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Interpretation of scattering from small aluminium cylinders on the seabed from dual-frequency SAS images, AEUK/2022/1813

R Brothers & A Burt, 23/06/2022

...a sound decision

ATLAS ELEKTRONIK UK
A company of the ATLAS ELEKTRONIK Group

Abstract

Interpretation of scattering from small aluminium cylinders on the seabed from dual-frequency SAS images

Over recent years ATLAS ELEKTRONIK UK (AEUK) have conducted research into the development of wideband sonar for the survey of seabed objects in order to mitigate difficulties associated with the use of traditional sonar in difficult, cluttered environments.

This paper focusses on scattering results obtained from small, free-flooding, aluminium cylinders placed on the seabed, imaged using an AEUK dual frequency Synthetic Aperture Sonar (SAS). We will show that a full interpretation of the scattering features exhibited in the sonar data requires a detailed understanding of the vibro-acoustic wave physics, associated with scattering from thin shelled, elastic objects. Modelling of wave speed dispersion and the paths of circumferential, helical, and meridional shell-borne waves, together with internal scattering in different cylinder orientations can be used to explain the differences in scattering at different frequencies. This understanding will provide the ability to design a sonar system better able to distinguish man-made objects from natural ones.

To provide a physical interpretation of the data, numerical modelling is used to support the interpretation of SAS image evidence.

This work has been conducted for Dstl.

Understand the physics → Interpret scattering data → Distinguish man-made and natural objects

AEUK dual band SAS

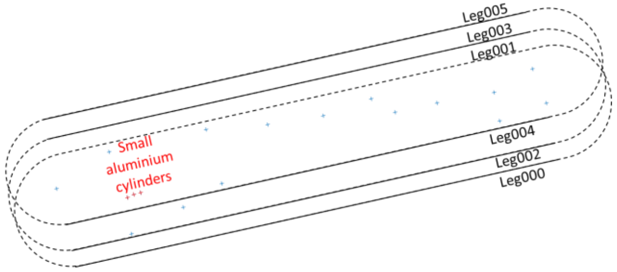
This system was put together from existing components, rather than by design from outset

Trial conducted in Portland Harbour against a range of objects

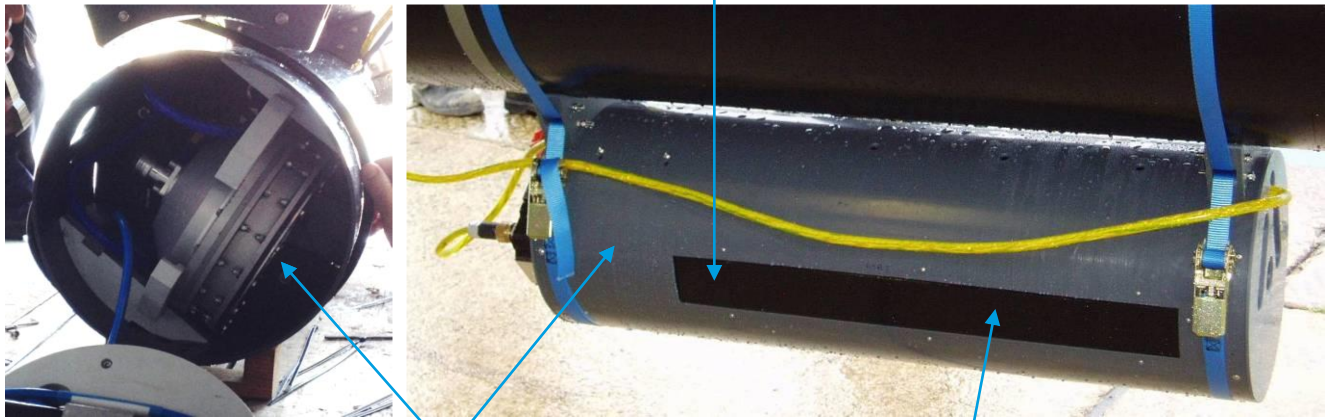
- HF Vision 600 SAS Tx and Rx
- Multi-purpose single crystal LF Tx developed for Dstl
- Packaged to fit on medium sized Autonomous Underwater Vehicle (AUV), and underslung on large Marlin AUV

- HF band
  - Centre frequency 150 kHz
  - Bandwidth 60 kHz
  - Transmit beam width 25° @ 120 kHz, 15° @ 180 kHz
- LF Band
  - Centre frequency 20 kHz
  - Bandwidth 24 kHz
  - Transmit beam width ~44° @ 12 kHz, 27° @ 30 kHz

Marlin AUV



HF transmit array

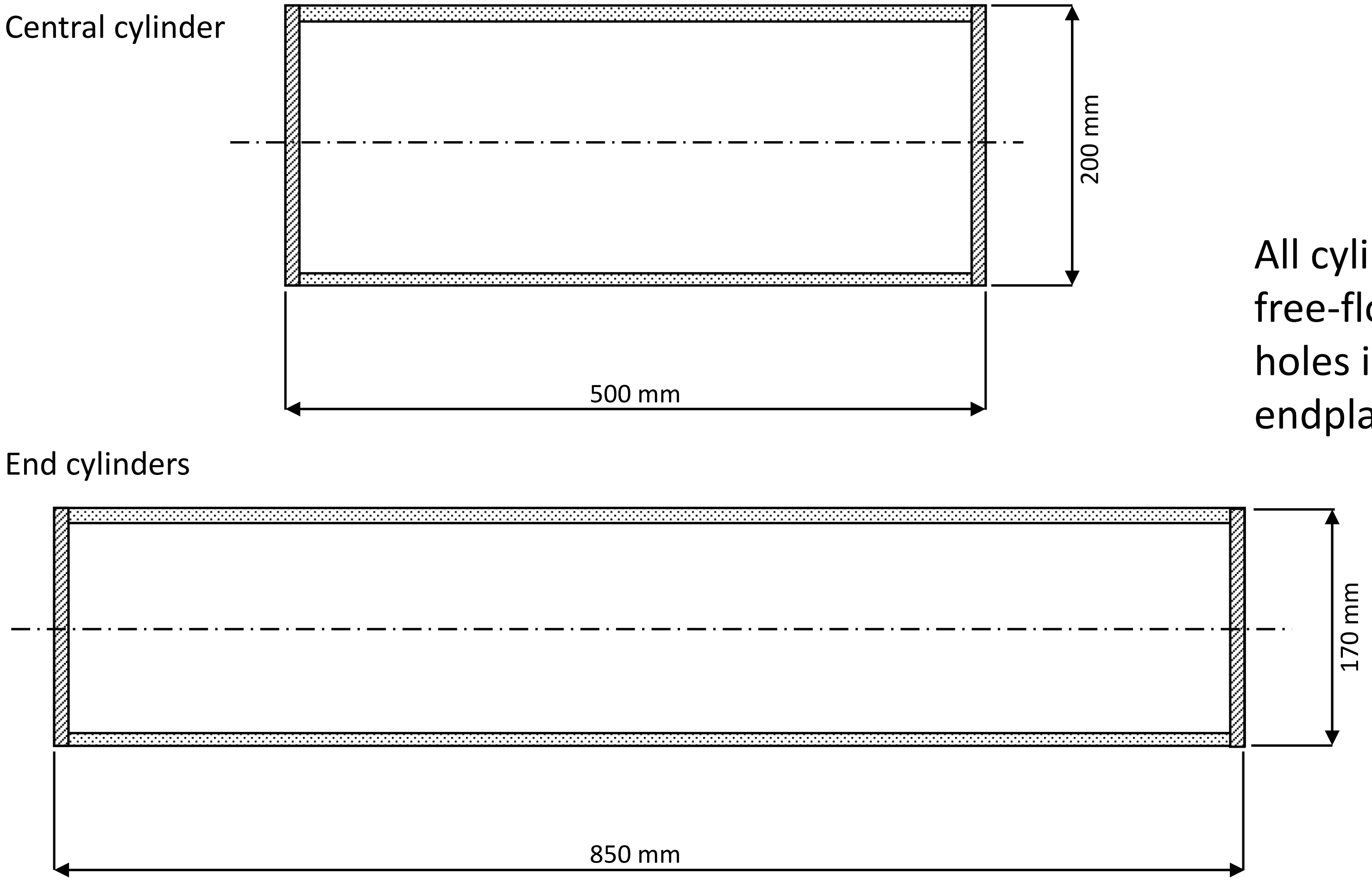


LF transmit array (behind fairing)

Receive array

Small aluminium cylinders

3 cylinders connected by a line placed on the seabed (spaced by ~4m) with a concrete sinker

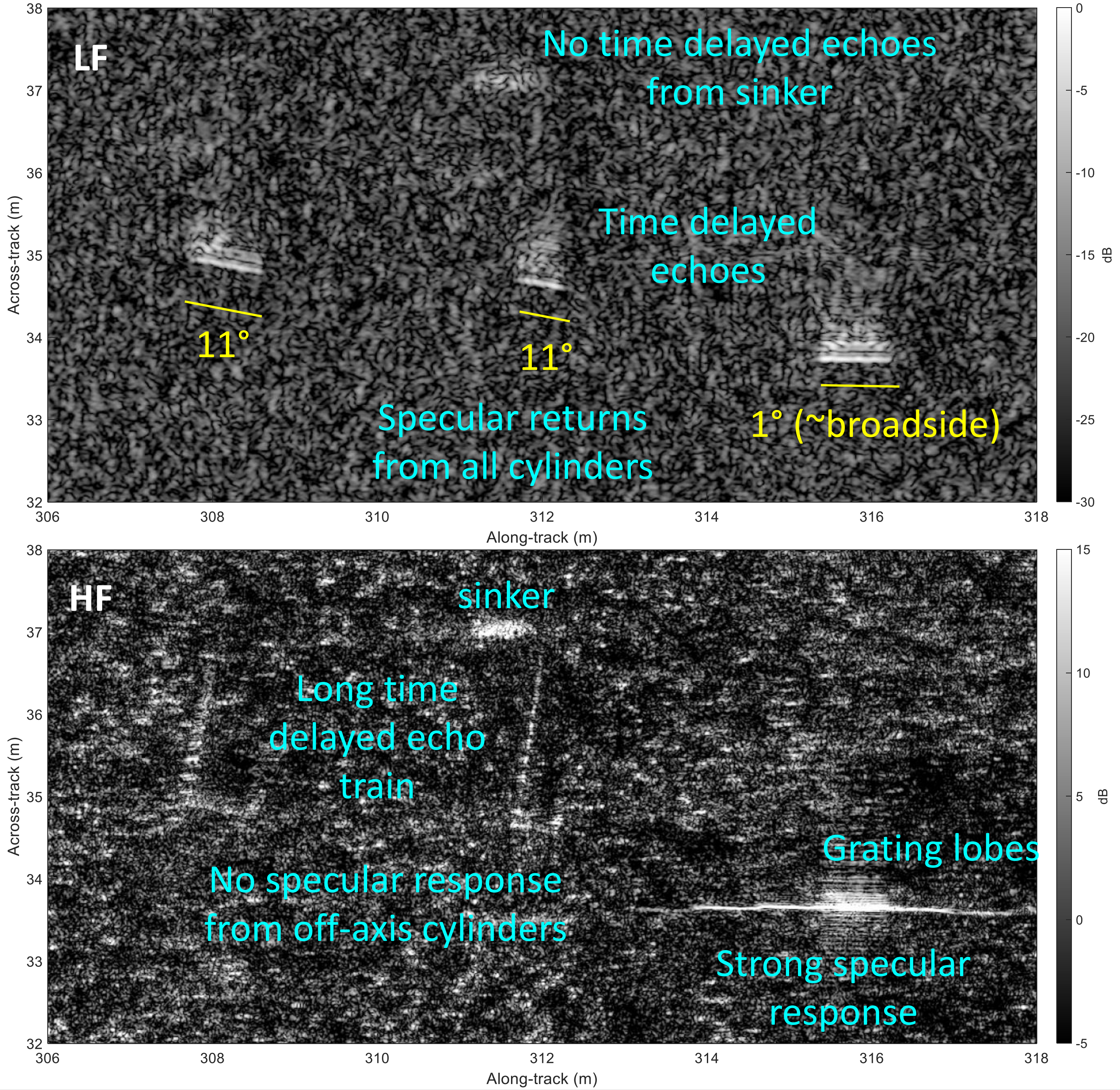


All cylinders are free-flooding via holes in the endplates

LF + HF SAS images – Leg 000

Response of the small aluminium cylinders is very different at LF and HF

- Both LF and HF contain time delayed echoes assumed to be associated with elastic target responses, but these are very different at LF and HF
- HF is not specular return only for off-broadside targets

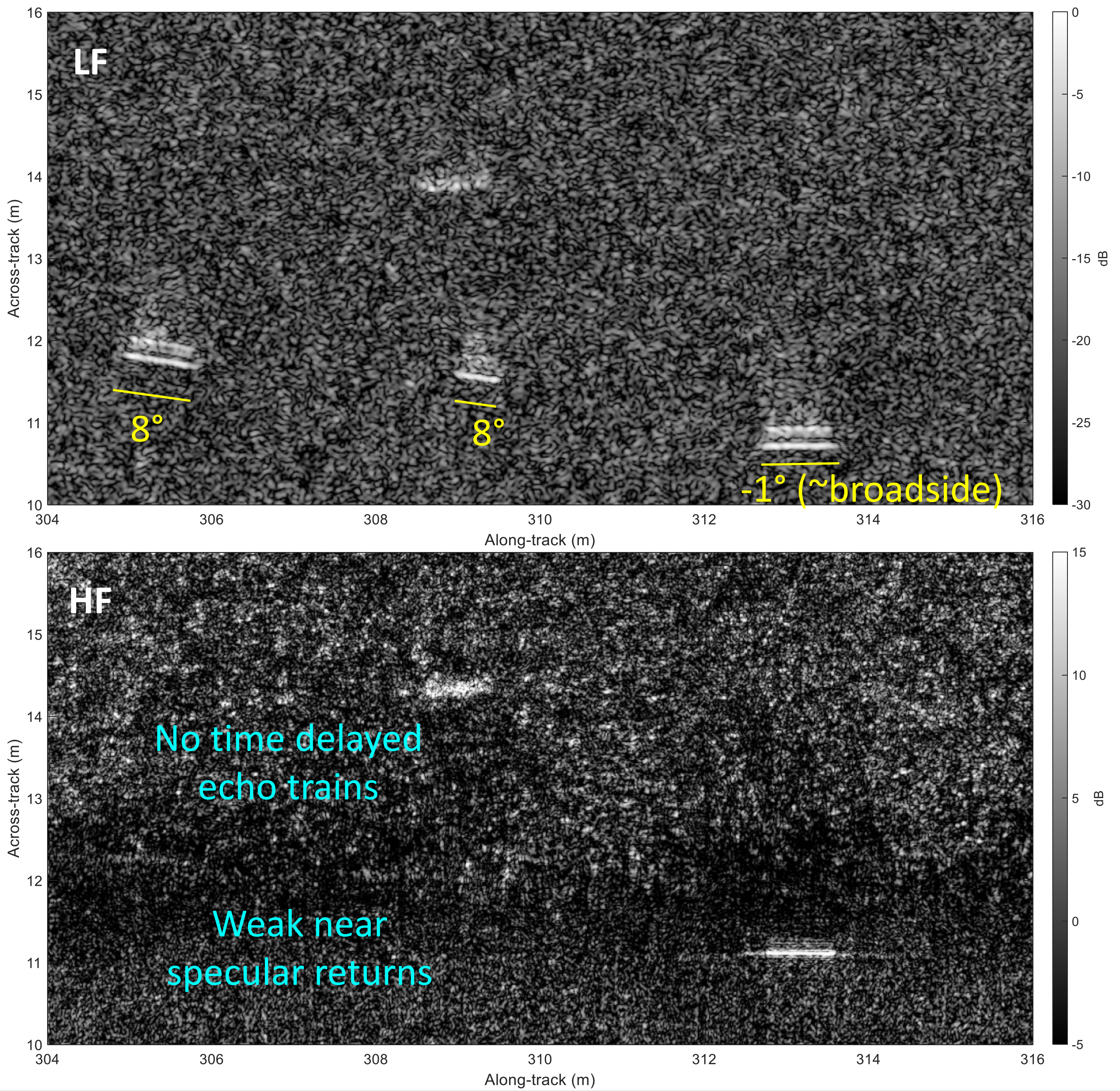


LF + HF SAS images – Leg 004

In Leg 004 the time delayed echo trains in HF not observed at all

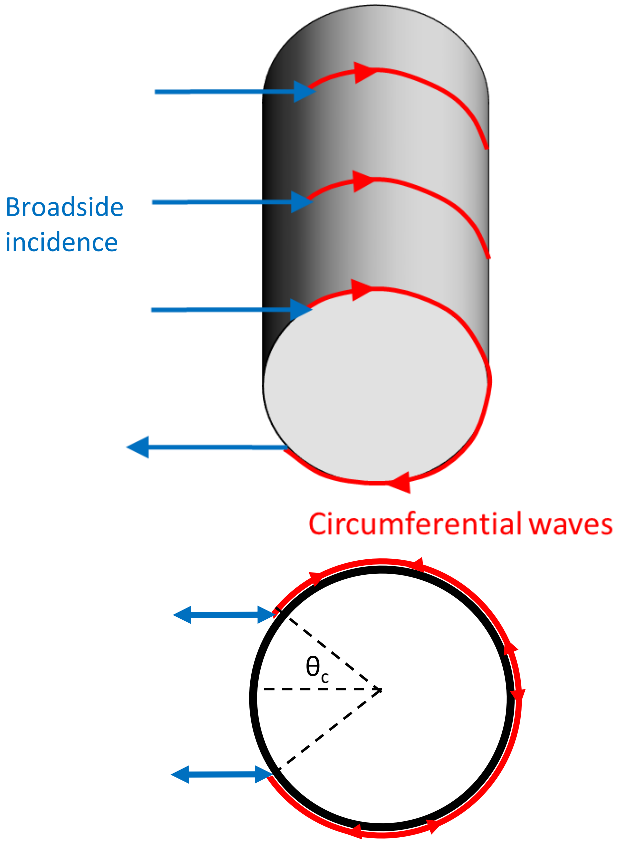
Leg 004 orientation slightly different by a few degrees

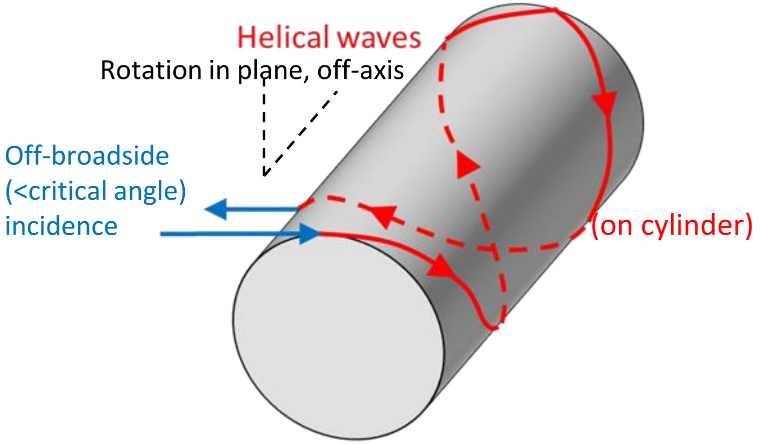
- No time delayed echoes for off axis cylinders
- Shorter ranger

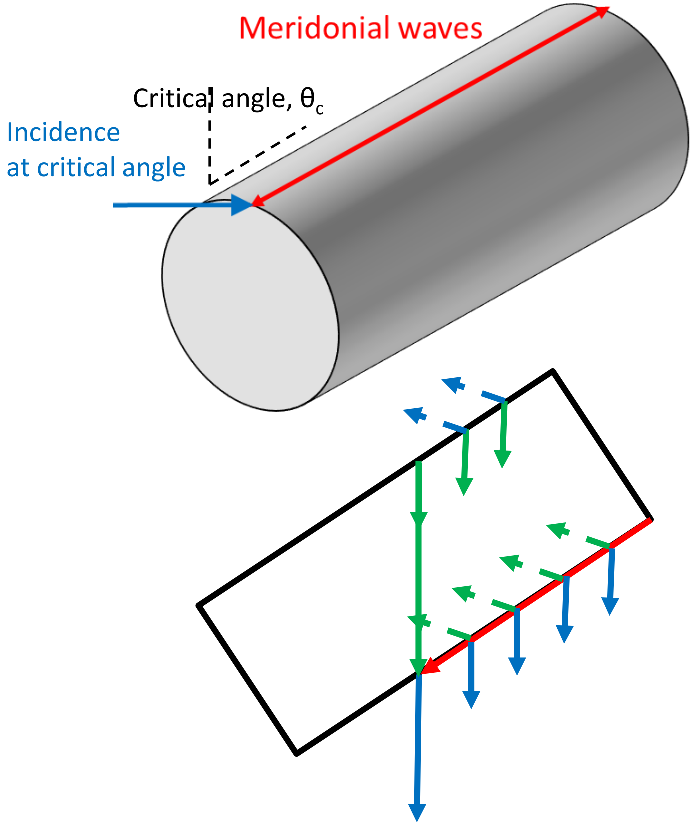


Elastic wave scattering from shell-borne waves in a thin-shelled cylinder

Scattering from a cylindrical, elastic target depends strongly on the cylinder orientation wrt the sonar



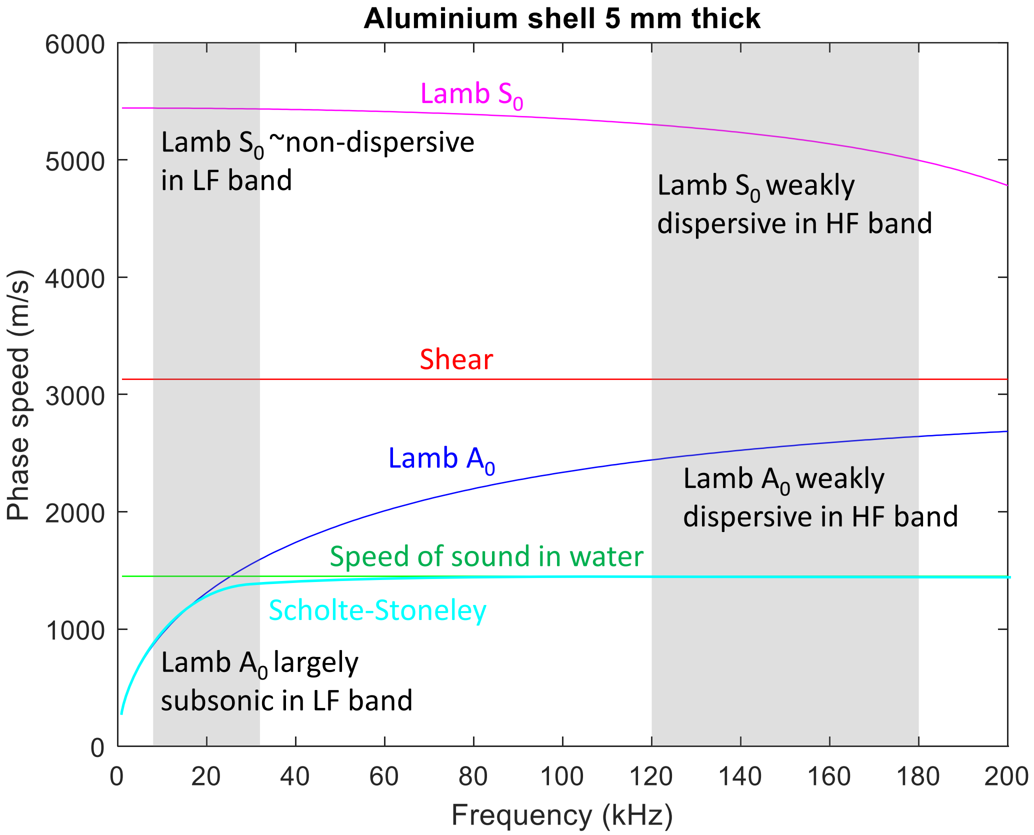


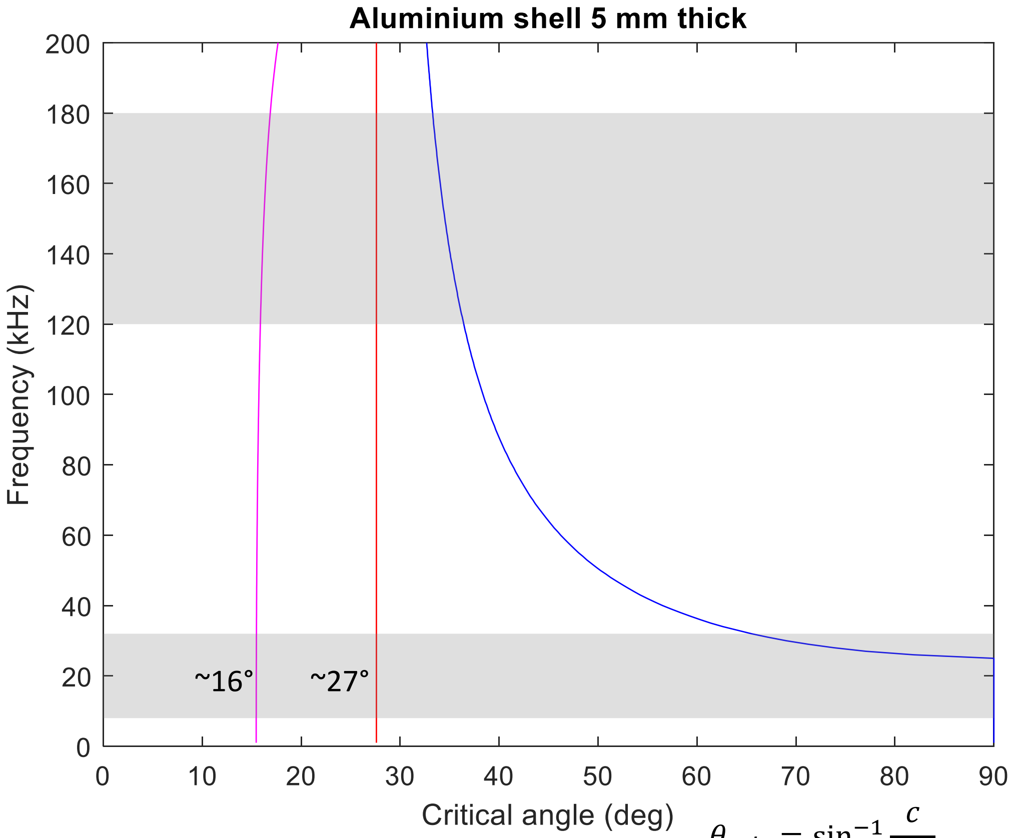


Shell-borne wave dispersion

Understand the physics → Interpret scattering data → Distinguish man-made and natural objects

For an aluminium shell thickness of 5 mm (plate approximation [1])





$$\theta_{crit} = \sin^{-1}\frac{c}{c_{ph}}$$

[1] Kargl, S, and Marston,. P, ‘Observations and modeling of the backscattering of short tone bursts from a spherical shell: Lamb wave echoes, glory, and axial reverberation’, J. Acoust. Soc. Am, 85(3), 1014-1028, March 1989.

Scattering features at different target aspects and frequencies (1/2)

TES enhancements associated with the critical angles of different super-sonic wave types will be observed based on horizontal Tx beam width and target aspect

Tx horizontal beam:

- - - - - - LF band (12 kHz)

------------ HF band (180 kHz)

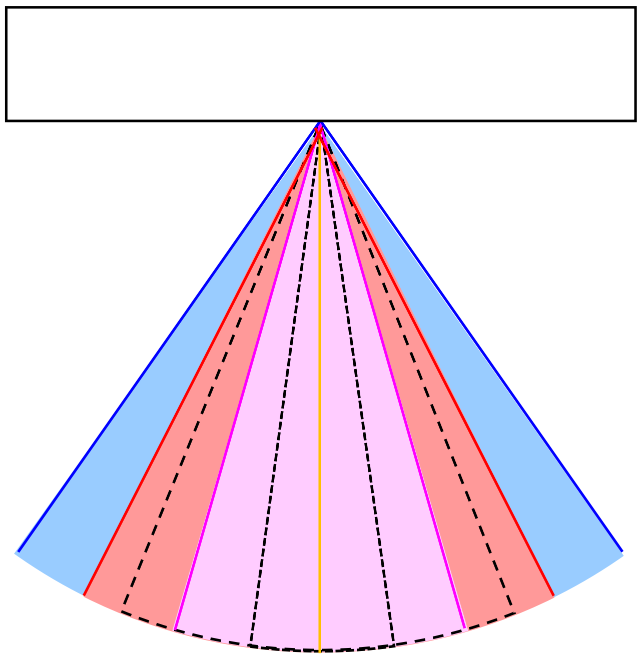
Broadside specular response

Shear critical angle

Lamb S_0 critical angle (mean)

Lamb A_0 critical angle (min)

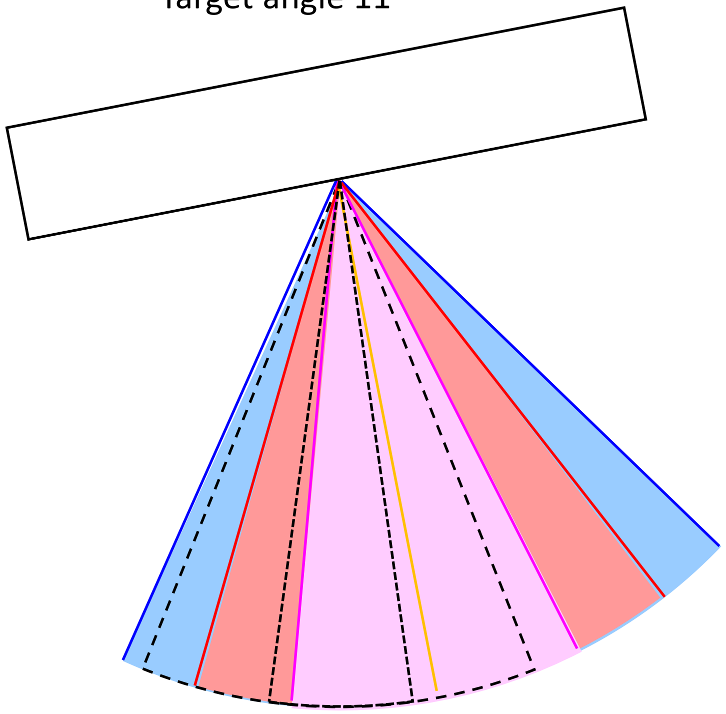
Target angle 0° (broadside)



Observable at LF: Specular, Lamb S_0

Observable at HF: Specular

Target angle 11°



Observable at LF: Specular, Lamb S_0, and shear

Observable at HF: Lamb S_0

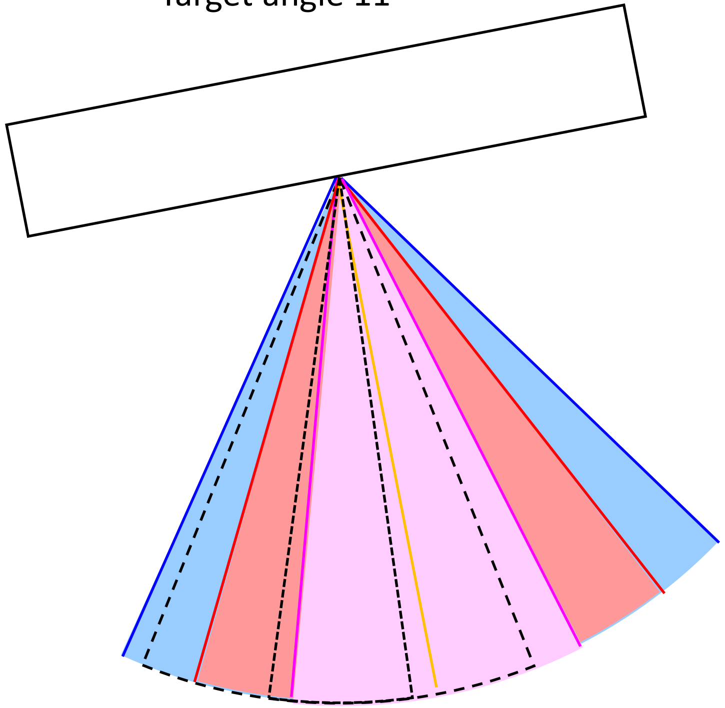
Scattering features at different target aspects and frequencies (2/2)

TES enhancements associated with the critical angles of different supersonic wave types will be observed based on horizontal Tx beam width and target aspect

Tx horizontal beam:
- - - - - - LF band (12 kHz)
----------- HF band (180 kHz)

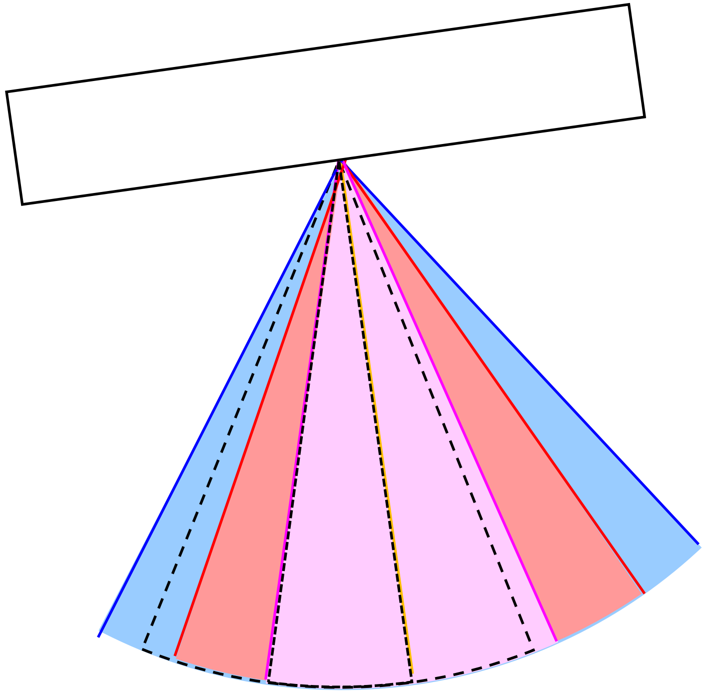
Broadside specular response
Shear critical angle
Lamb S_0 critical angle (mean)
Lamb A_0 critical angle (min)

Target angle 11^o



Observable at LF: Specular, Lamb S_0, and shear
Observable at HF: Lamb S_0

Target angle 8^o

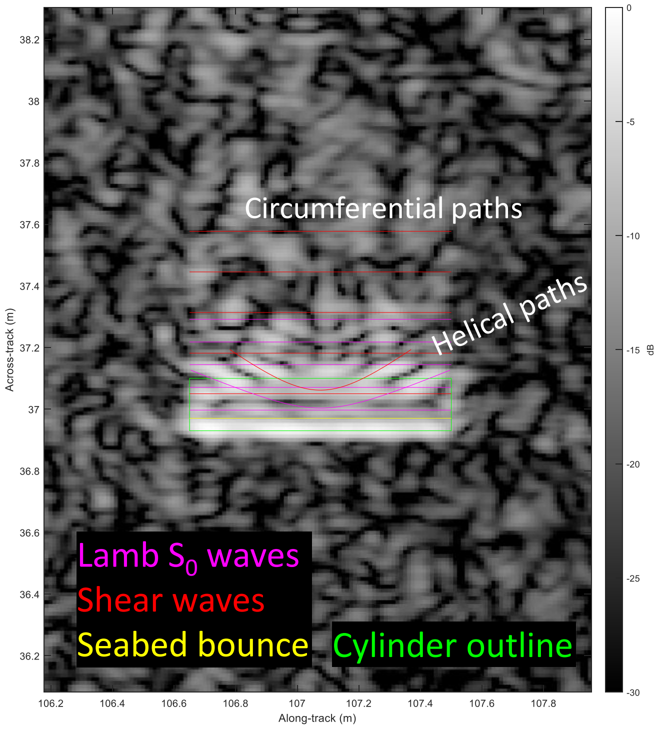


Observable at LF: Specular, Lamb S_0, and shear
Observable at HF: -

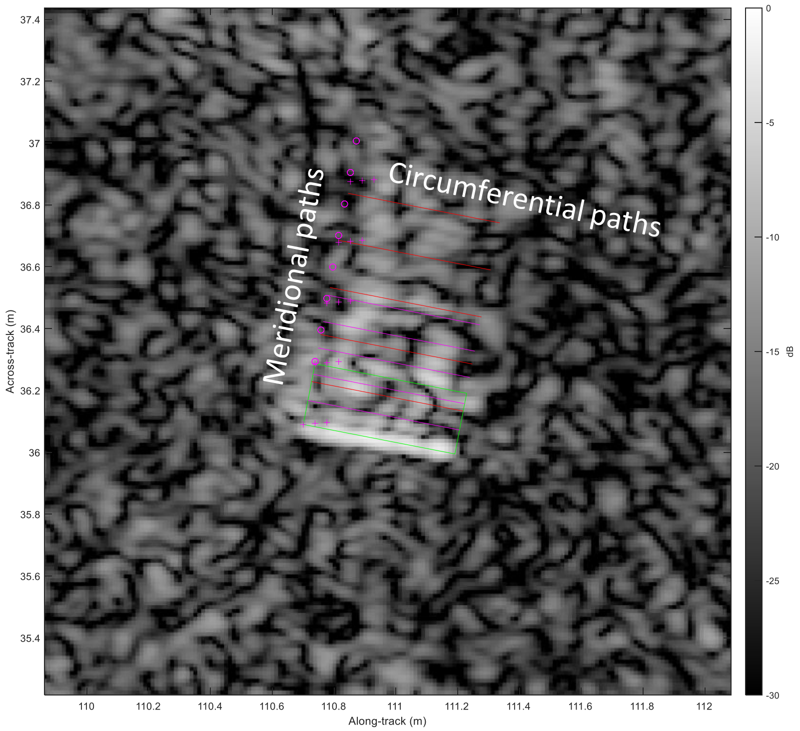
Comparison of data and matching models – LF

Matching models e.g. [2] based on geometry and material properties can be compared with observed features
Small aluminium cylinders Leg 003

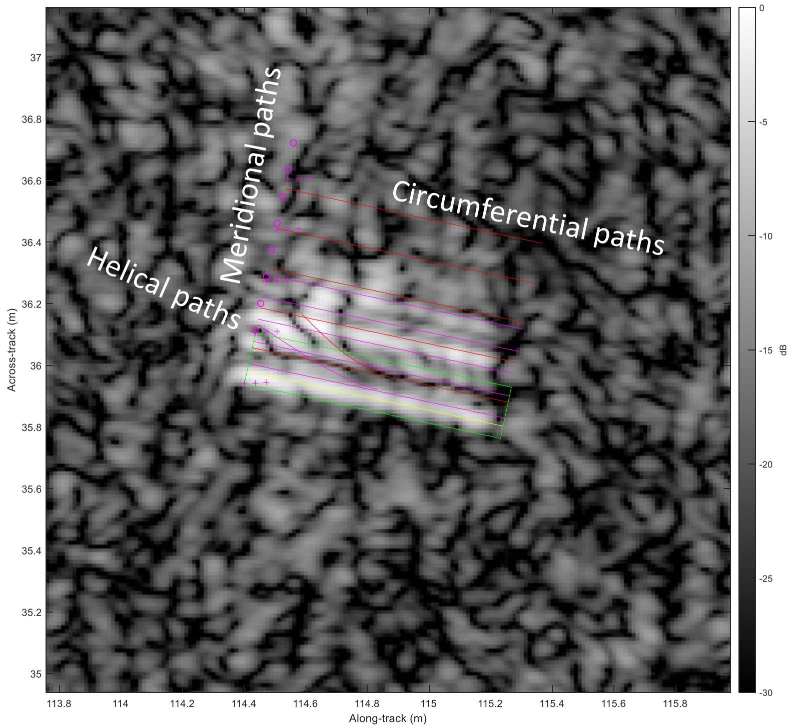
Broadside



10° off-broadside



10° off-broadside



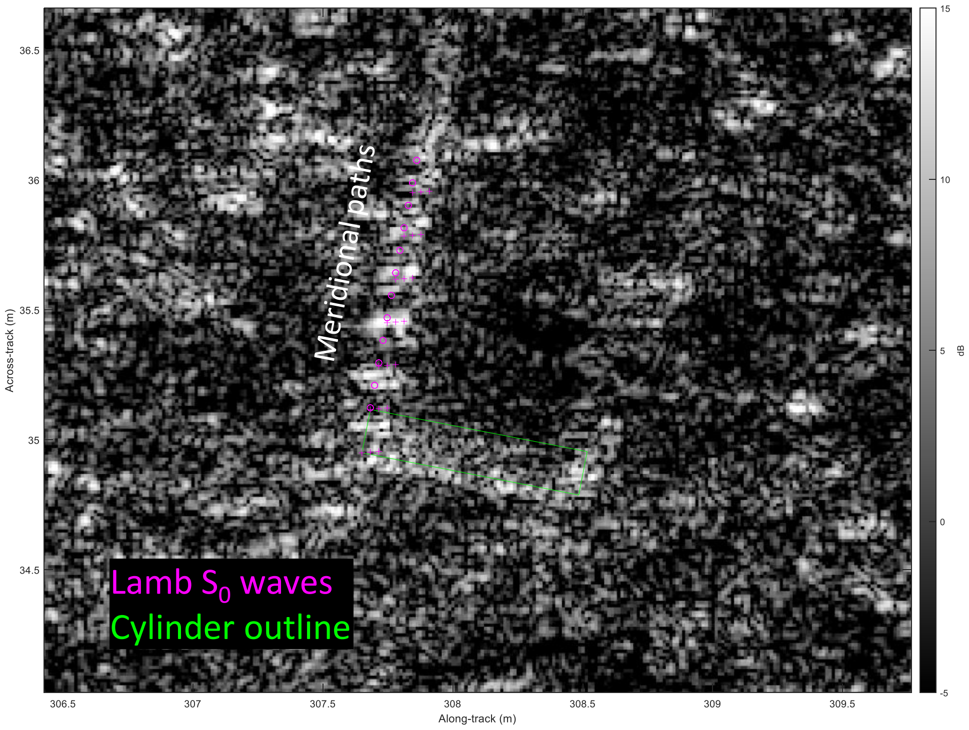
[2] Tesei, A, Fawcett J, Fox, W, and Maguer, A, Resonance Analysis of the Acoustic Response of a Water-Filled Cylindrical Shell, SACLANTCEN Report SR-295, September 1998.

Comparison of data and matching models – HF

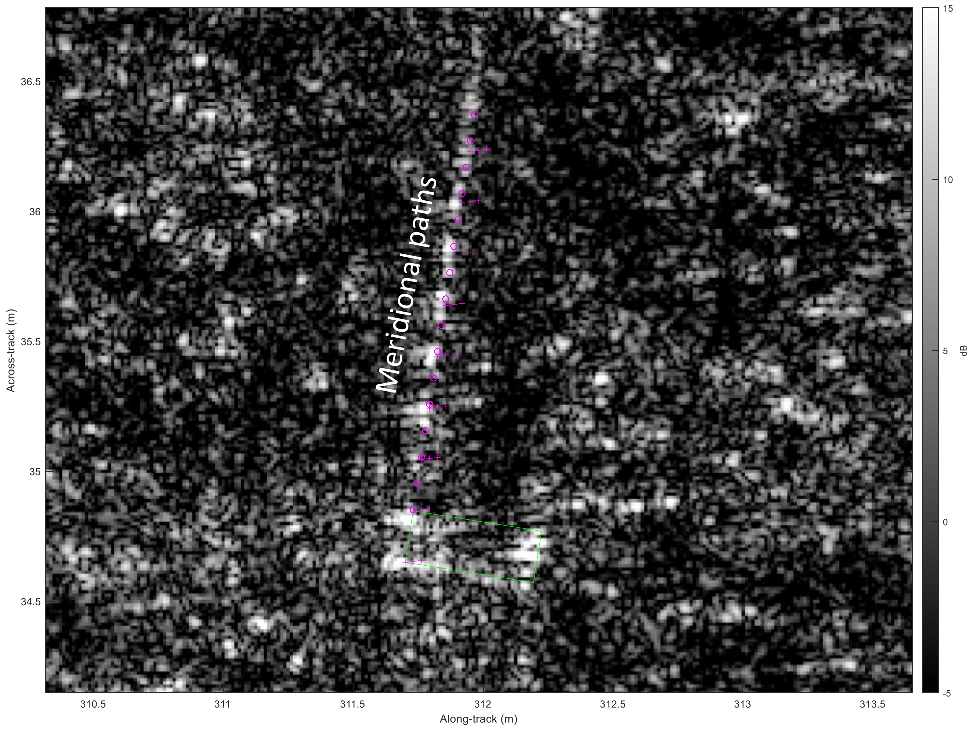
Understand the physics → Interpret scattering data → Distinguish man-made and natural objects

Small aluminium cylinders Leg 003

10° off-broadside



10° off-broadside

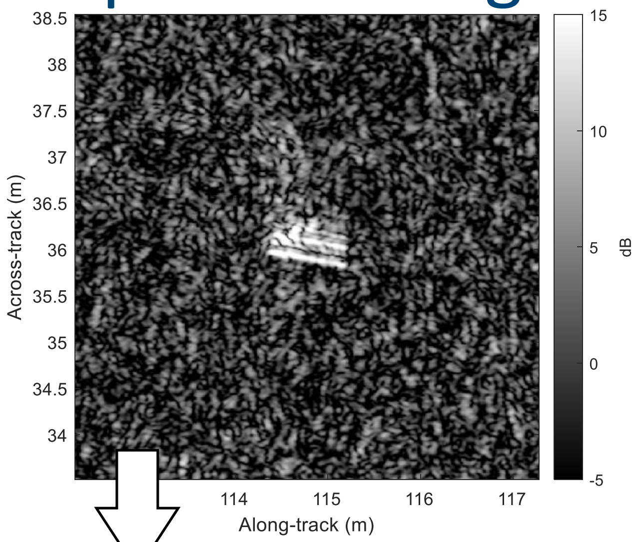


This uses the matching model described in [3]

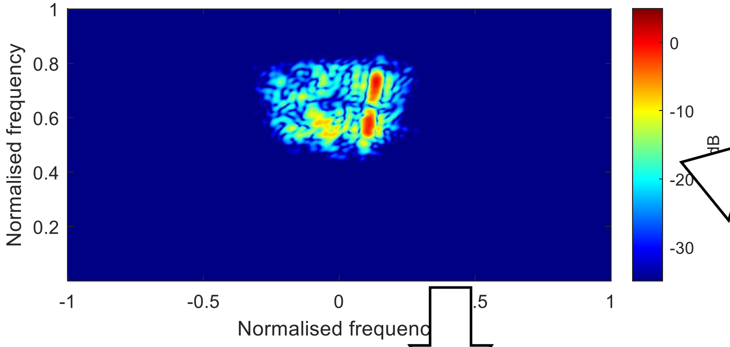
[3]Tesei, A, Groen, J., Low- and high-frequency elastic scattering analysis of fluid-filled, flat-endcapped cylindrical shells proud on a sandy seabed, Physics, 2008.

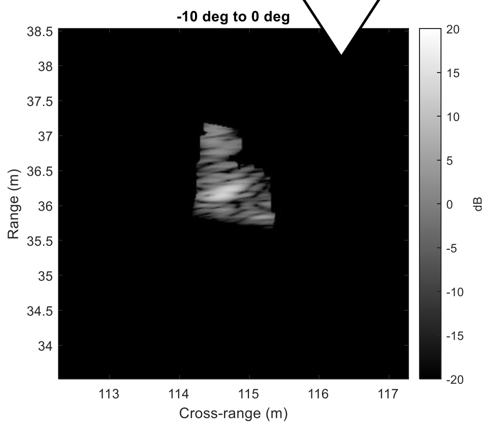
SAS subband images and sub-aperture images

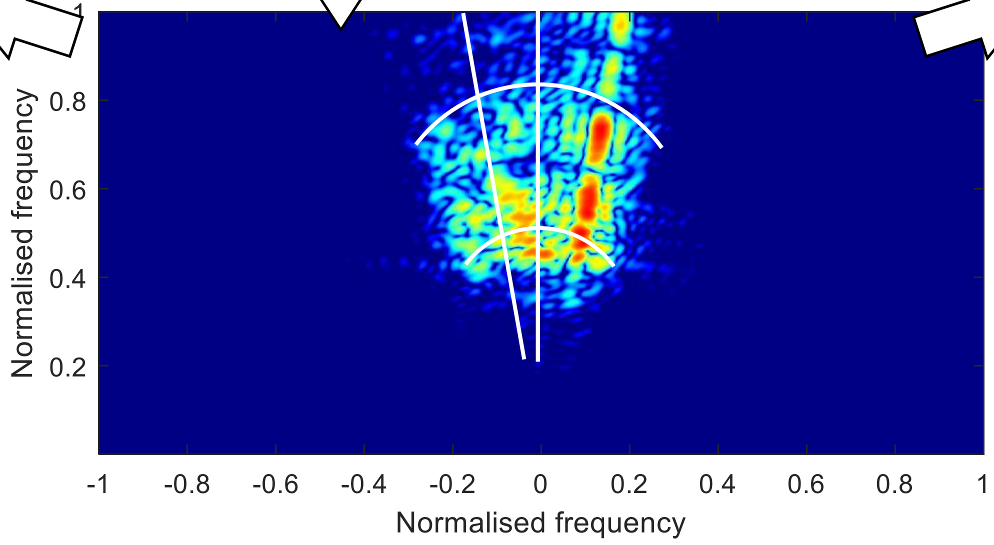
Detected SAS image snippets can be converted to a Frequency-Aspect (FrAS) data representation using a reversible process e.g. [4]



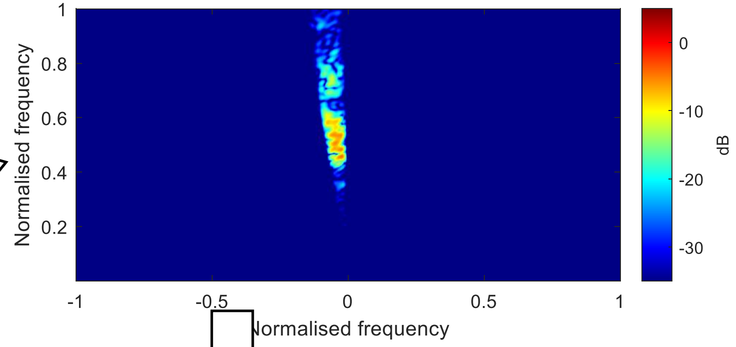
Sub-band (band-pass filtered) images

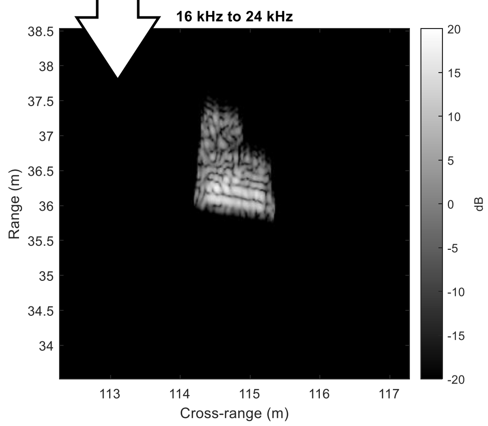






Sub-aperture (aspect-pass filtered) images





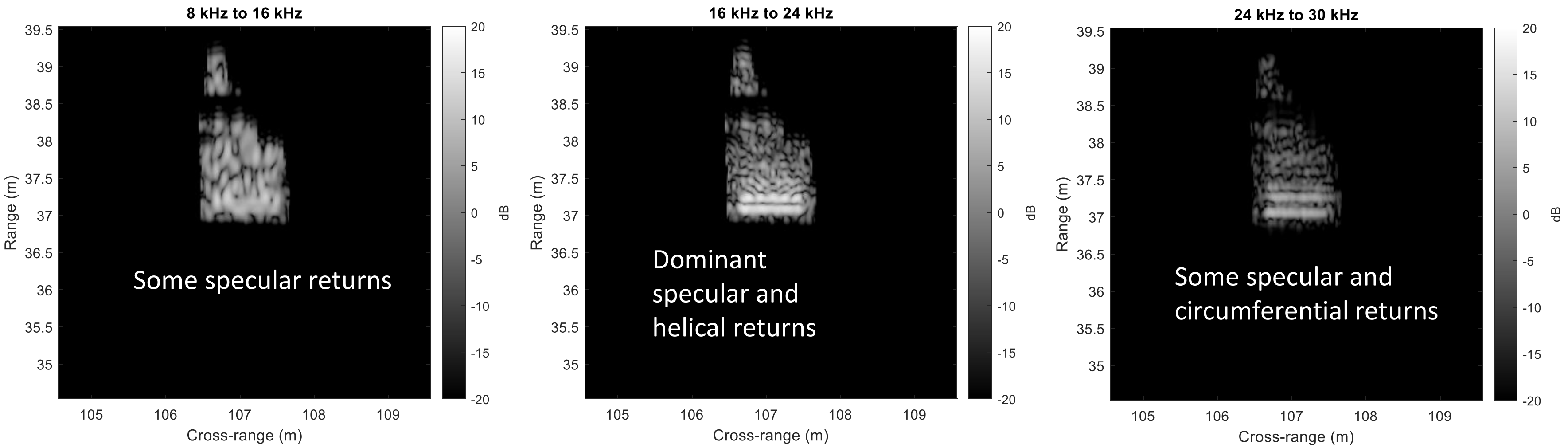
[4] Hunter, A, and van Vossen, R, Scattering Resonances, filtering with Reversible SAS processing, and applications of Quantitative Ray Theory, J. Acoust. Soc. Am. 135 (1), 262-268, January 2014

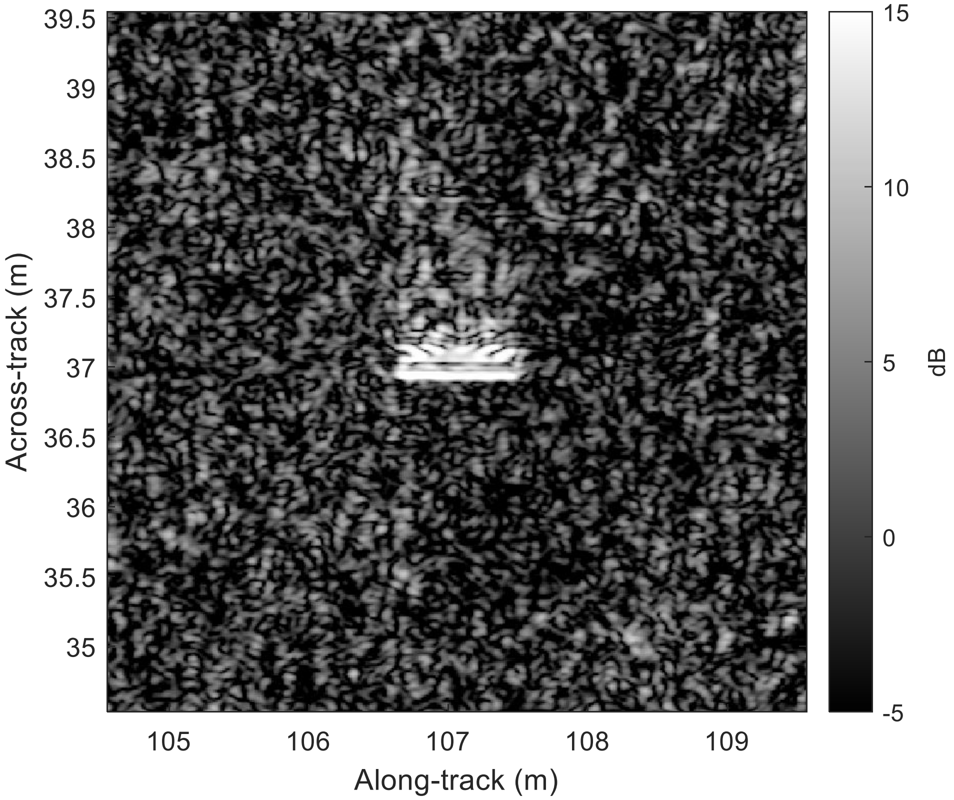
Sub-band images

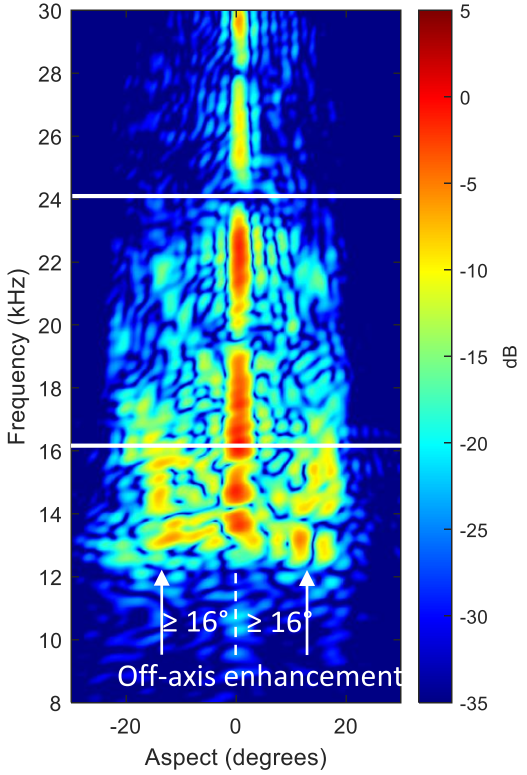
Leg 003

Small aluminium cylinder
(length 0.85 m, Ø 0.17 m)

Broadside





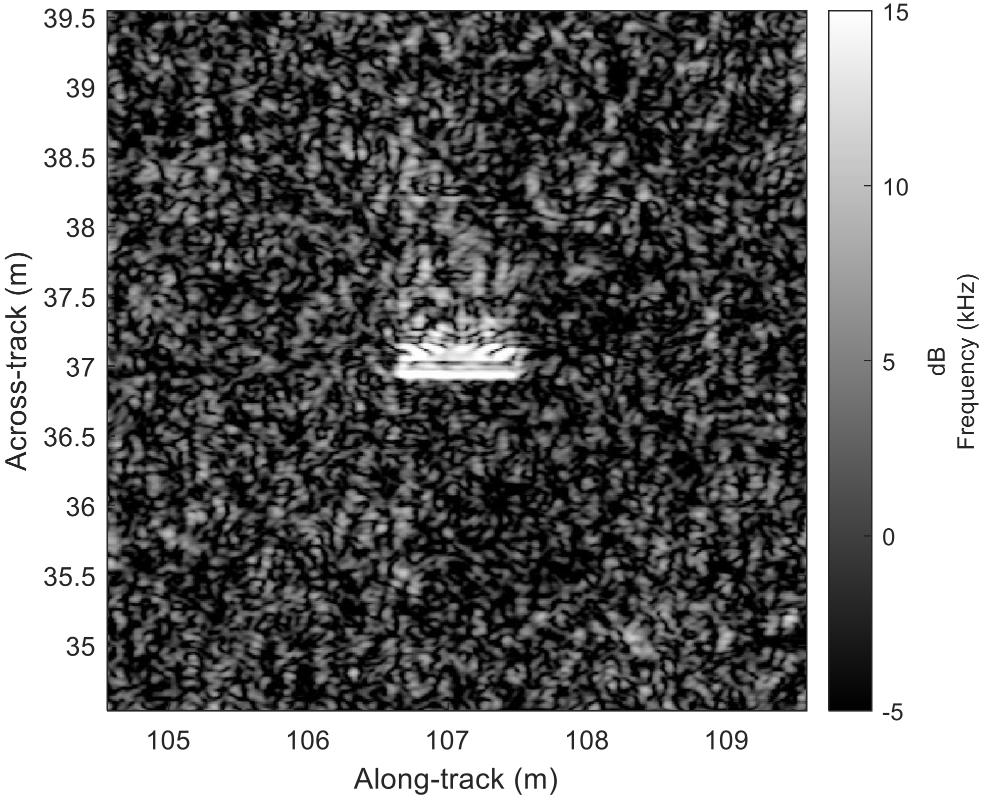


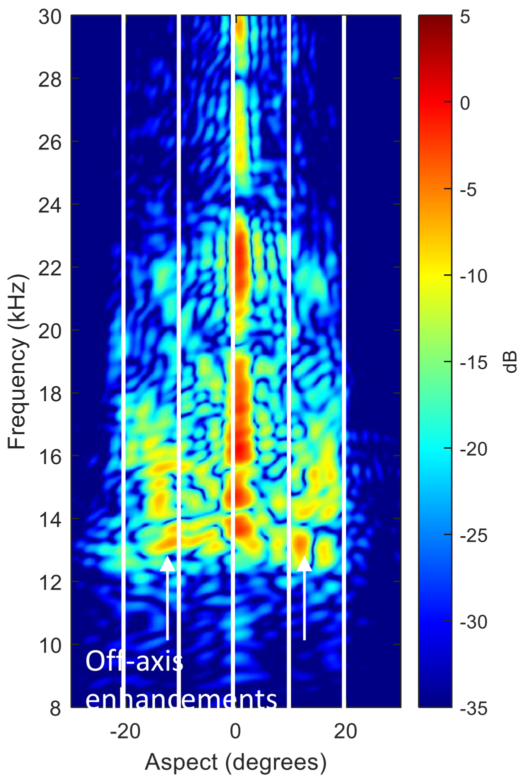
Sub-aperture images

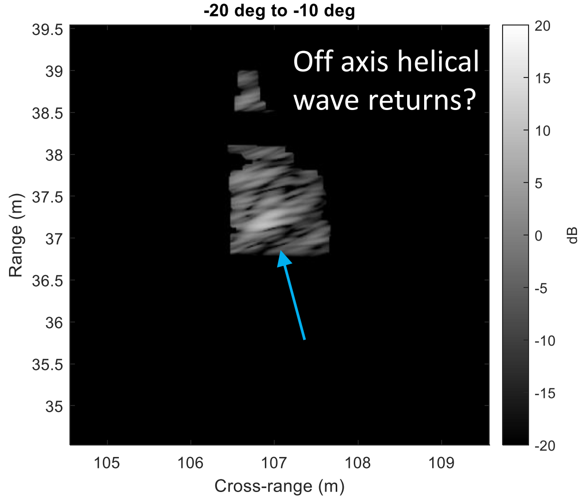
Leg 003

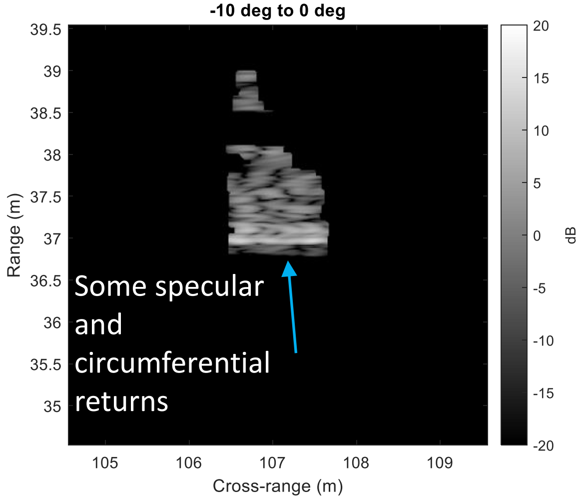
Small aluminium cylinder (length 0.85 m, Ø 0.17 m)

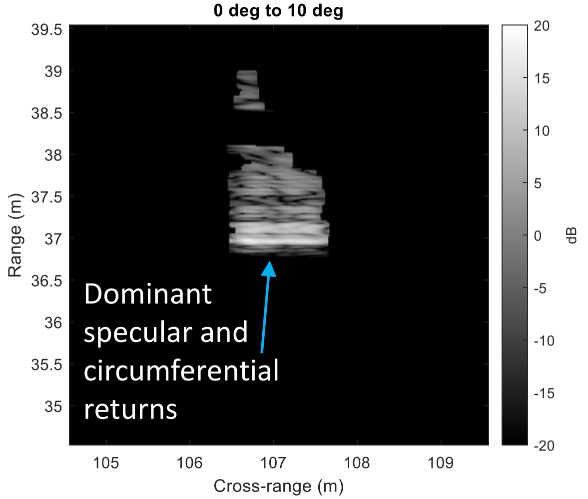
Broadside

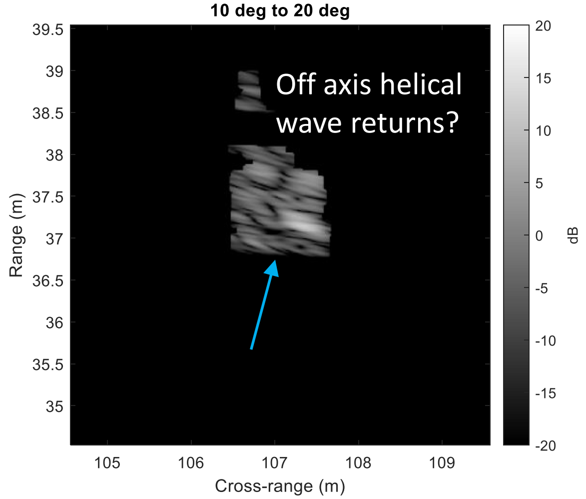












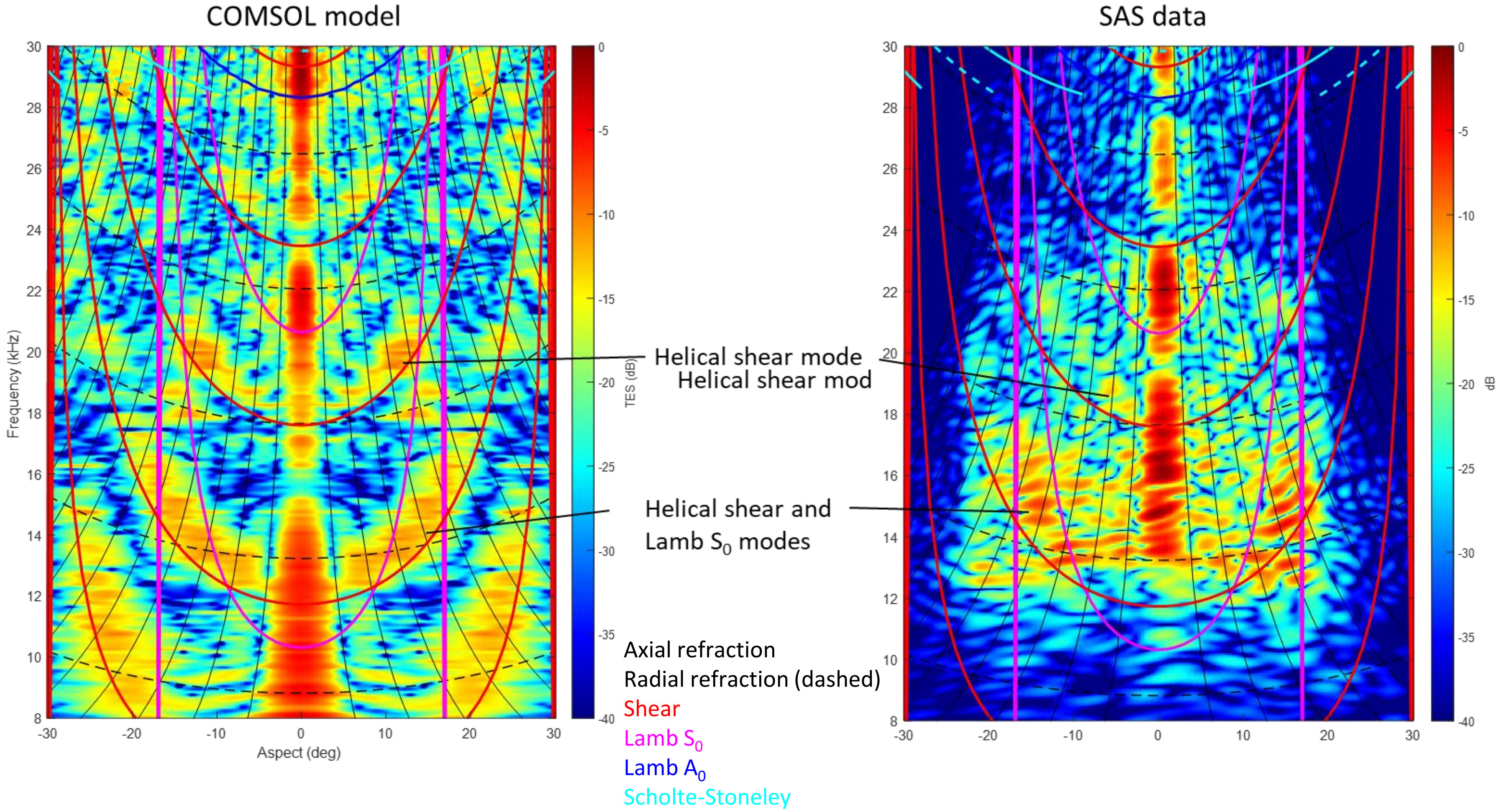
COMSOL modelling

The objects examined during the SAS trial were insonified over the angle subtended by the synthetic aperture (over the transmit horizontal beam width) only, and had set dimensions

We model the small aluminium cylinder in the free-field to examine scattering from the cylinder only (removing seabed effects)

Scattering features in the FrAs representation of cylinder TES correspond closely with matching model predictions

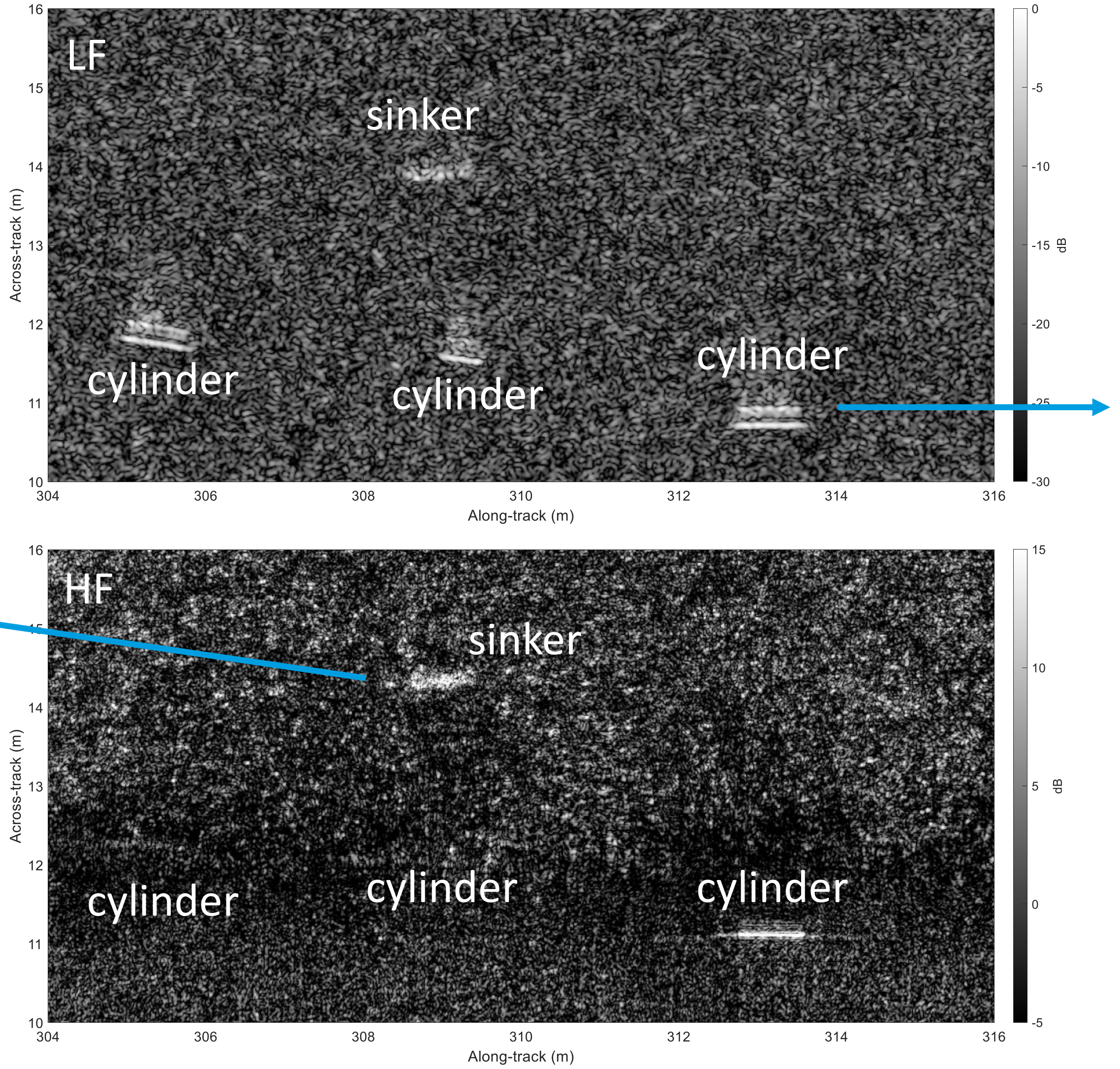
FrAs produced from SAS snippet also picks out some of these physics based features

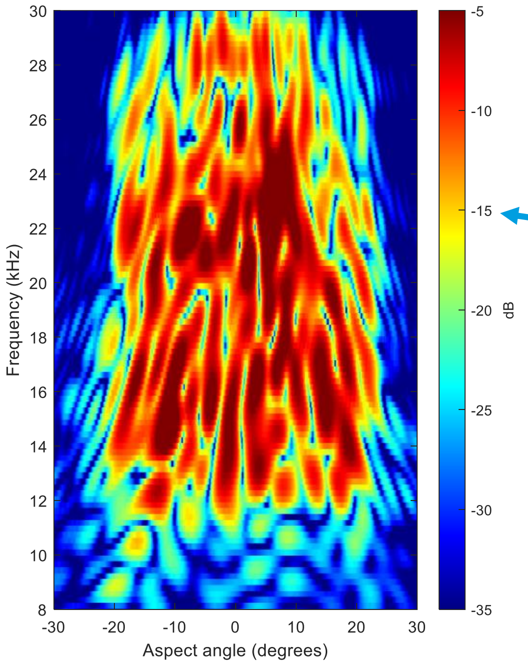


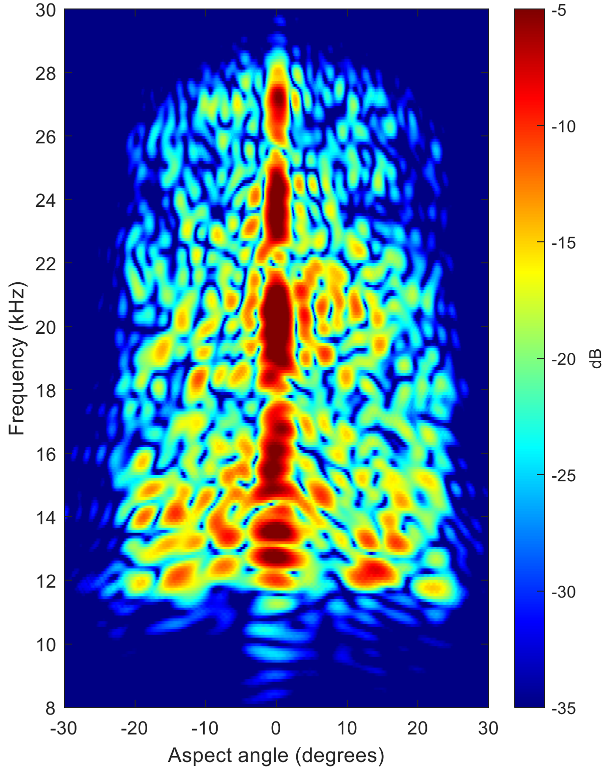
Discriminating man-made and natural features

Understand the physics → Interpret scattering data → Distinguish man-made and natural objects

Scattering features evident in both SAS image and FrAs data representations can be used to distinguish man-made objects from natural ones







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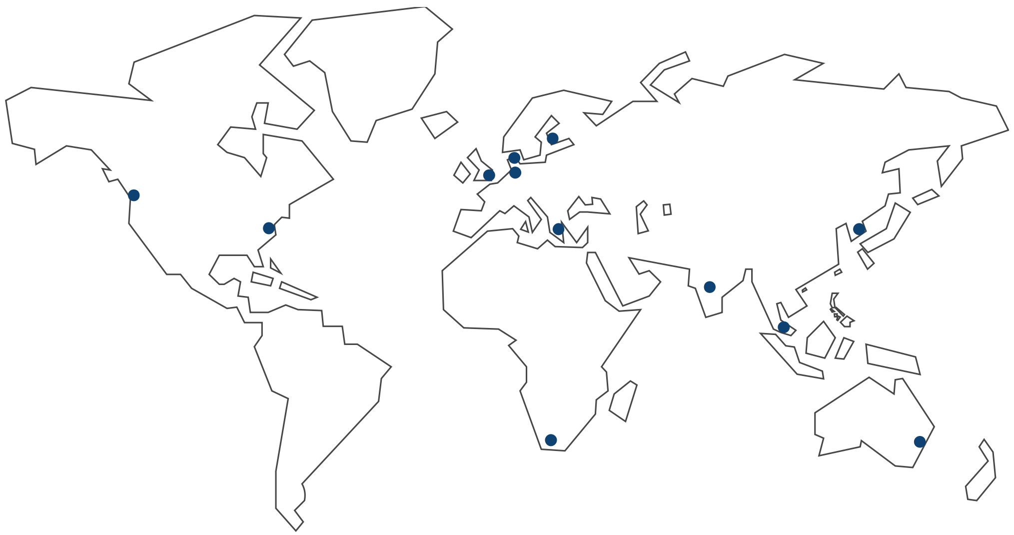

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