Numerical simulations of sound source localization with two-dimensional bio-inspired antennas of varying geometric complexities

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5th Joint Meeting
Acoustical Society of America and Acoustical Society of Japan
Honolulu, Hawaii
28 Nov. - 2 Dec. 2016

Motivation: Mammalian hearing

Localization mostly with level and time differences

Also: Sound conducted by the skull

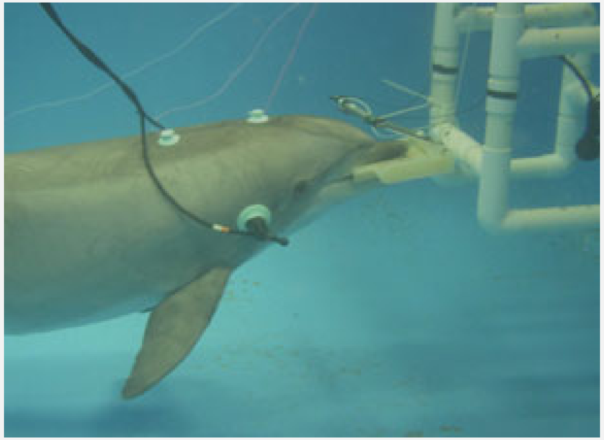

Image: public.navy.mil (accessed 11/07/16)

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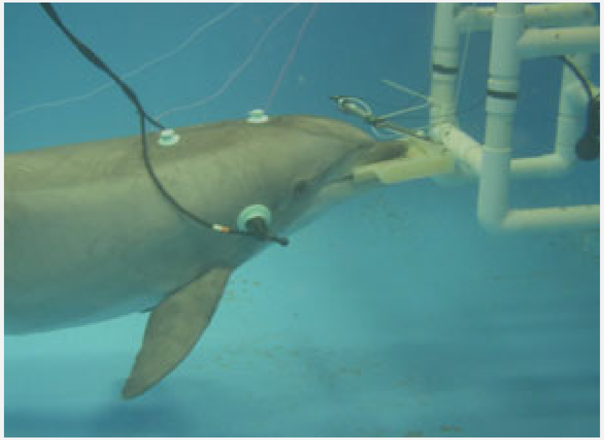
Also: Sound conducted by the skull

Shape/geometric complexity

Localization algorithms using elastic waves



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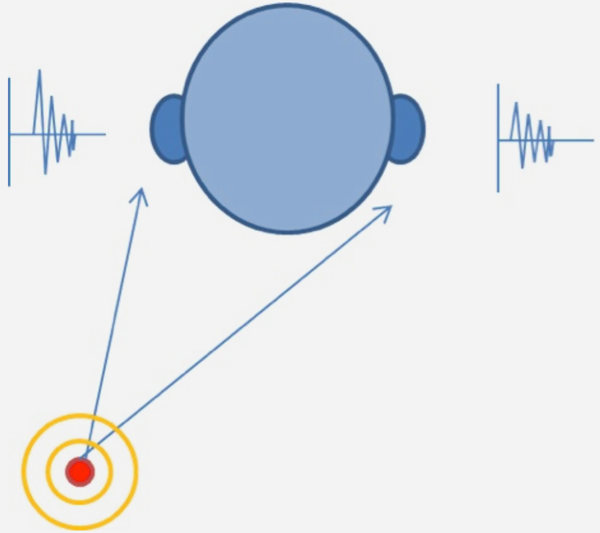
Methods: Outline

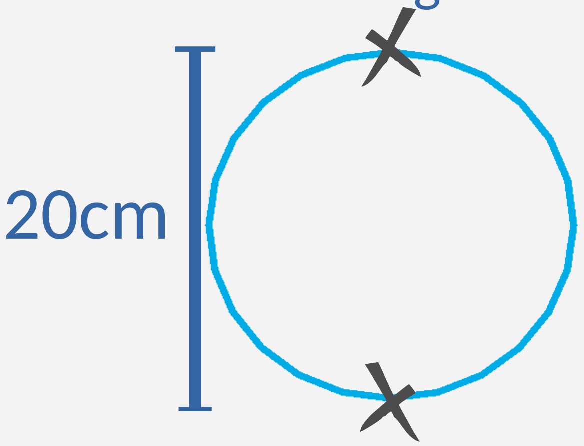
- Simulation of 2D wave propagation with SpecFEM2D*
- Bio-inspired antennas
- Source localization with time reversal using elastic waves



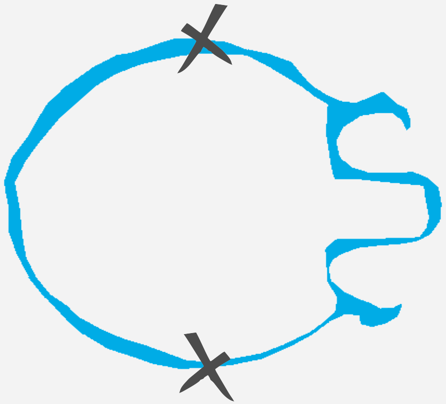
*geodynamics.org; Image: modified from innovationintelligence.com (accessed 11/07/16)

Methods: Geometries & Receivers

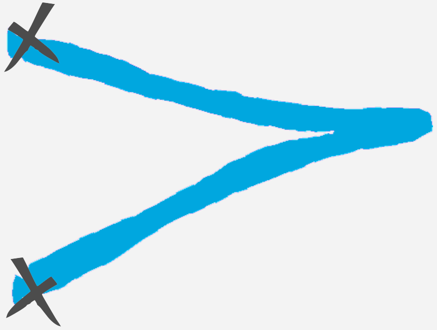
Ring

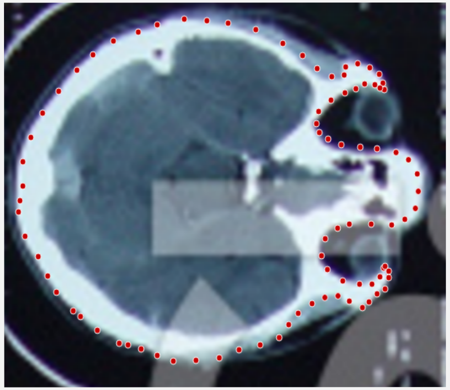


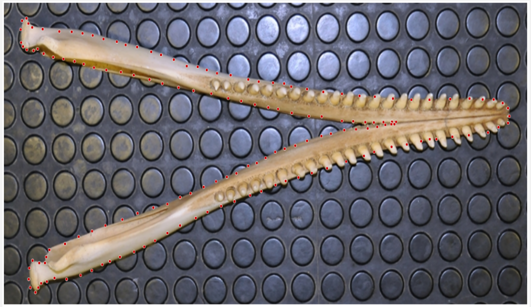
Human skull



Dolphin mandible



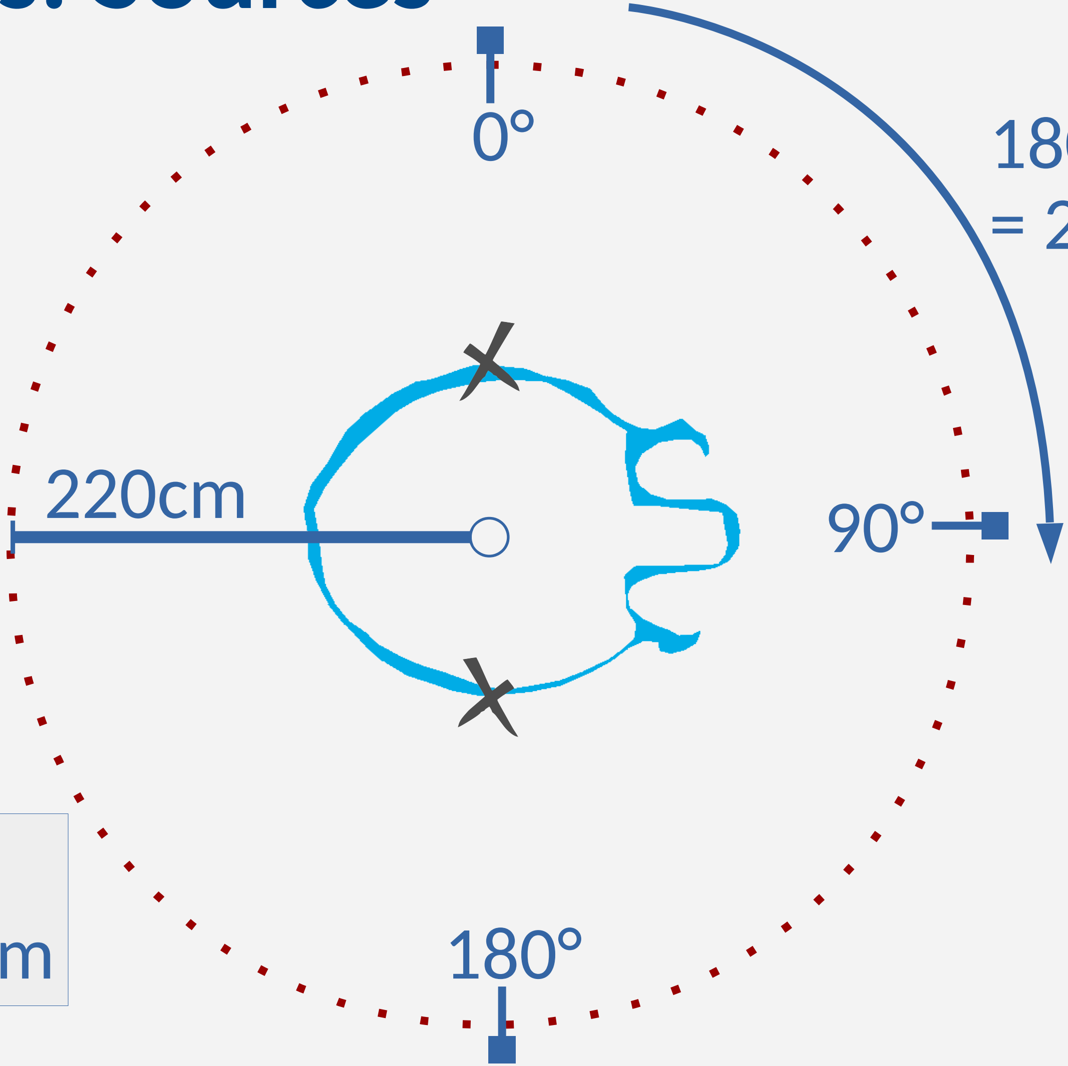


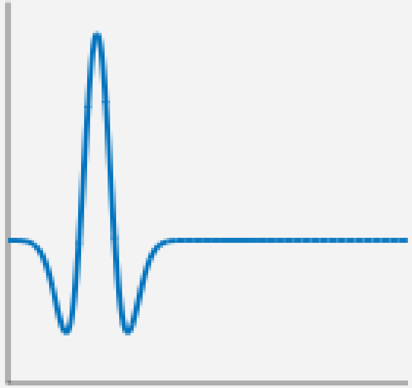


✗ = Displacement in elastic medium

Images: modified from hopkinsuniversity.org and ccaro.org (both accessed 11/07/16)

Methods: Sources





= Displacement in elastic medium

Method: Time reversal

Elastic waves

Recorded signal · Source · Impulse response

$$S_o(t) = c(t) \otimes IR_o(t)$$

Time reversal

Analytically computed correlation:

$$S_o(t)_{TR} = IR_o(-t) \otimes IR_i(t) \quad (o \in i = [1\ 180])$$

Recognition processing to find acoustic signal IR_o in a reference library (all IR_i)

Spatial correlation map

Method: Time reversal

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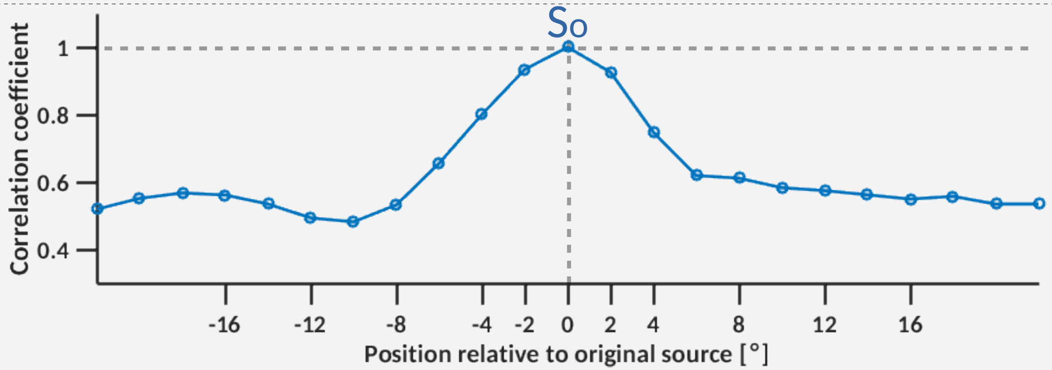
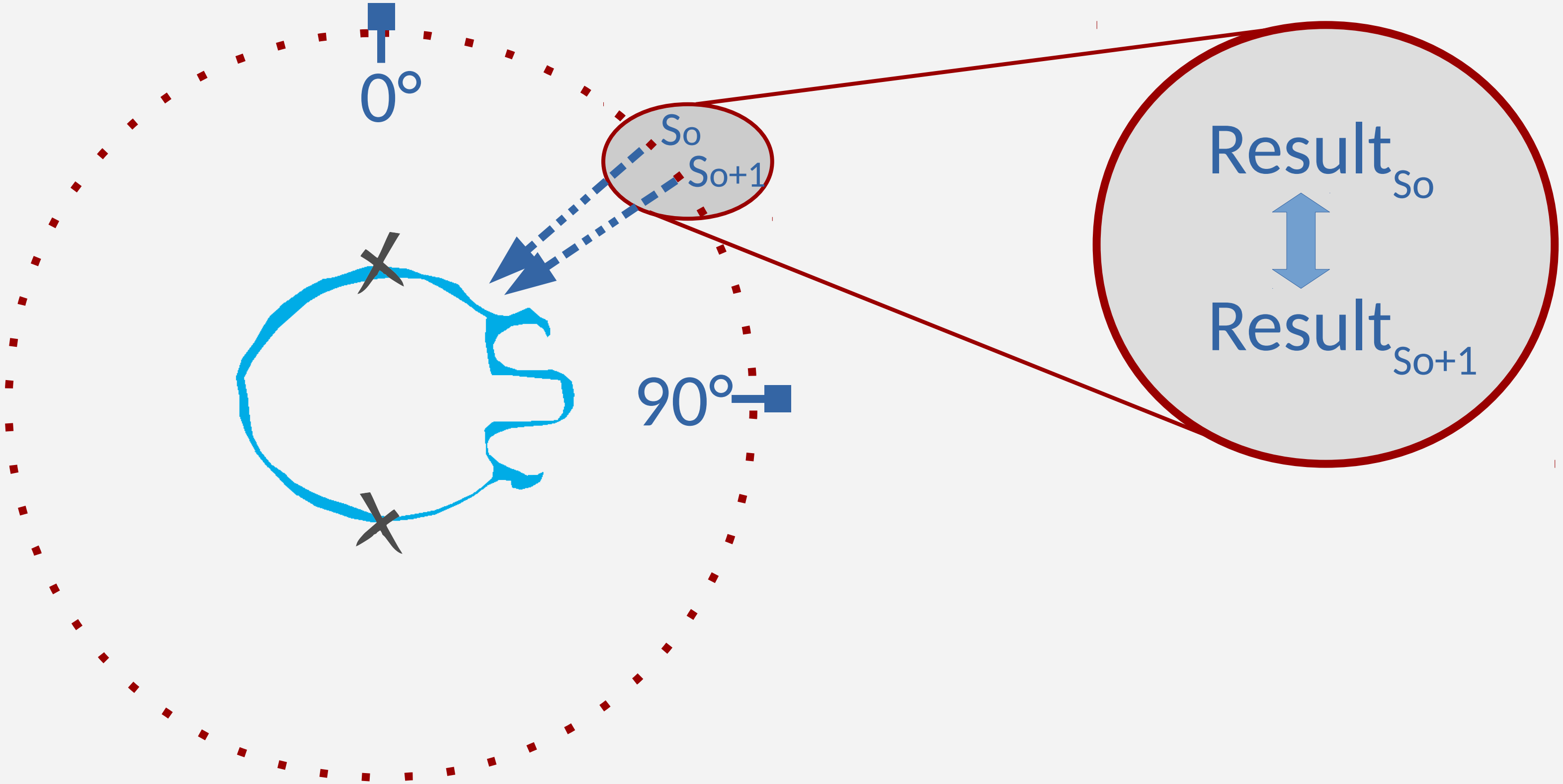


(Method adapted by Catheline et al. 2007)

Methods: Goal

Goal: Differentiation between two collateral sources



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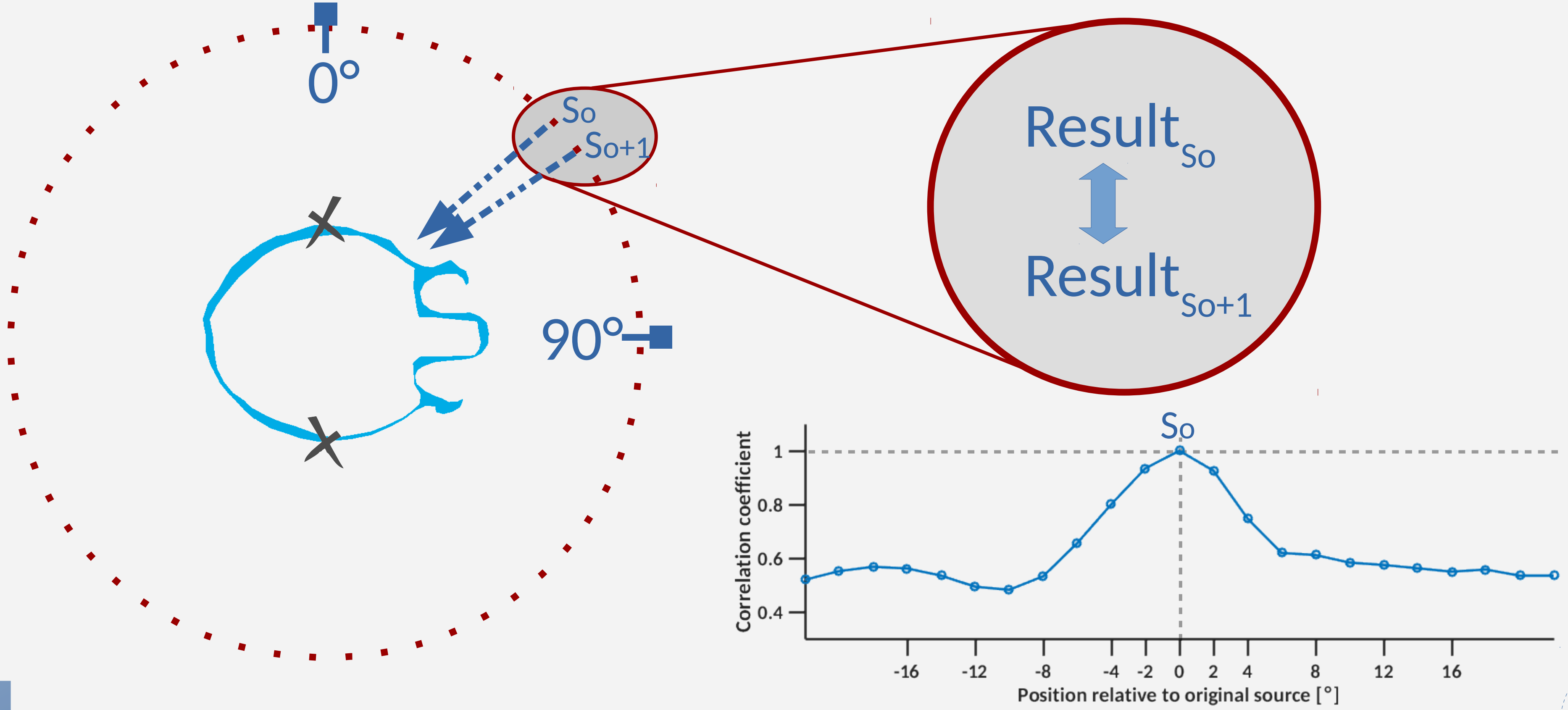

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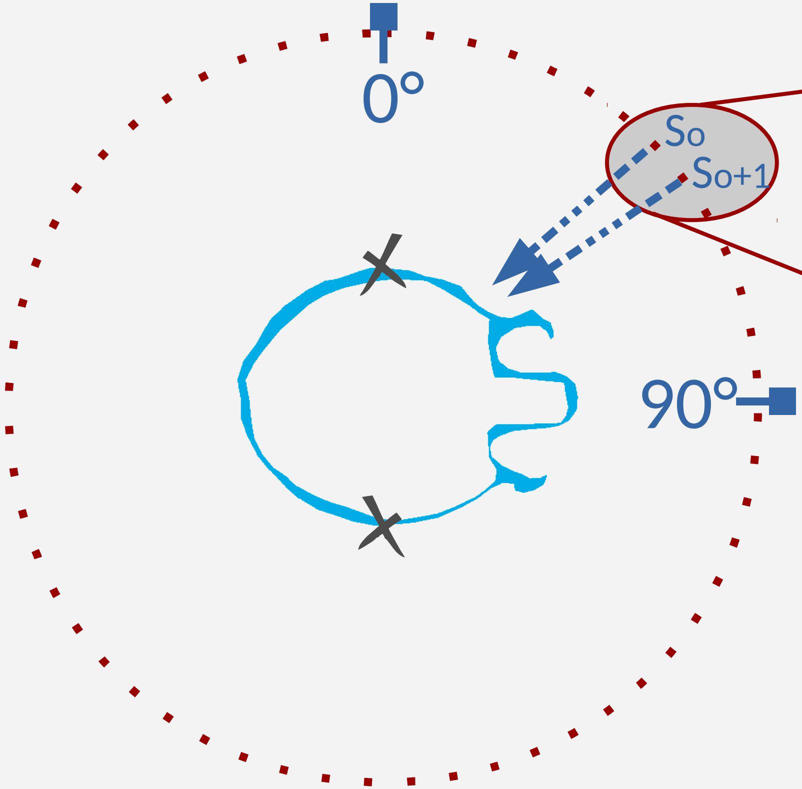

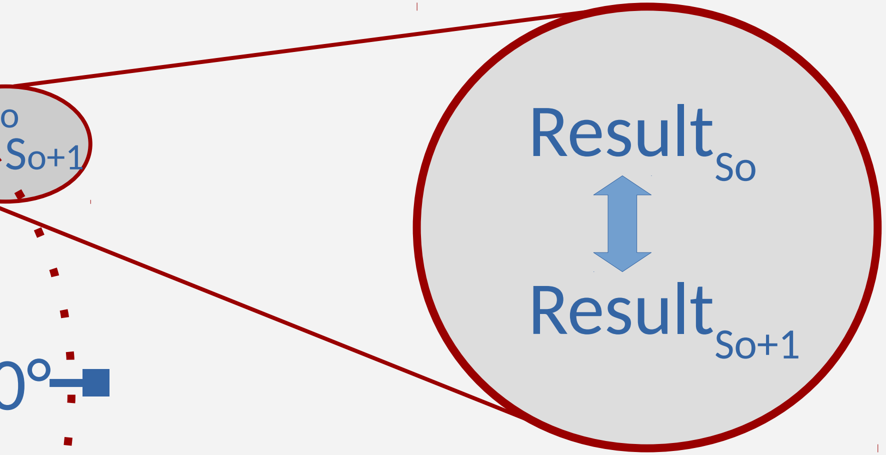

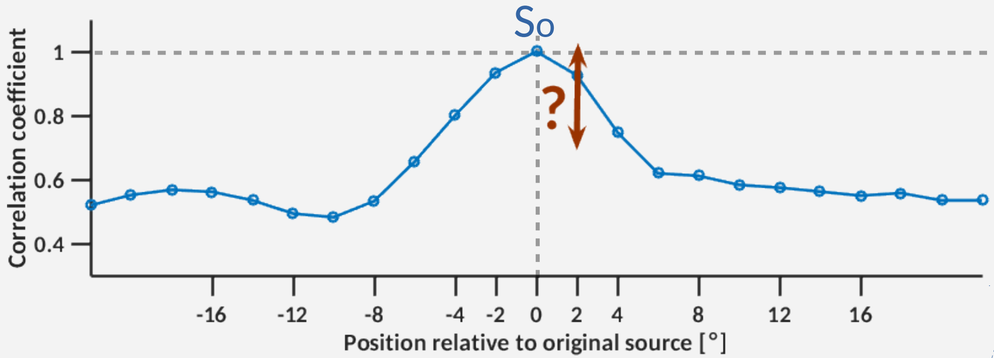

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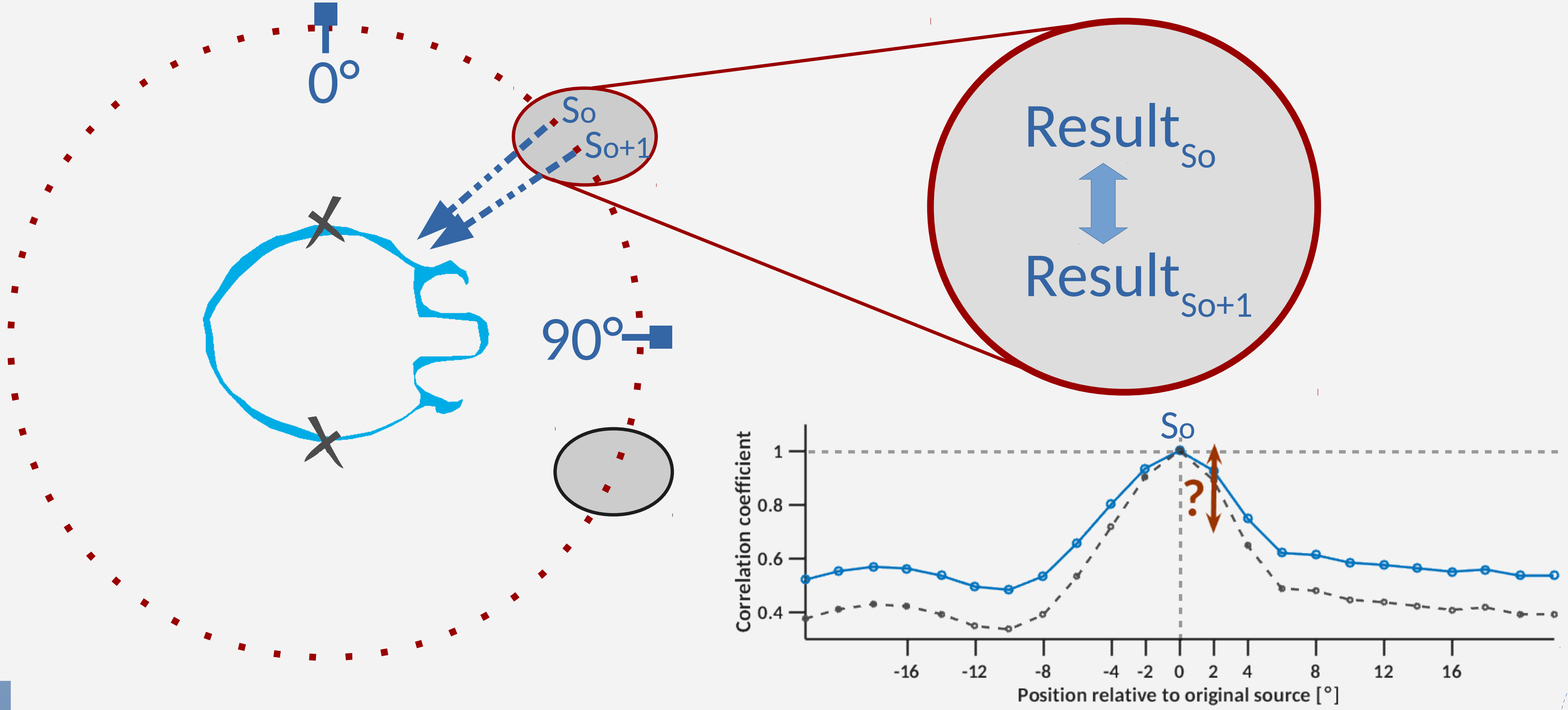
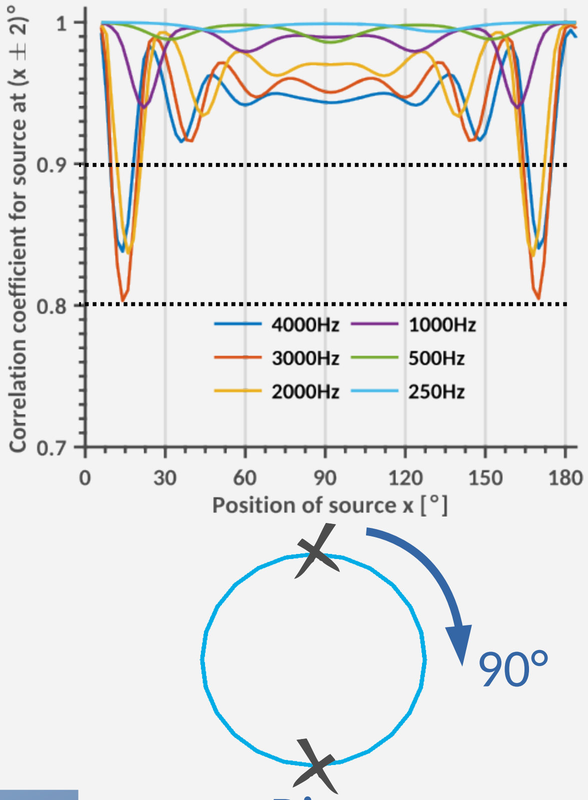
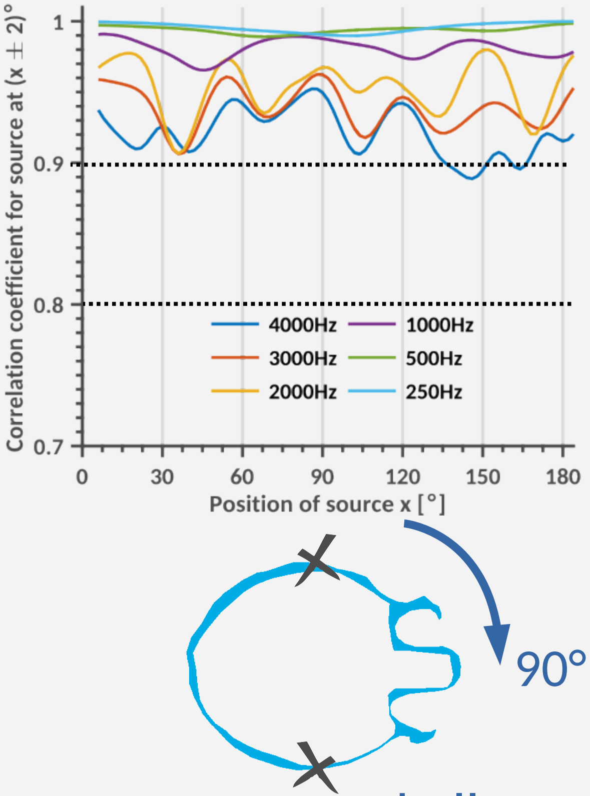


Results: Time reversal

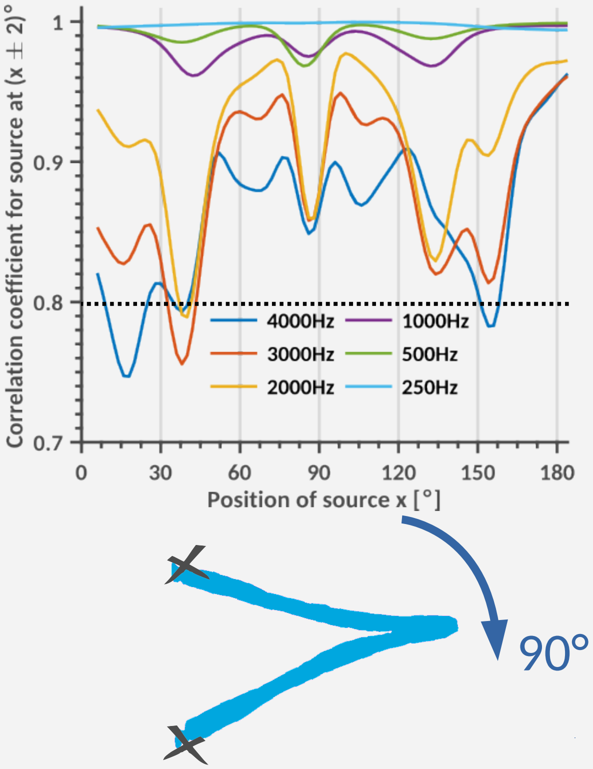
❗ Lower value = better resolution



Ring



Human skull

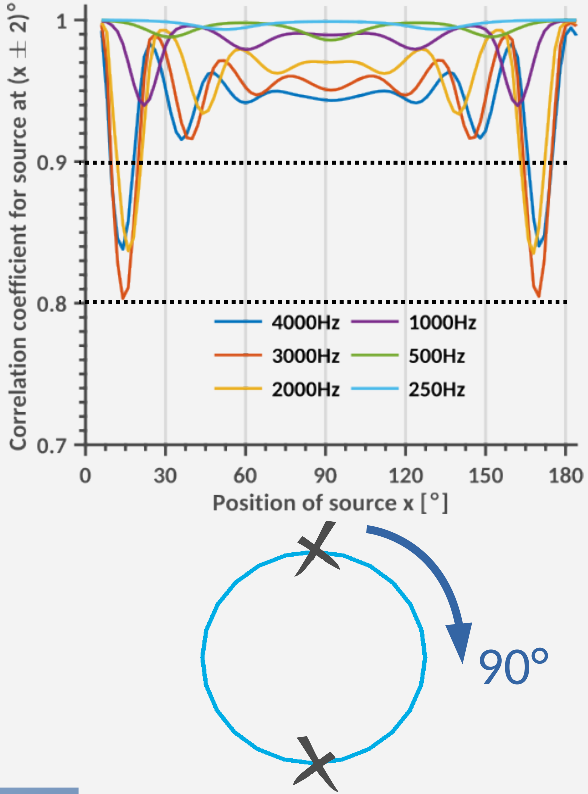


Dolphin mandible

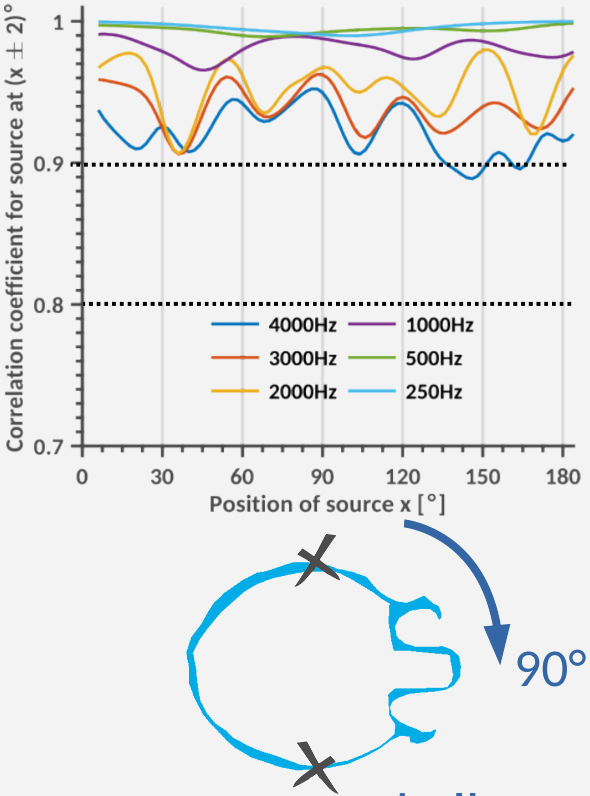
Results: Time reversal

Lower value = better resolution

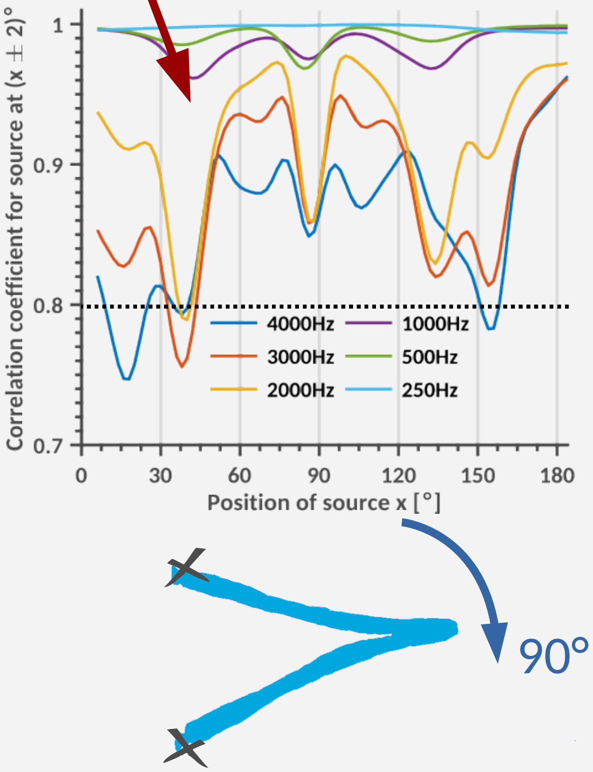
Overall improvement of resolution



Ring

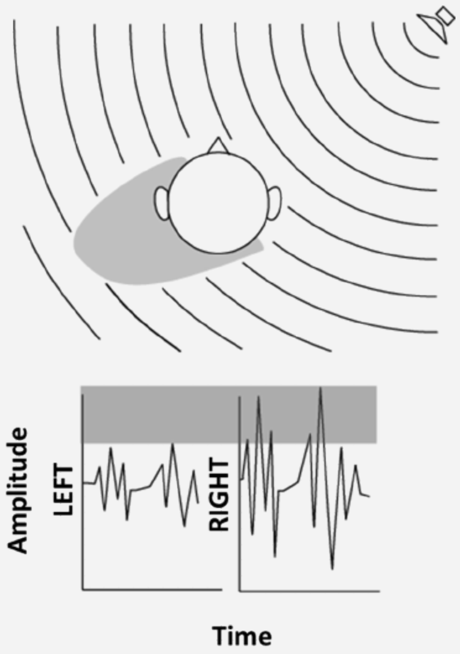


Human skull



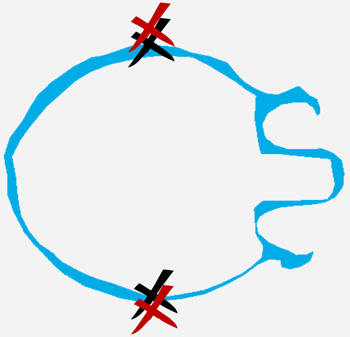
Dolphin mandible

Method 2: Interaural Level Difference



$$\frac{rms(s_1)}{rms(s_2)}$$

rms = root mean square



X = Acoustic pressure

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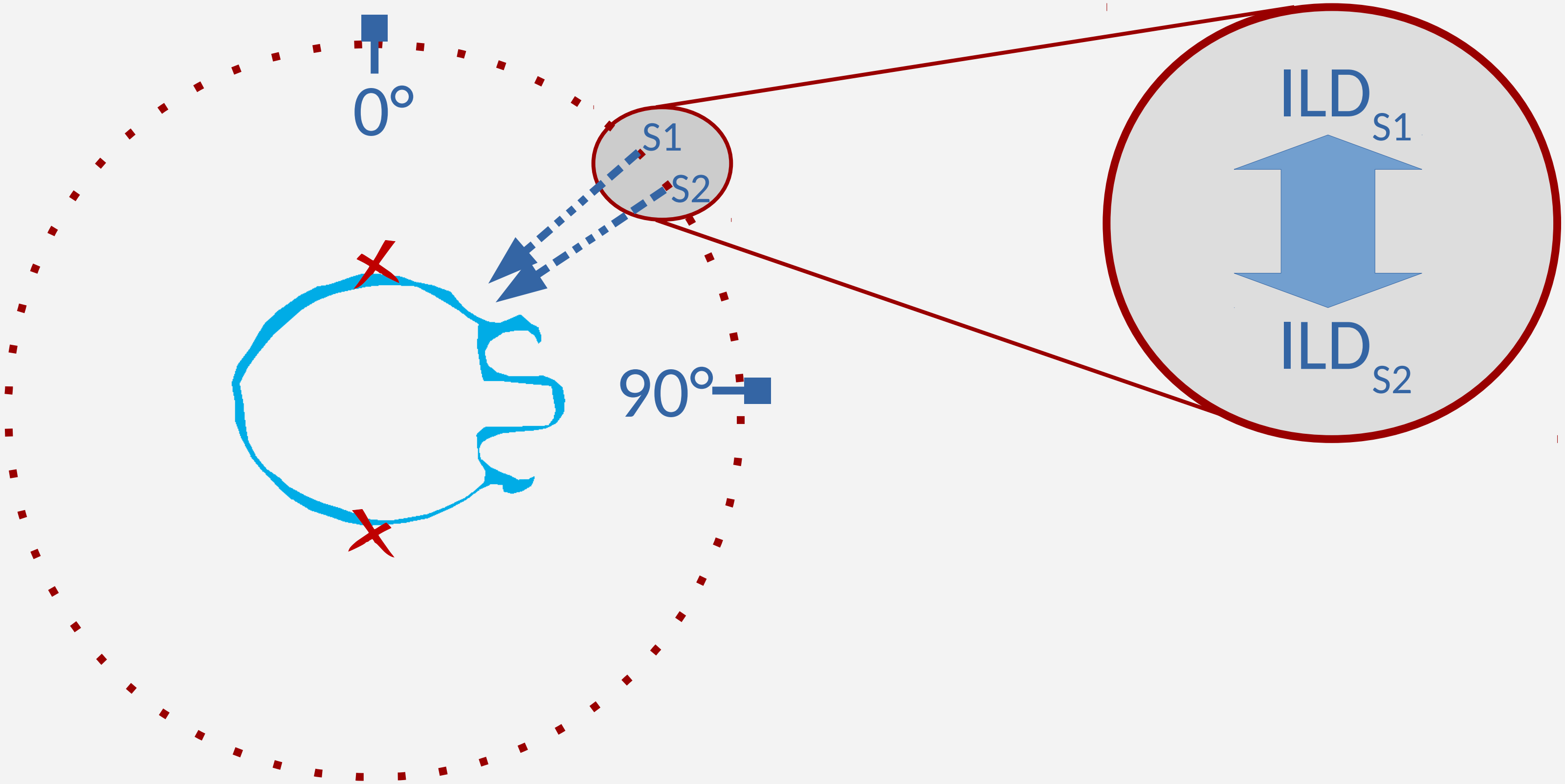
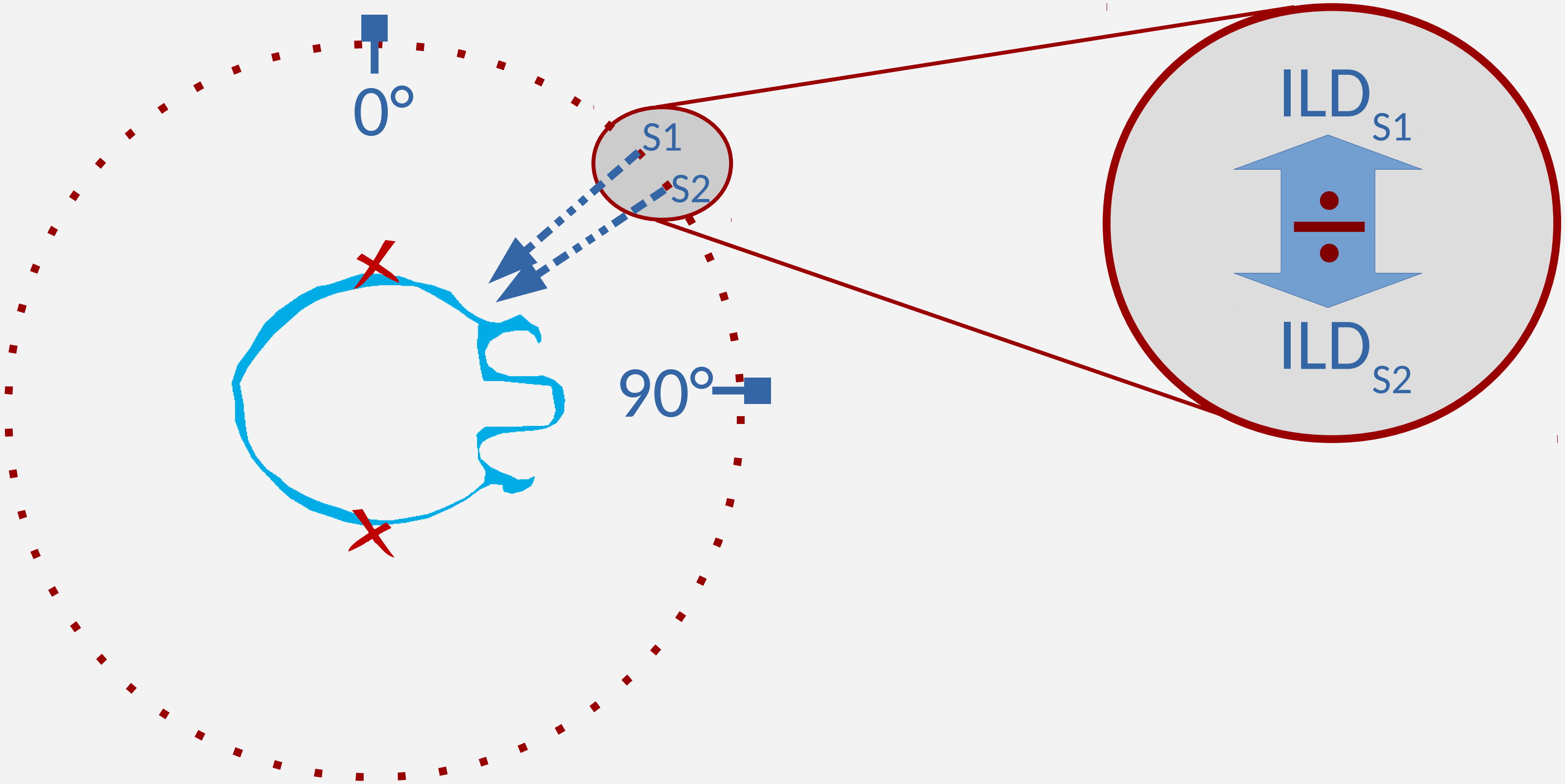


Methods: Goal

Goal: Differentiation between two collateral sources



Results: Interaural Level Difference

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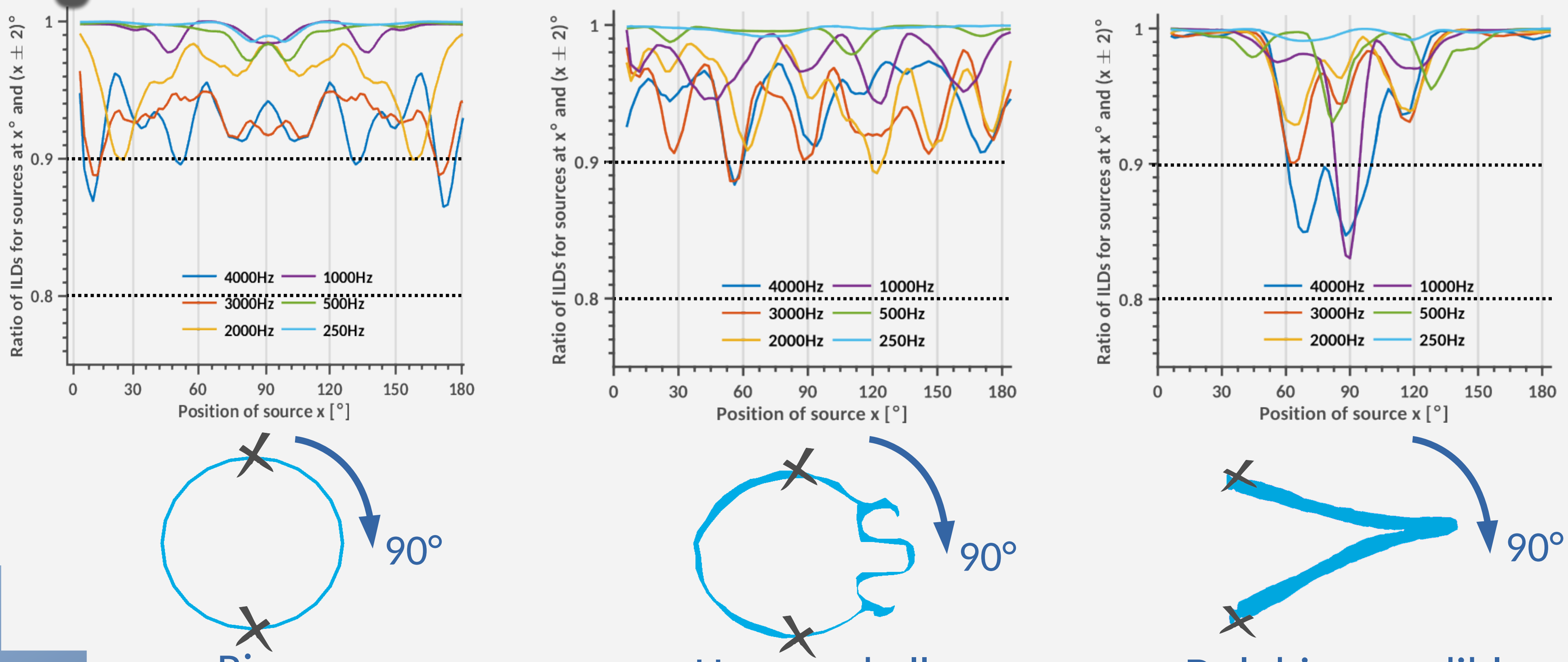

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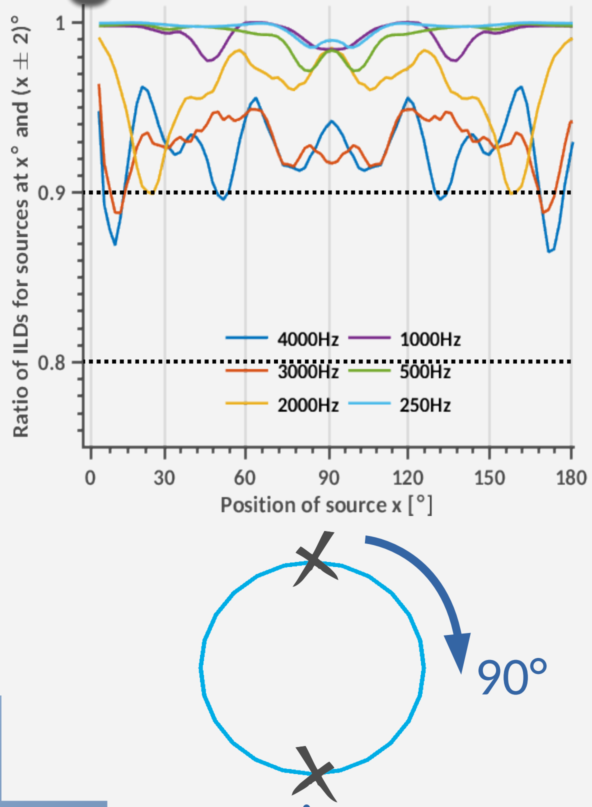
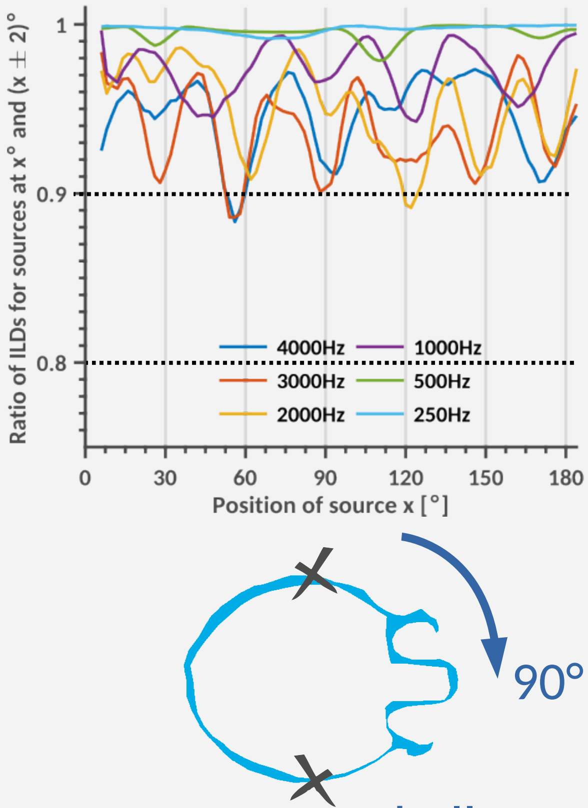
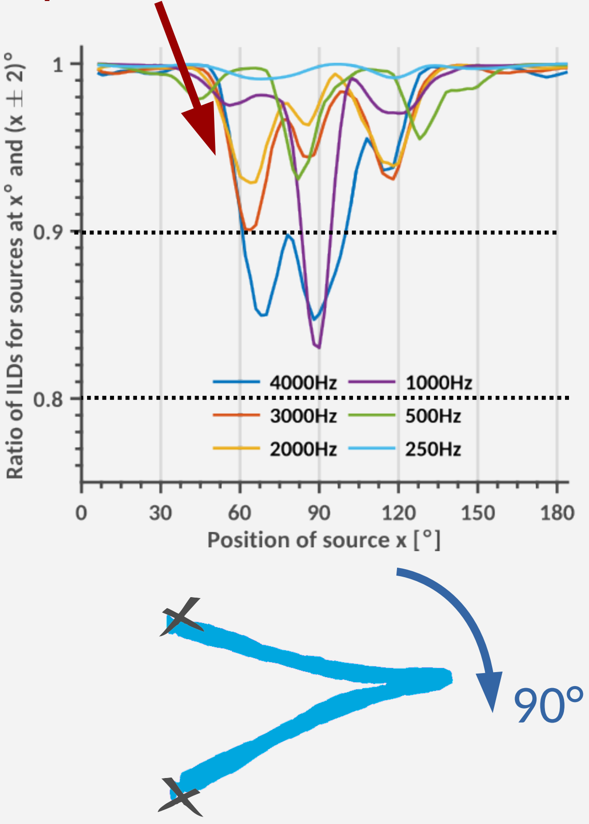


Ring



Human skull

Strong directional dependence



Dolphin mandible

Recap

How important is the shape/geometric complexity of the skull for localization algorithms?

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Wave propagation simulations
+
Localization algorithms
(Time reversal + level difference)
+
Bio-inspired antennas

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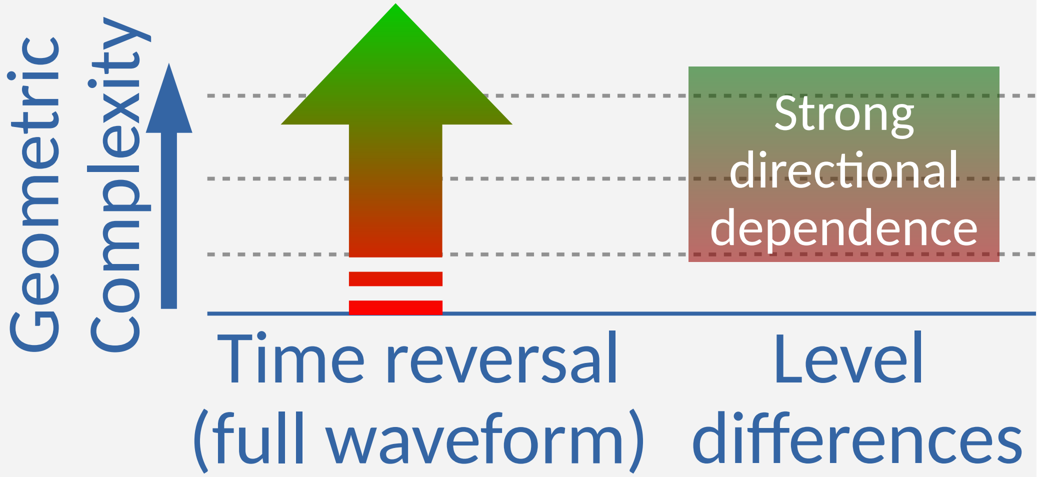

Outlook

- Further research on the role of bone conduction in mammalian acoustic source localization:

  - 3D simulations
  - Experiments with human and dolphin skulls
  - Psycho-acoustic experiments

Questions?

References:

- Catheline, S., Fink, M., Quieffin, N. and Ing, R.K., 2007. Acoustic source localization model using in-skull reverberation and time reversal. *Applied physics letters*, 90(6), p.063902.

- Zhong, X., Yost, W. and Sun, L., 2015. Dynamic binaural sound source localization with ITD cues: Human listeners. *The Journal of the Acoustical Society of America*, 137(4), pp.2376-2376.

- Birchfield, S.T. and Gangishetty, R., 2005, March. Acoustic localization by interaural level difference. In Proceedings.(ICASSP'05). *IEEE International Conference on Acoustics, Speech, and Signal Processing*, 2005. (Vol. 4, pp. iv-1109).