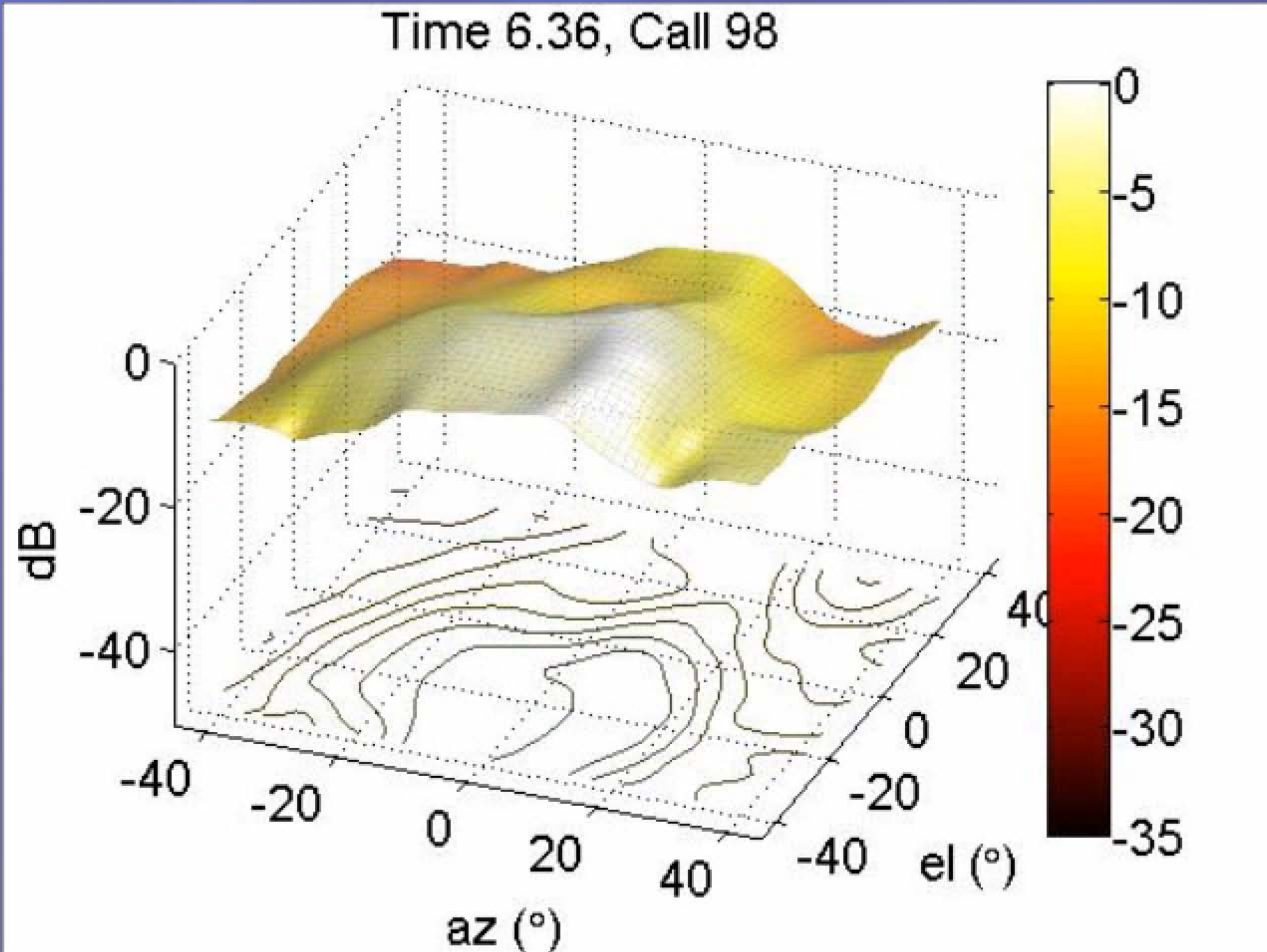

Ear and mouth movements during echolocation

Ear and mouth movements during echolocation

Acknowledgements

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Professor Whitlow Au
Dr. Aude Pacini
Trainers Marlee Breese, Stephanie Vlachos, Christopher Quintos, Rocky Owens
Students Adam Smith, Aliza Milette, Sanami Nakayama
Technician Andy Brown

Brown Team: Bat Lab

Professor James Simmons, Professor Andrea Simmons
Students Jason Gaudette, Erika Alexander, Jon Barchi, Alyssa Wheeler
Technician Michaela Warneke
Assistants Fabien Steinbeck and Sean Yancey

UMass Team: Acoustic Signal Processing Lab

Professor John Buck
Students Kaushallya Adhikari, David Hague, Peter Khomchuk, Yang Liu, Ian Rooney, Saurav Tuladhar