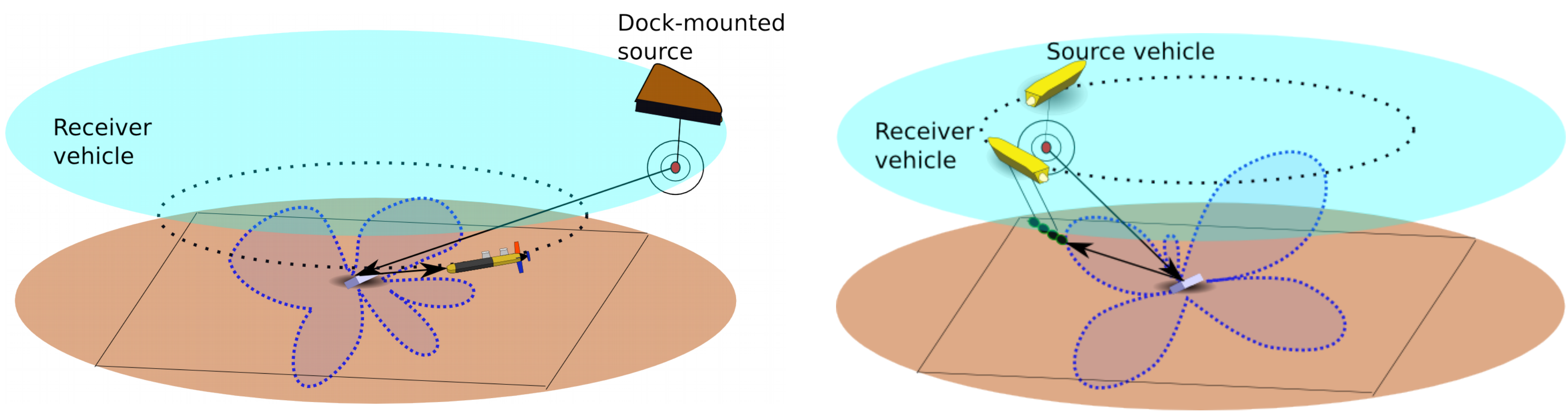
Seabed target discrimination using bistatic and multistatic acoustic scattering data



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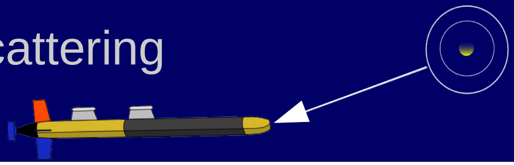

Acknowledgements

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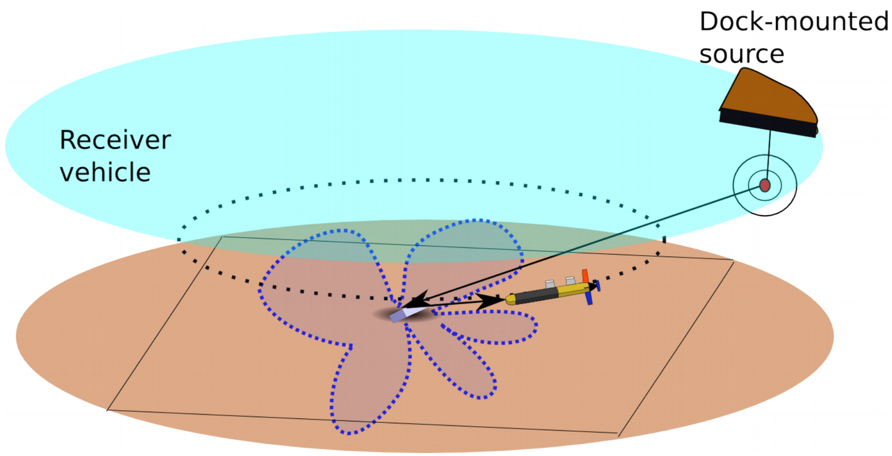
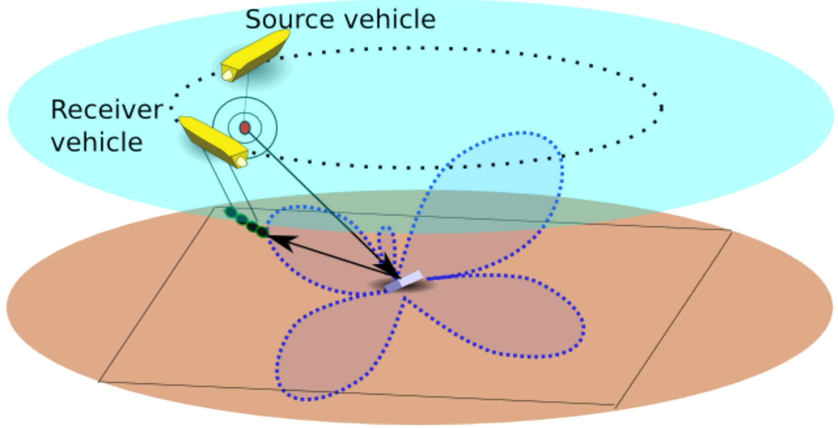
- Henrik Schmidt from MIT
- NSWC Panama City, Kevin Williams and his APL-UW team (BayEx'14)

Motivation and approach

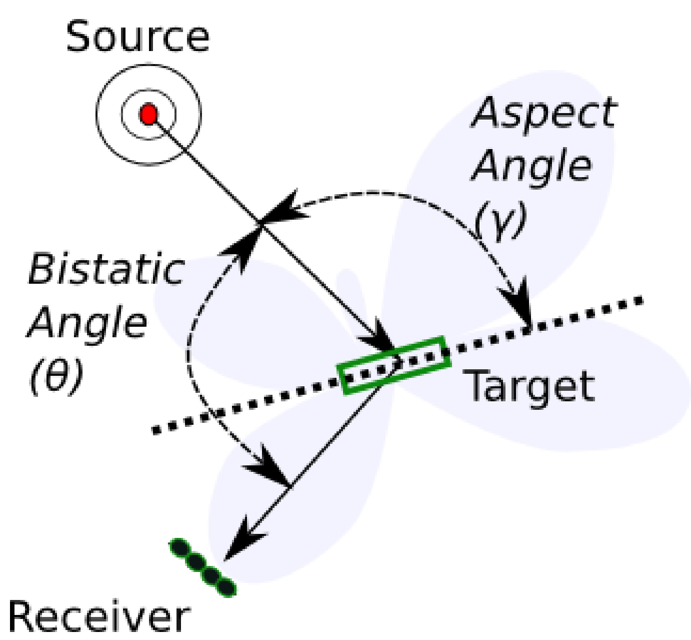
- Target discrimination using:
  - Low-cost, low-power autonomous vehicles
  - Multiple autonomous vehicles (AUV or ASV)
- Real-time identification/ characterization of targets



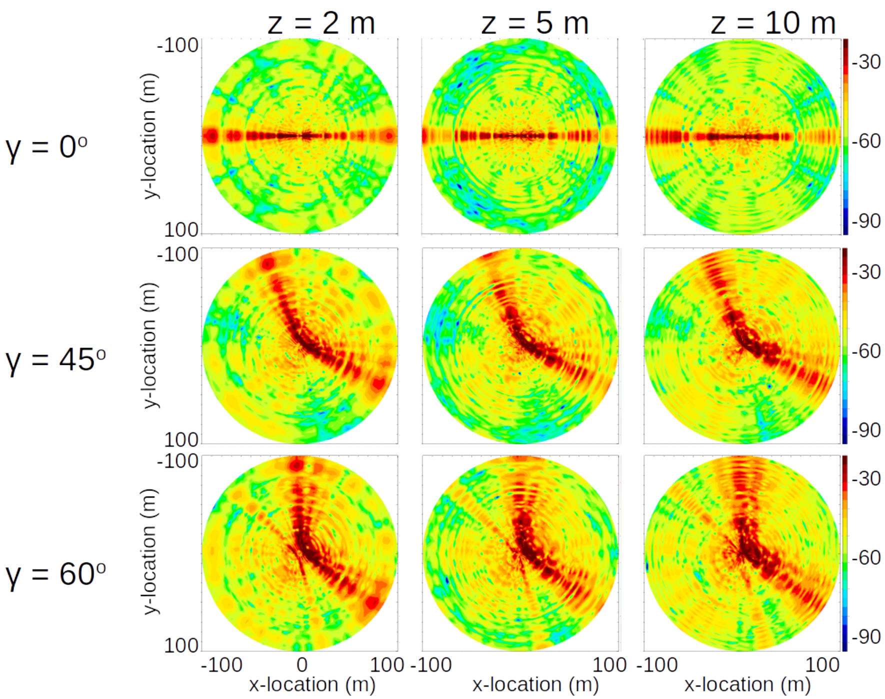


Using scattering radiation patterns for classification

- Scattering radiation patterns (amplitude-only):
  - Dependent on target geometry and composition
  - Greatest dependence on bistatic angle – aspect angle relationship (not range, depth)

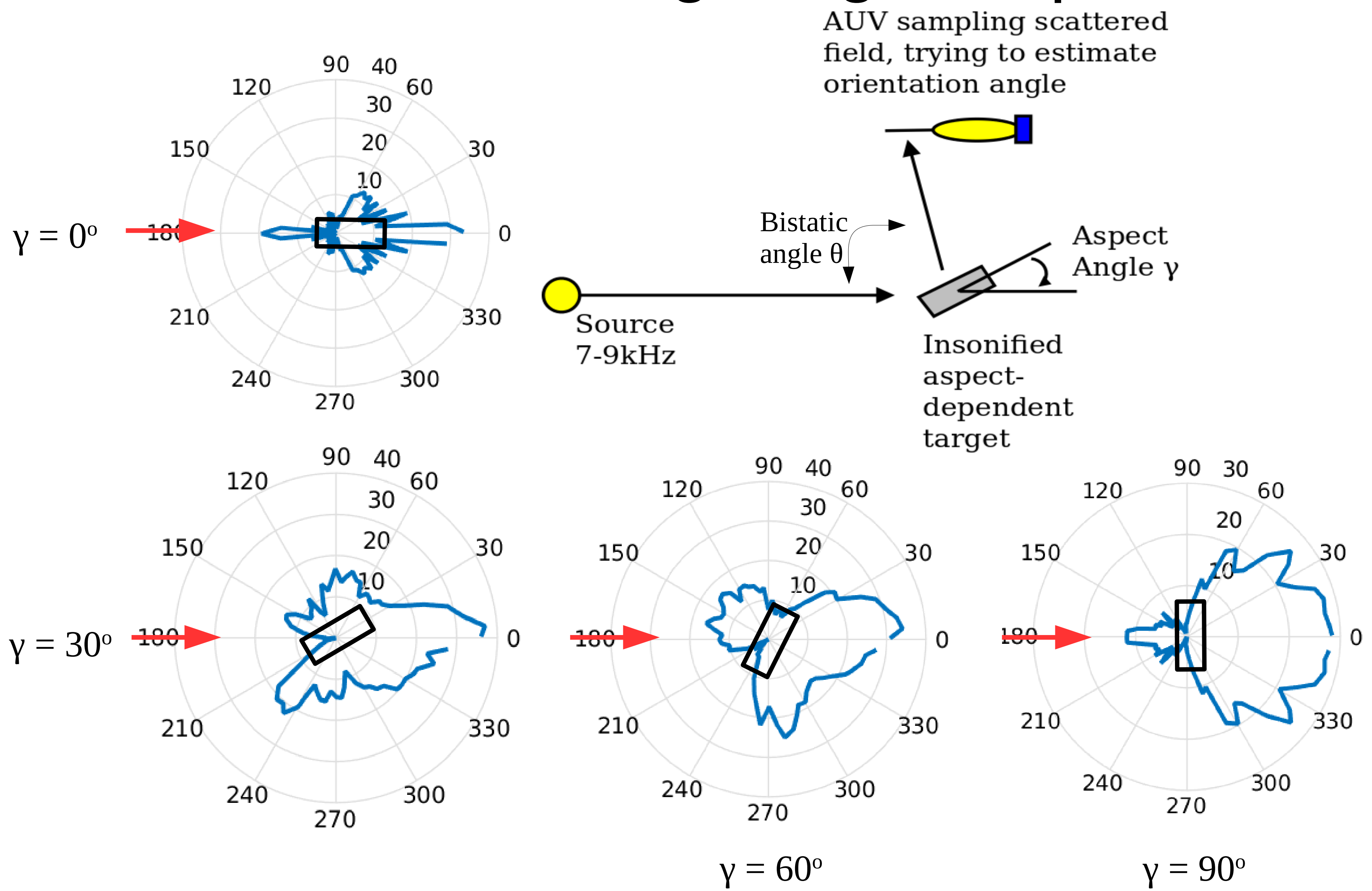


Source-target-receiver geometry for bistatic or multistatic problem



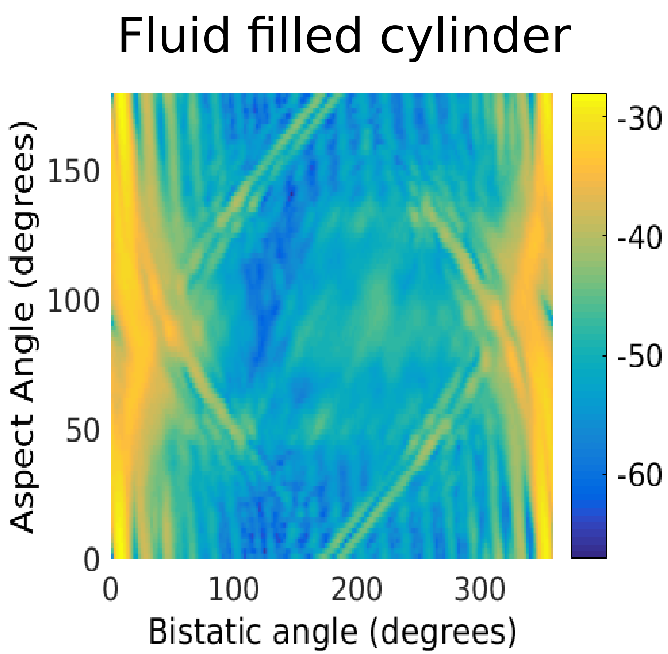
Simulated bistatic scattering from air-filled cylinder, 15 m water depth, 8 kHz, sand bottom.

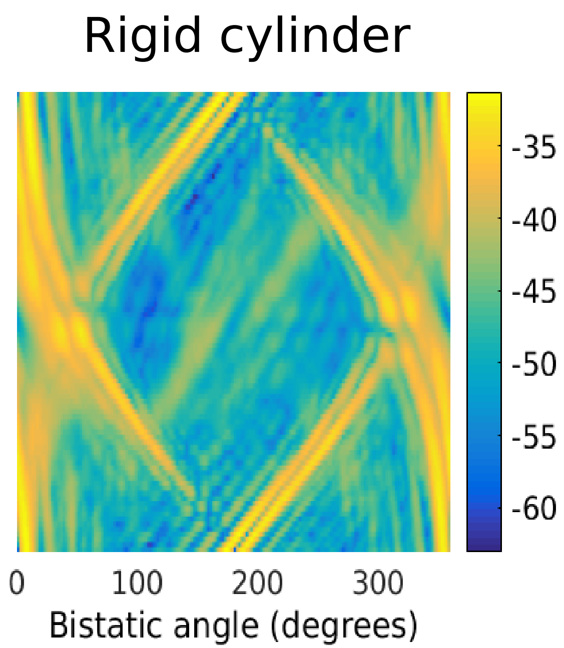
Multistatic Scattering: Angle Dependence

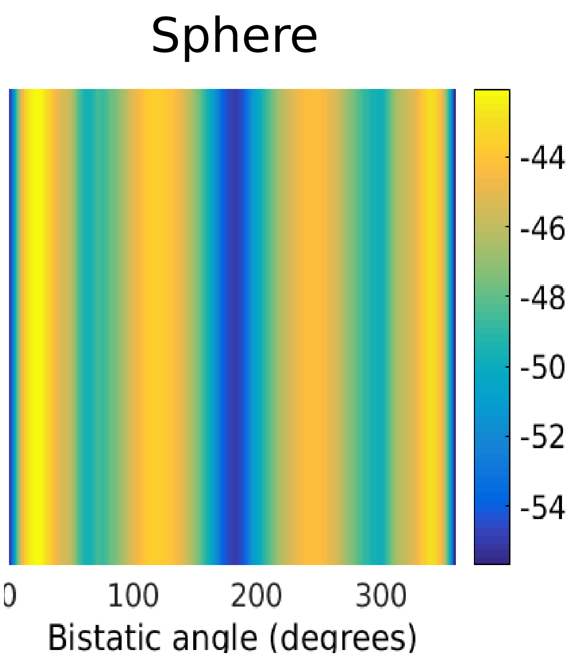


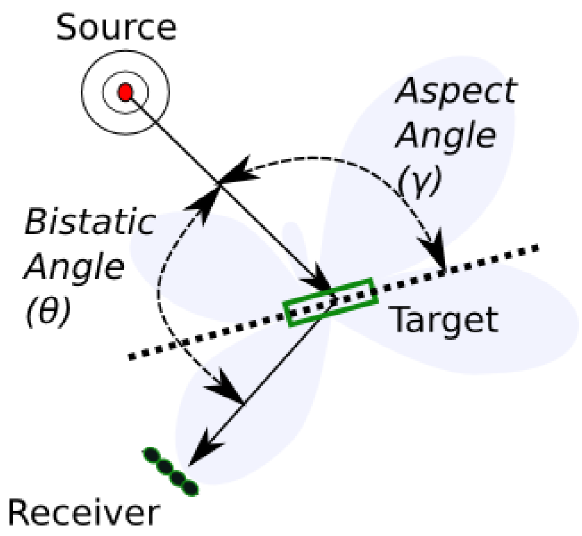
Bistatic angle v. mean scattering strength at several aspect angles.

Multistatic Scattering Amplitude Space



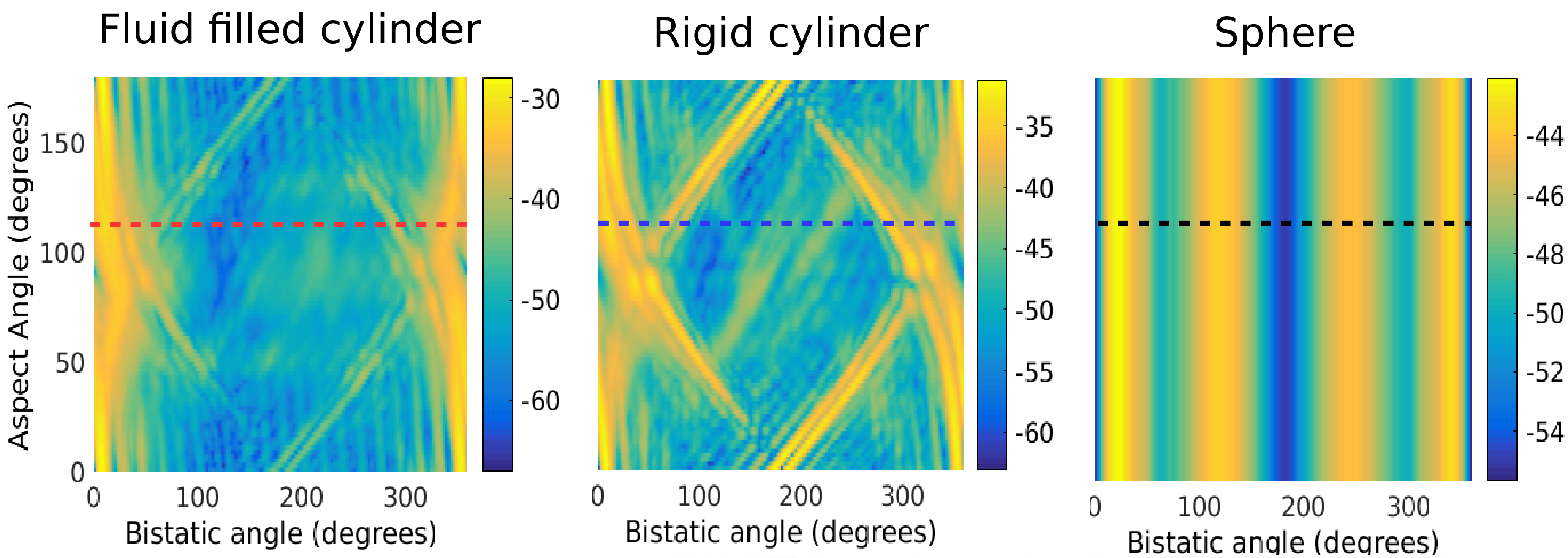


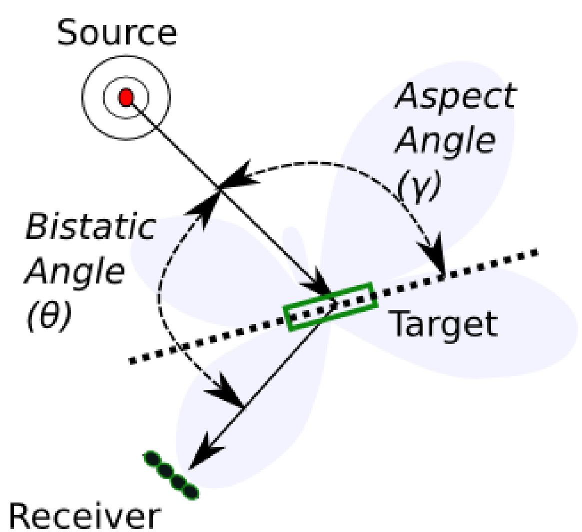


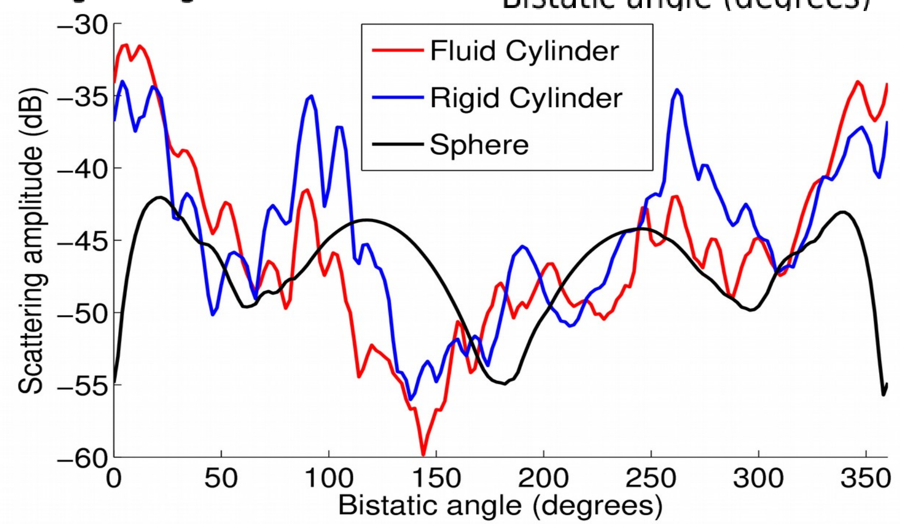


Sample 3D scattered field by changing source/receiver locations to exploit features.

Bistatic Sampling (Fixed-Source)

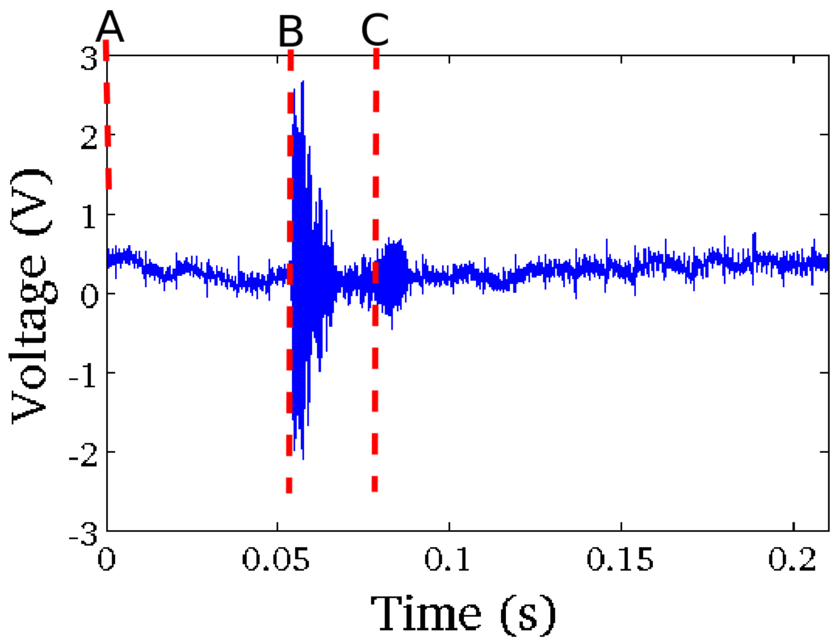






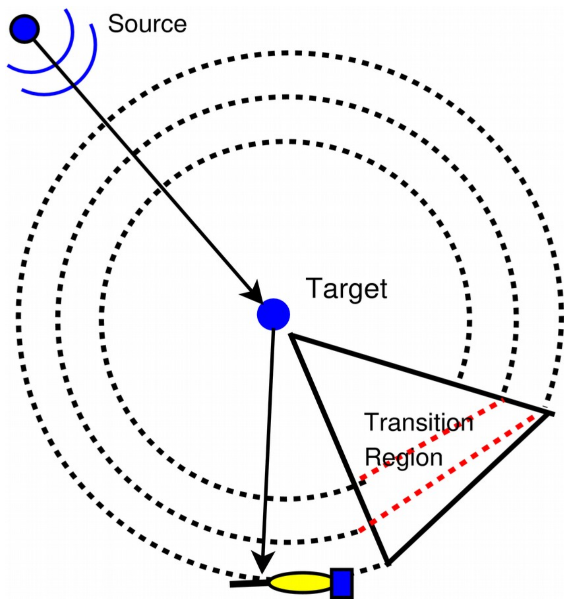
Target Scattering from Data

- Time-synchronization between acoustic source and AUV-based data recording (chip-scale atomic clock)
- Hydrophone array (16-channel, synchronized data collection)
- Matched filter, beamform
- Track targets, calculate scattering amplitude v. time

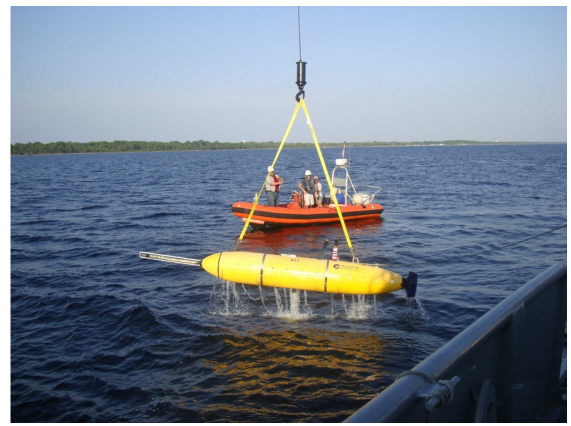


One channel of raw acoustic data

Bistatic Acoustic Data Collection



- Demonstrated during 2014 scattering experiments.
- AUV *Unicorn*, Bluefin 21 AUV.
- 16-element nose array, 0.05 m spacing.
- Acoustic source insonified targets using 7-9 kHz LFM.
- Showed target amplitude features from real data could be used for target discrimination.



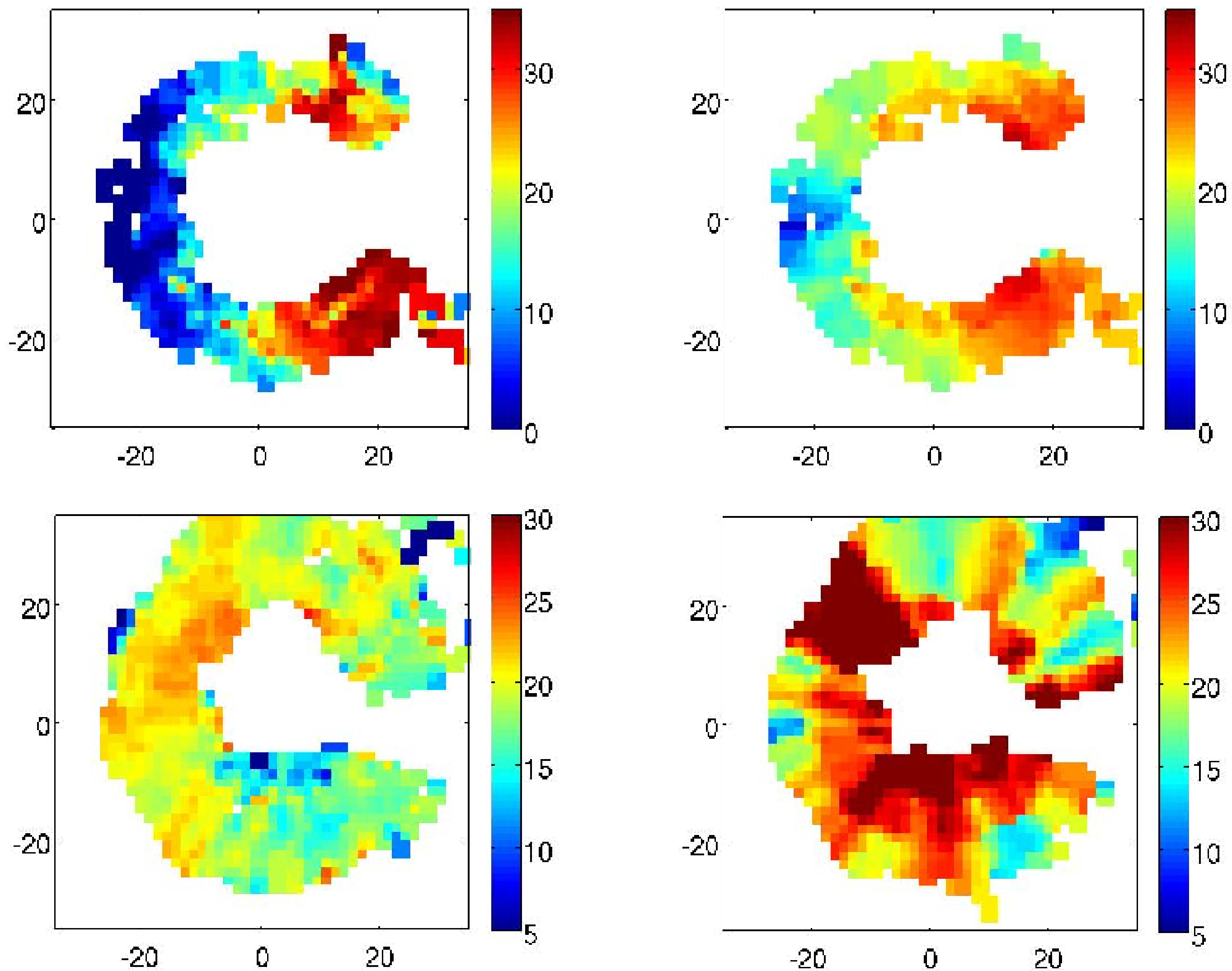

AUV Unicorn during BayEx'14 and Mass Bay experiments

Sphere and Cylinder Scattering: BayEx'14

Real | Simulated

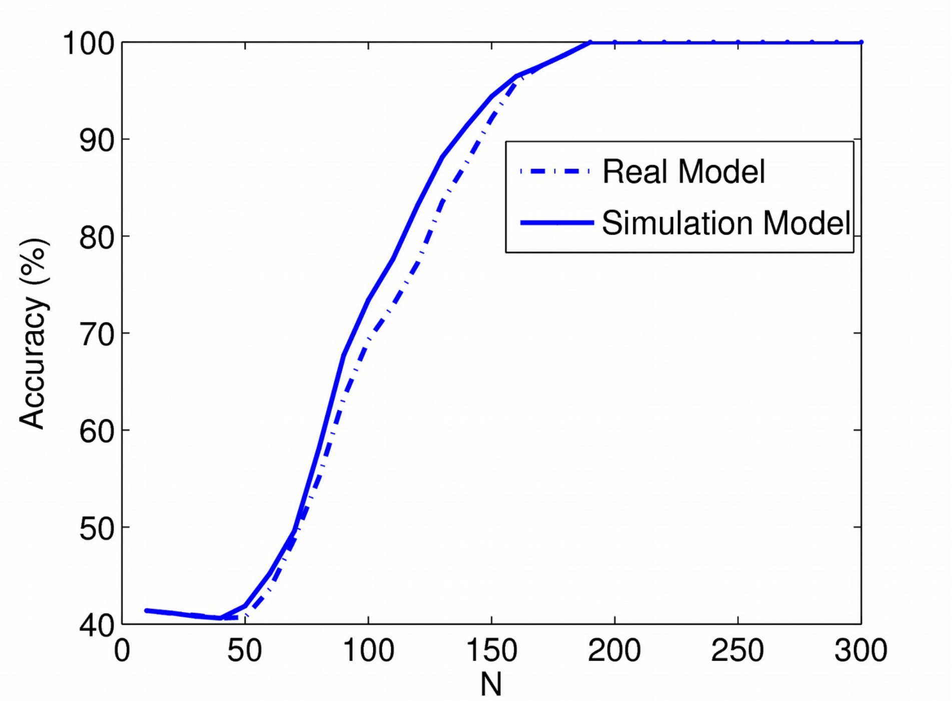
Sphere

Cylinder

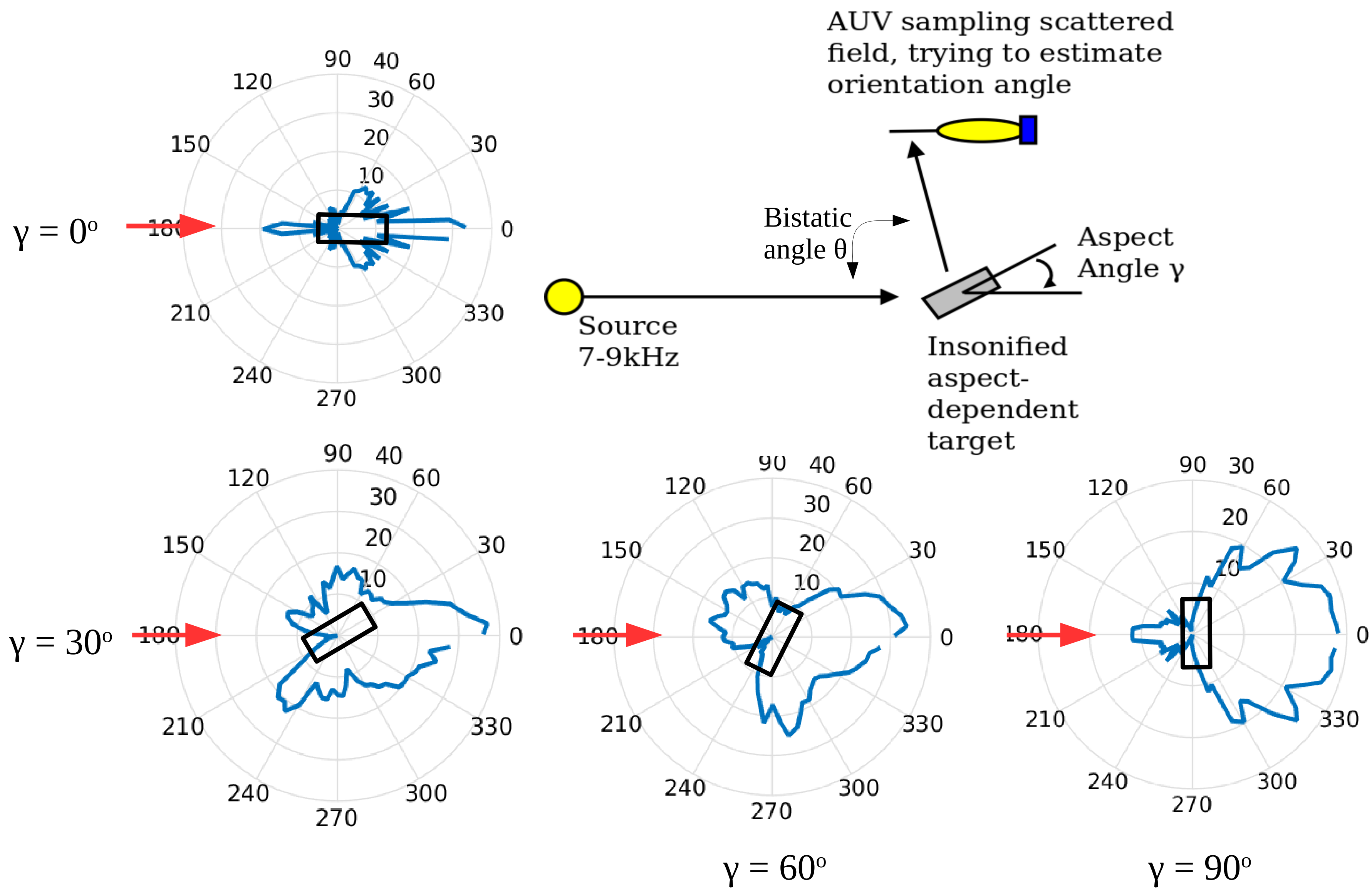


Sphere/Cylinder Bistatic Classification

- Classification: Sphere v. cylinder
  - 1 model based on OASES-SCATT, 1 model based on ½ real data.
  - Classify ½ real data from BayEx'14
  - 99% accuracy with < 5 minutes of data

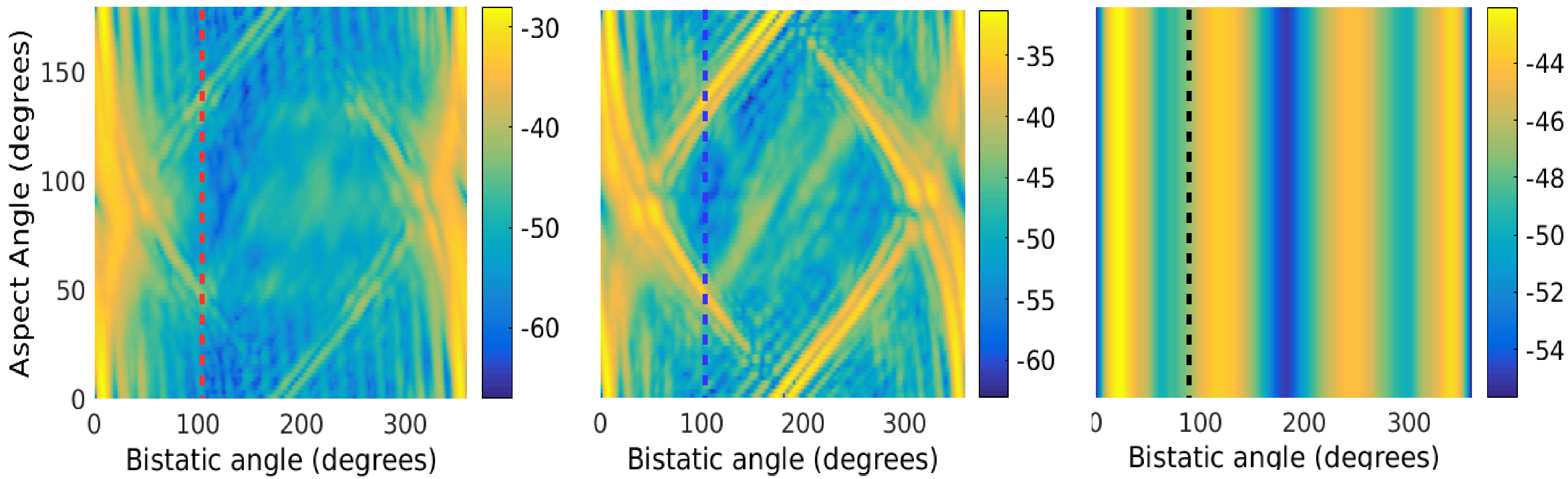


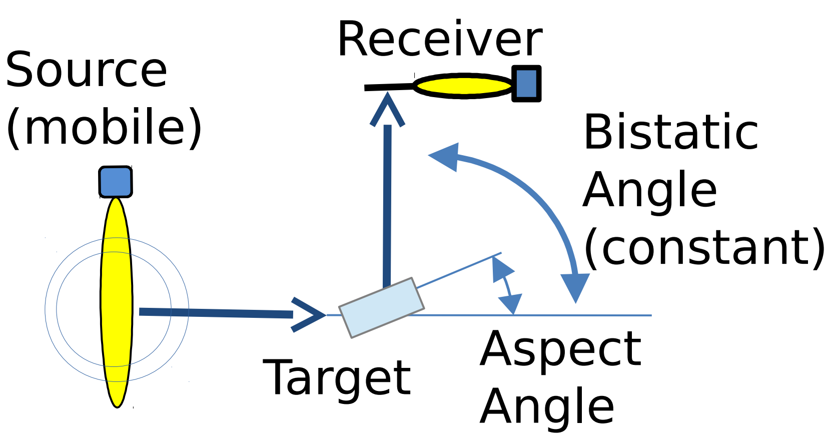
Problem with Bistatic: Aspect Dependence

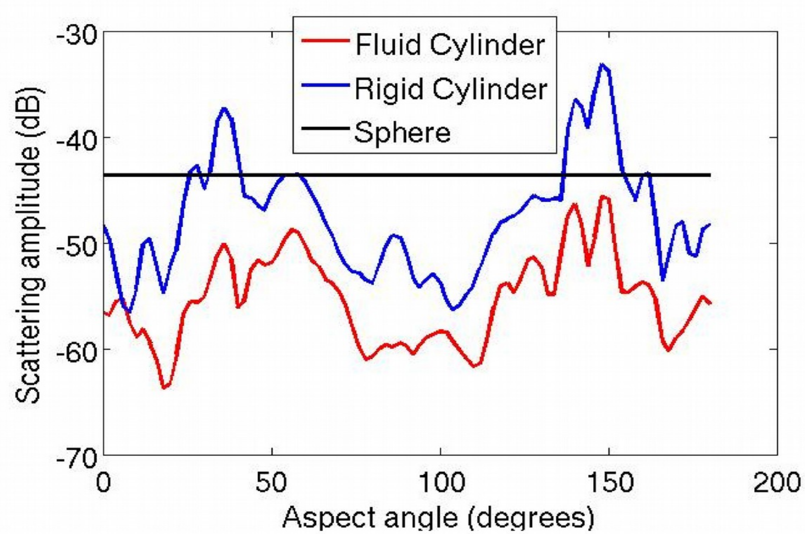


20 + minutes for angle estimation, compared to < 4 minutes for classification when aspect is know a priori.

Multistatic Sampling: constant bistatic angle

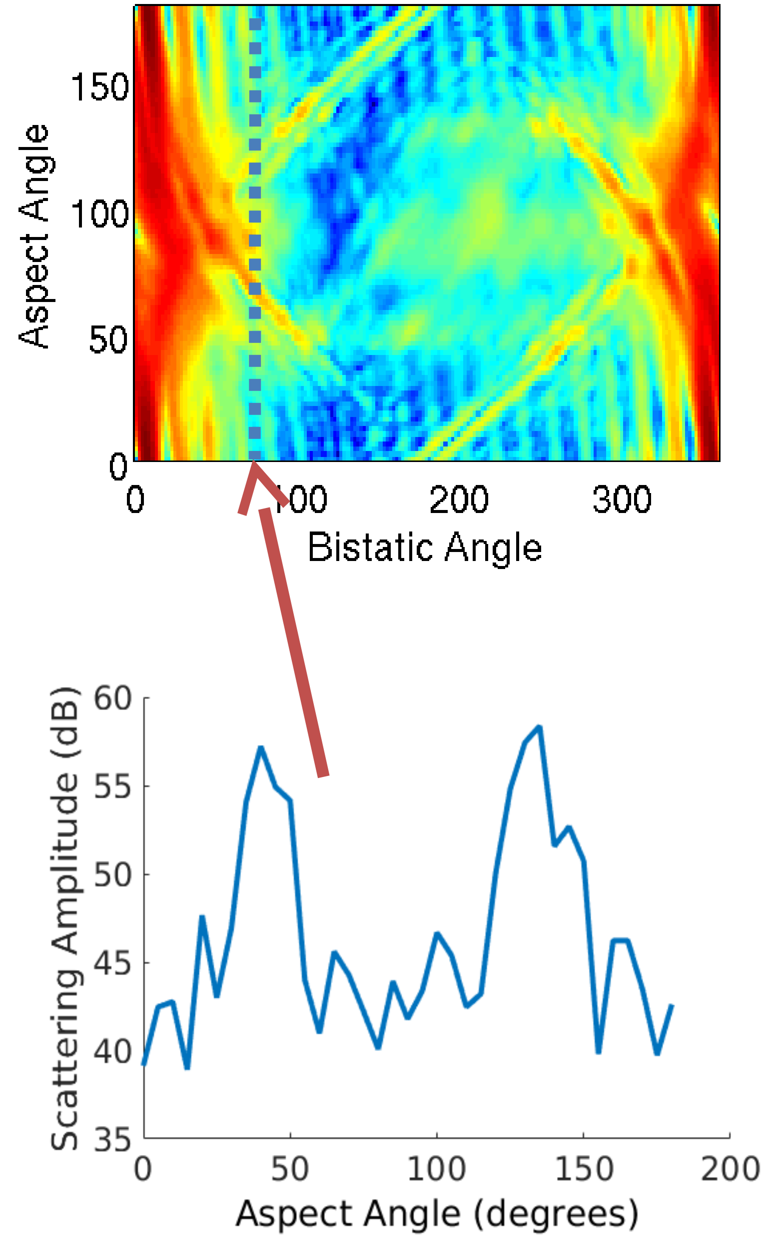




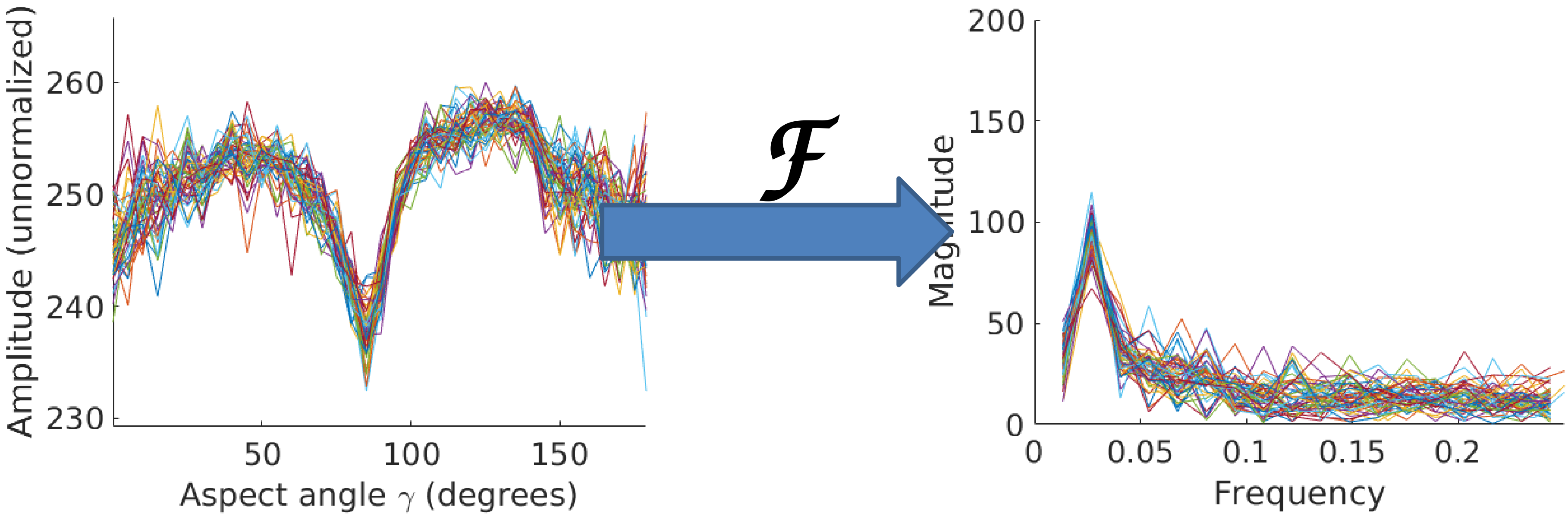


Simulation Studies: Multistatic

- Simulate scattered fields at all possible aspect angles
  - Source range = 45 m, depth = 3 m
  - Multiple targets
  - 7-15 m water depth
- Perform virtual sampling of scattering amplitudes
  - Constant bistatic angle θ between virtual source and receiver vehicles (+/- 5˚)
  - ~3 circles of target (250 samples)
  - Sampling ranges 30-40 m



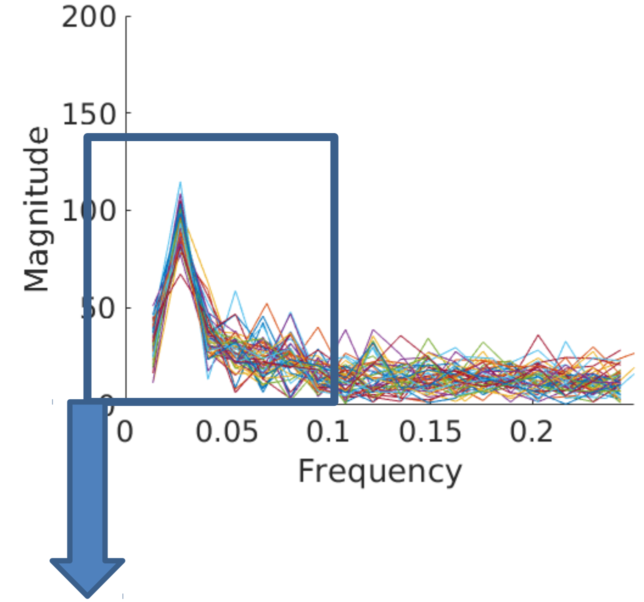
Virtual Sampling

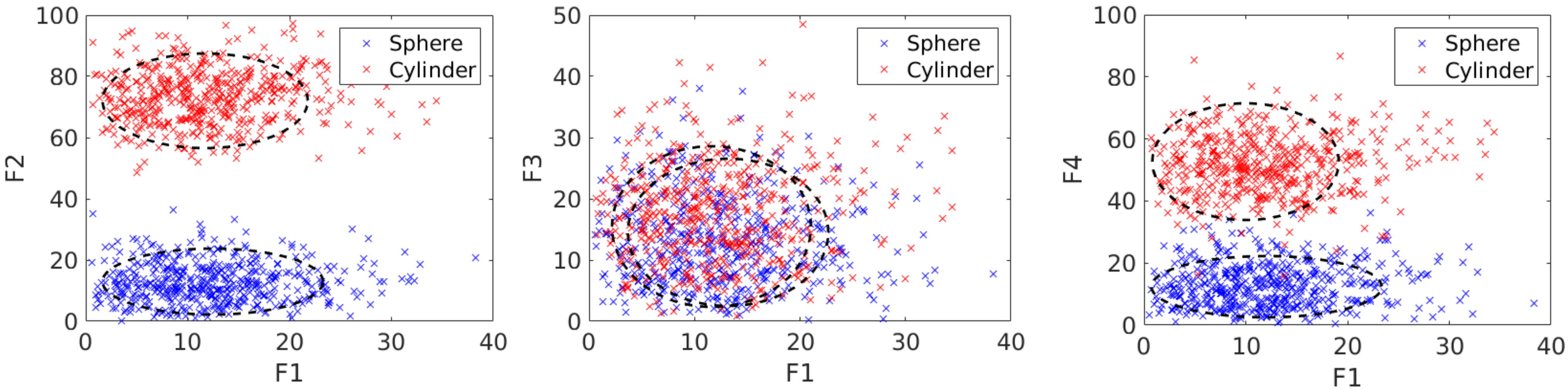


- Create many examples for each target, bistatic angle combinations
- Amplitude variation due to range, depth, random error in θ
- Fourier transform gives features for target discrimination.

Modelling

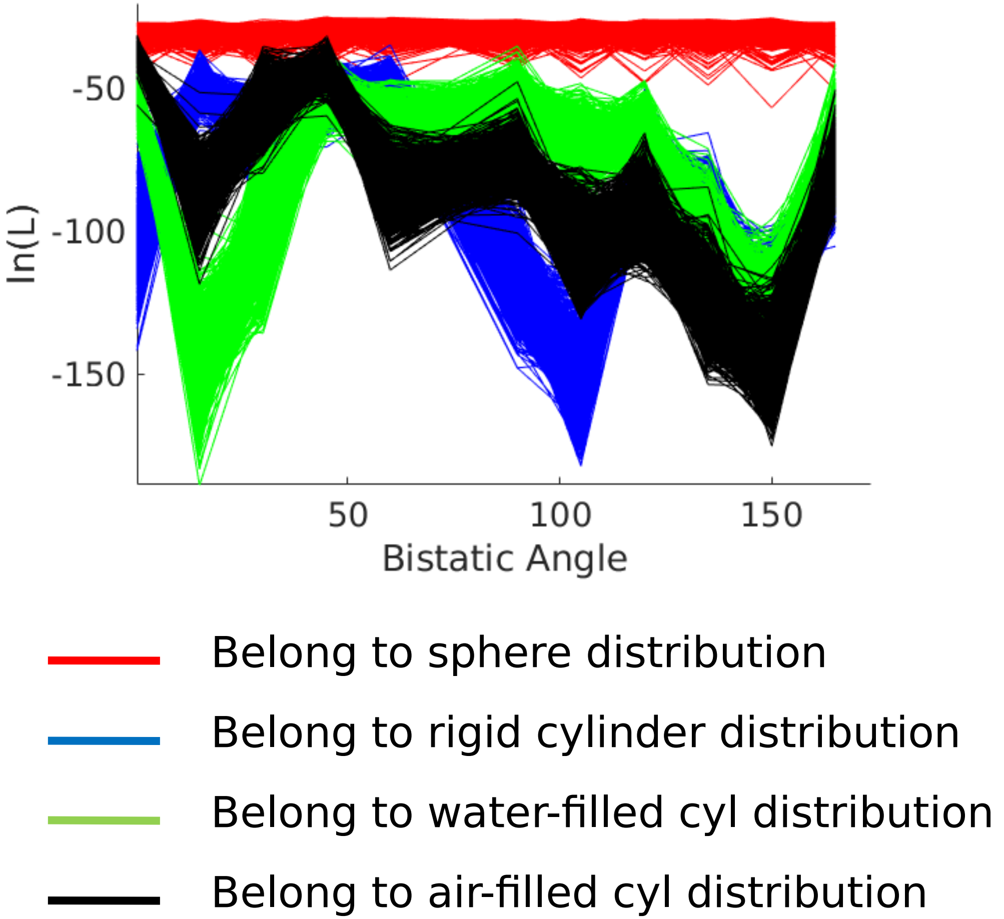
Multi-variate Gaussian $\mathcal{N}(\mu,\Sigma)$ using example values for first 5 frequency components.



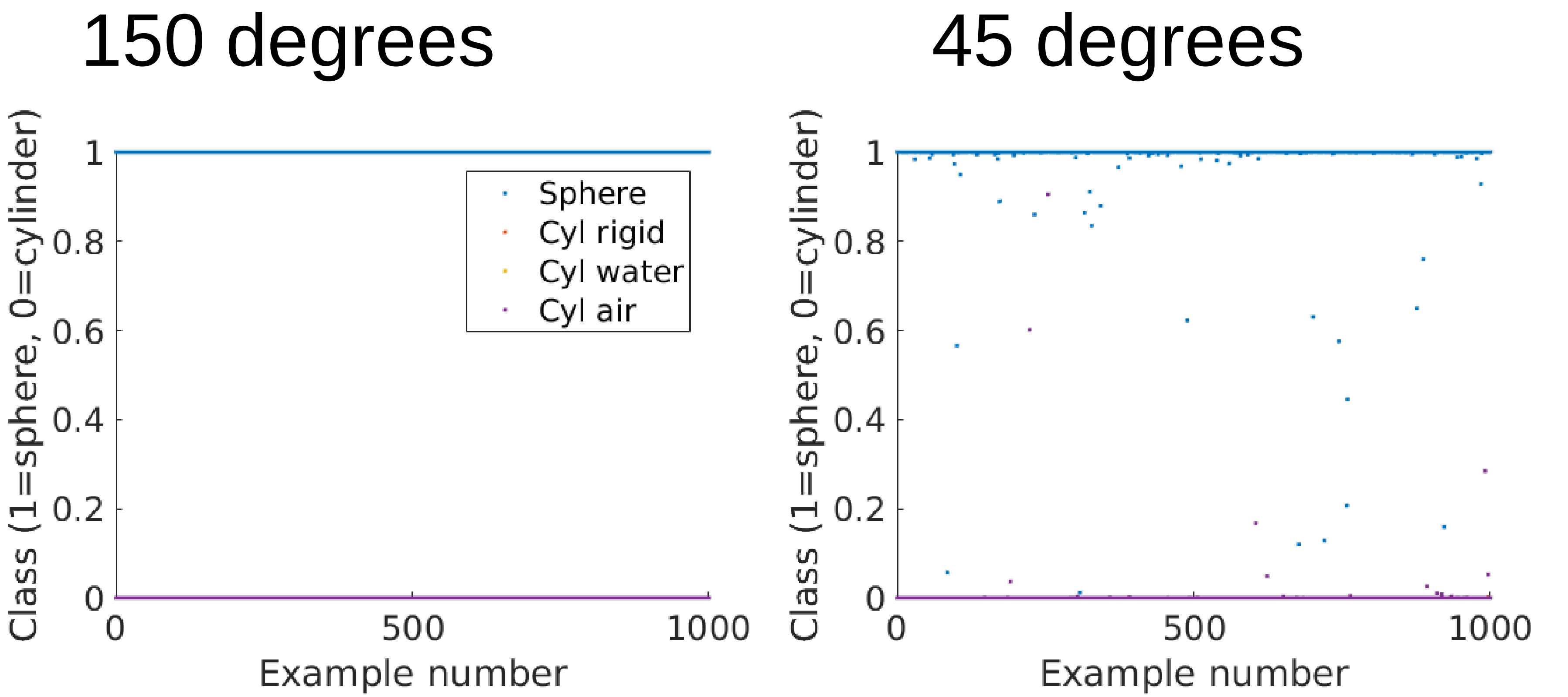


Target Discrimination: Sphere v. Cylinder

- Log-likelihood that 1000 random sphere examples belong to different distributions (sphere or cylinder)
- Some bistatic angles give better discrimination
- Different performance based on cylinder composition



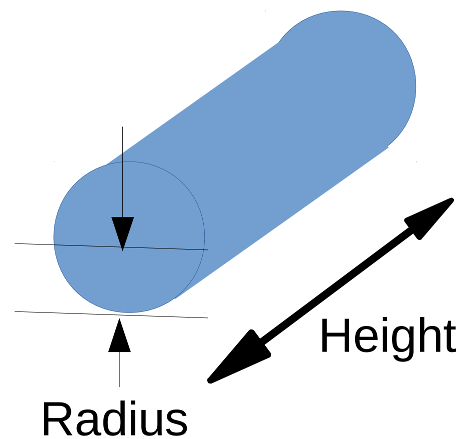
Classification



Classification results using log likelihood at 45, 150 degree bistatic angles, using log-likelihood probabilities as weighting

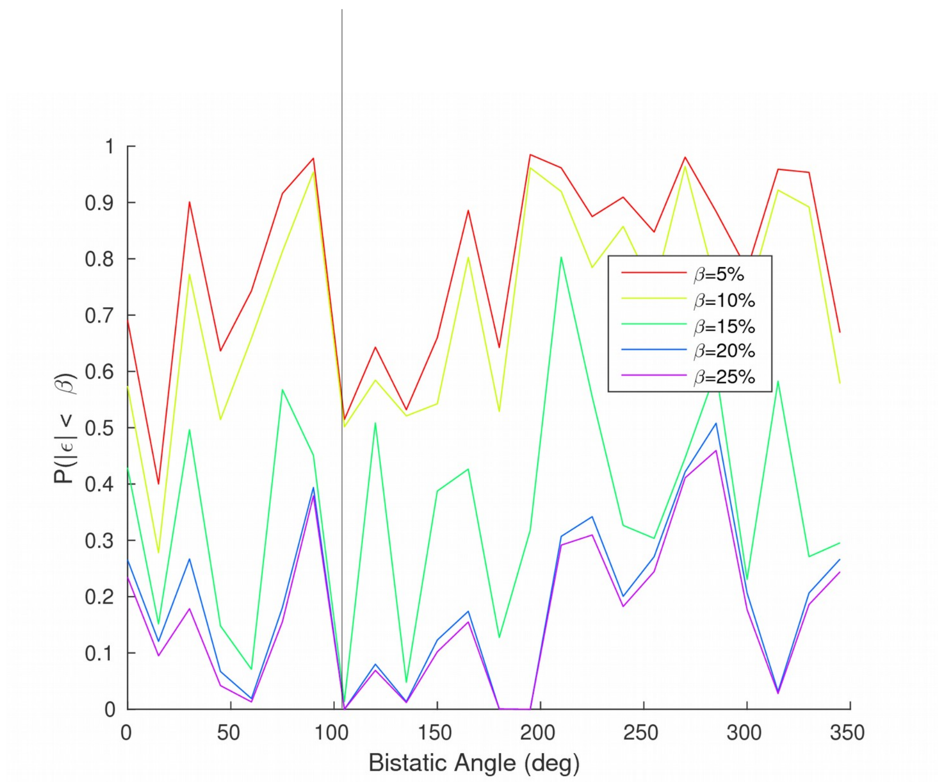
Target Volume and Aspect Ratio Estimation

Target no.	Radius (m)	Height (m)	Volume (m^2)	Aspect ratio
1	0.33	1.5	0.342	2.27
2	0.25	1	0.1962	2
3	0.1667	1	0.0872	3
4	0.1	1	0.0314	5
5	0.25	1.5	0.2945	3
6	0.125	0.75	0.0368	3

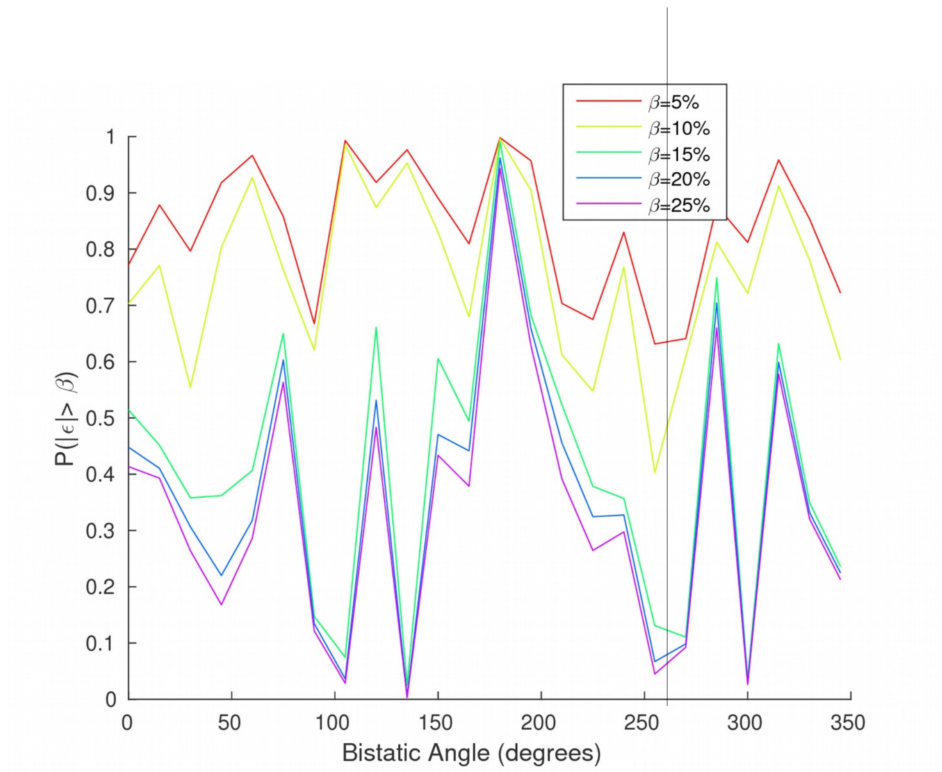


Train on 4 cylinders, test on 2

Estimation errors

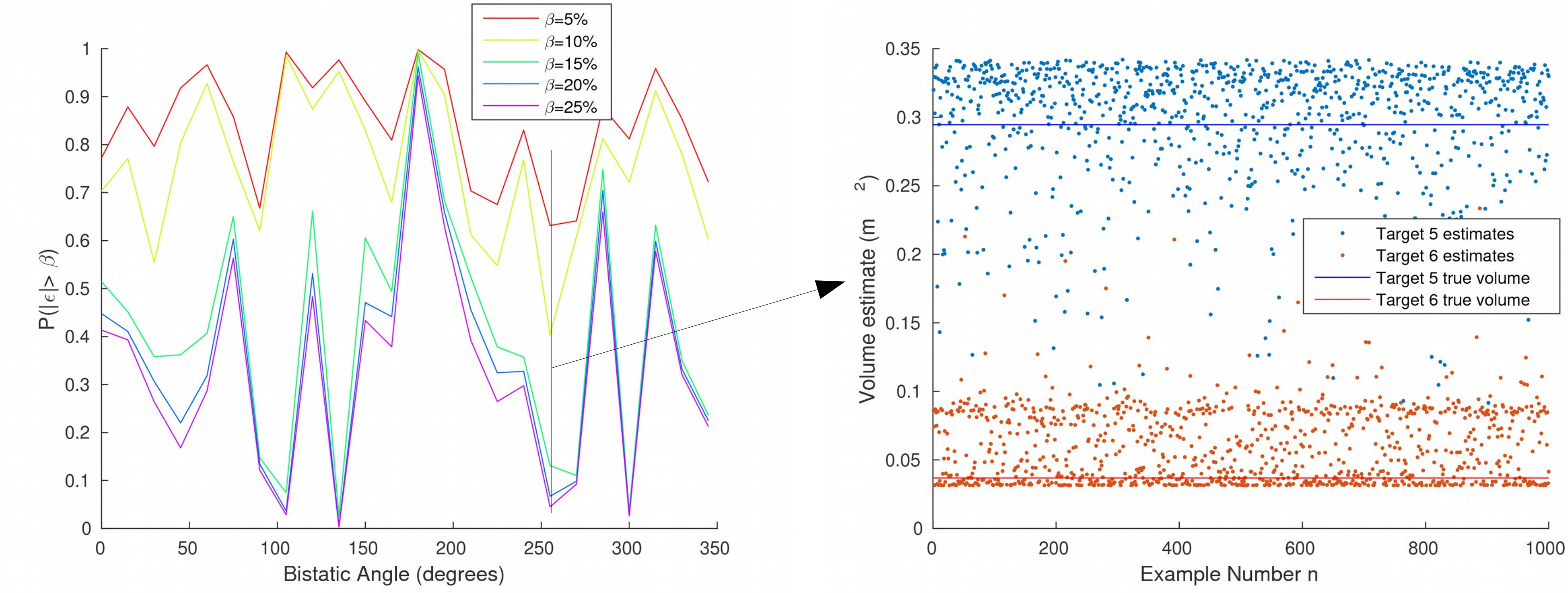


Probability of length/radius ratio estimation error less than β v. bistatic angle for targets 5 and 6.



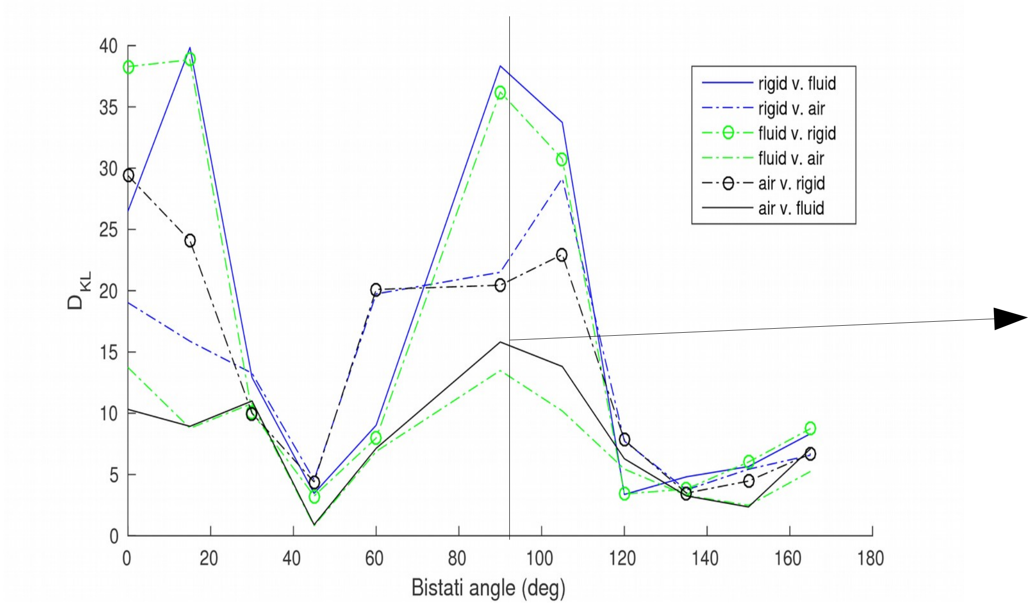
Probability of volume estimation error less than β v. bistatic angle for targets 5 and 6.

Target Volume Estimation

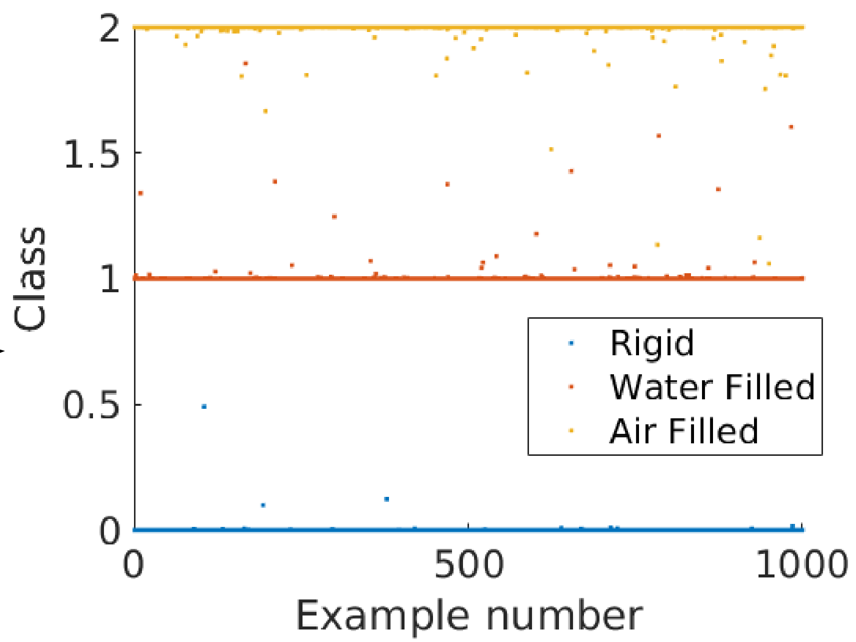


Target Composition

0 = rigid, 1 = water filled, 2=air filled



Kullback-Leibler divergence between Gaussian models from training set.



Classification result for 1000 test examples per class at 90 degree bistatic angle (99% accuracy).

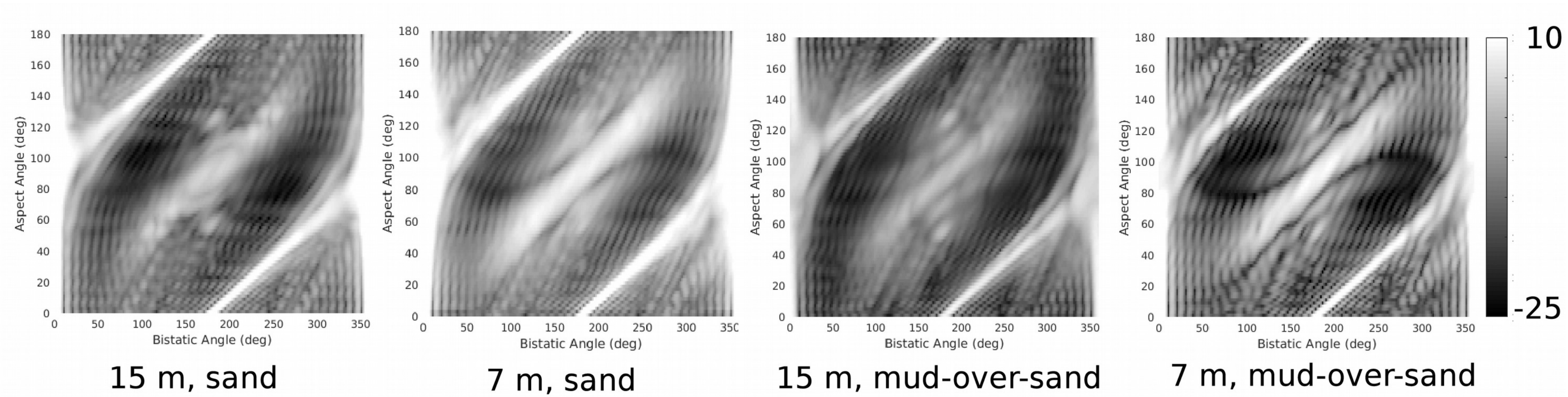
- Train on ½ data, classify ½ data.
- Different cylinders, θ = 90 degrees

Comparison with monostatic

- Multistatic is more complex
- Q: What advantage does multistatic provide besides distributed sensing?
- A: It depends on the characteristic.
  - Shape and composition: Monostatic works fine.
  - Size and aspect: Use multistatic.

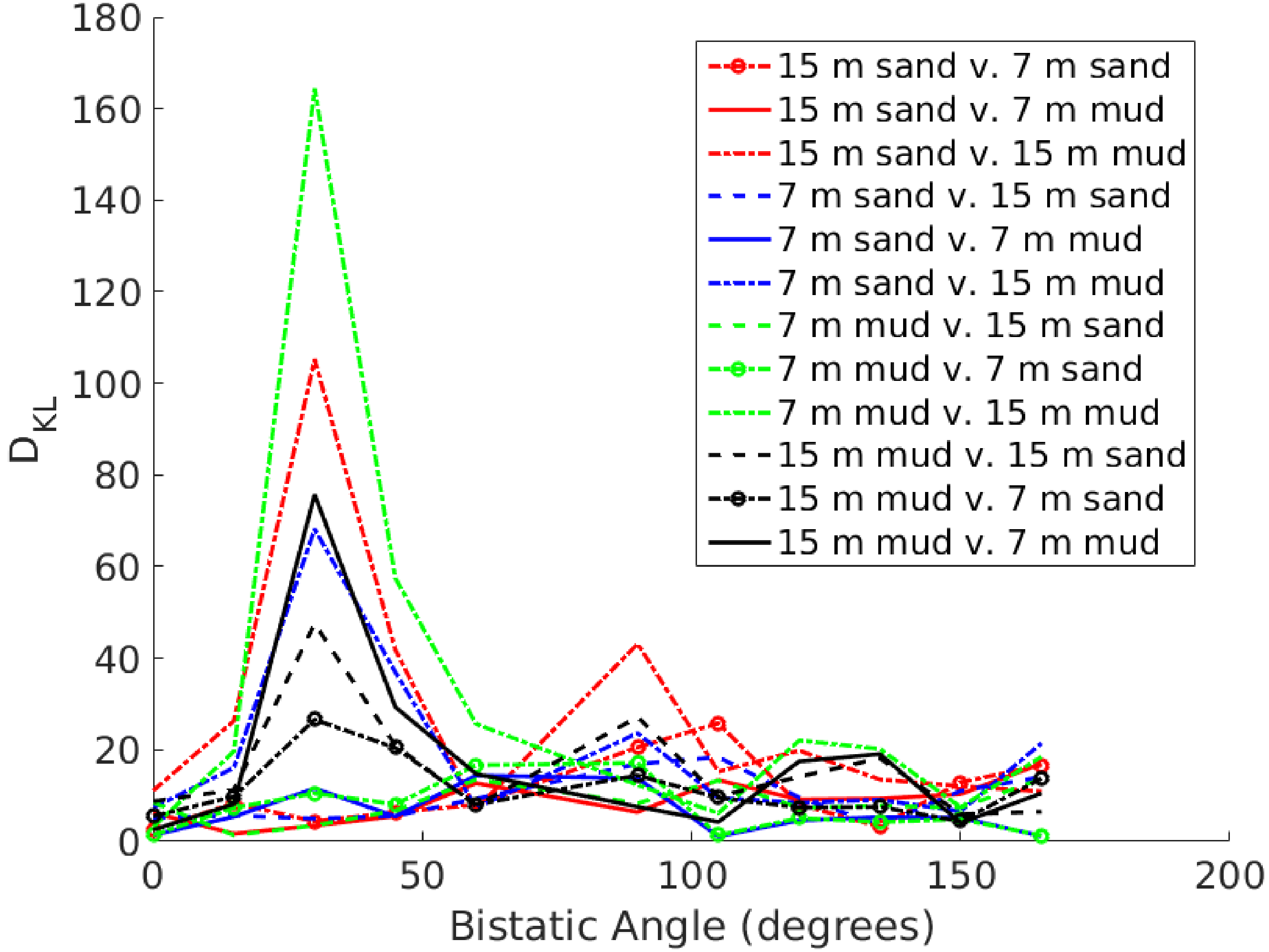
Characteristic	Monostatic result	Best multistatic result
Sphere v. Cylinder Classification Accuracy	98.7%	100%
Composition Classification Accuracy	99.2%	99.8%
Volume estimation P(error < 15%)	47%	89%
Length/radius estimation P(error < 15%)	56%	95%

Impact of environment



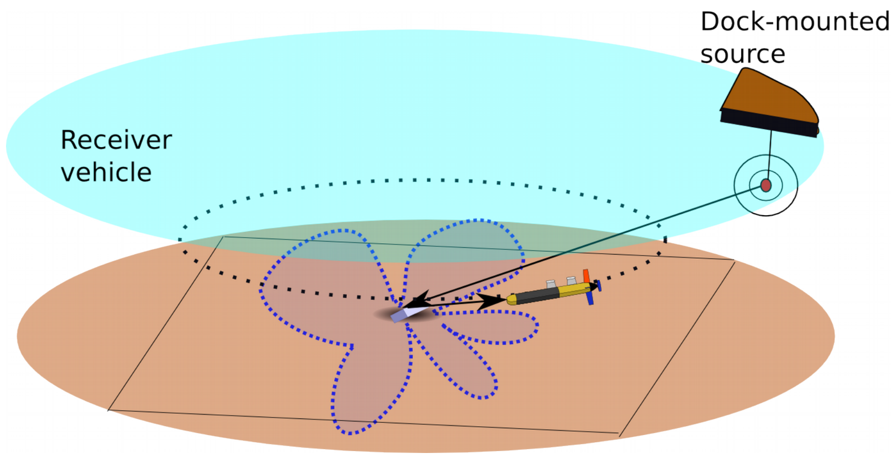
Change in multi-static scattering due to changes in bottom type and water depth.

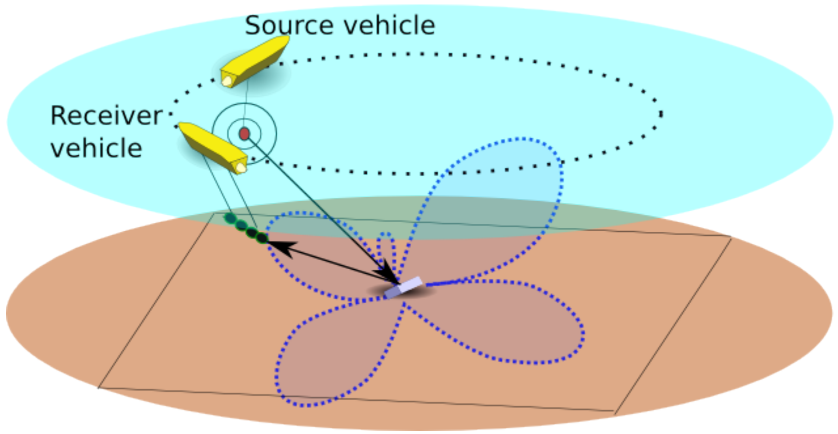
Environment Effect- multistatic



Kullback-Liebler divergence between environments at different bistatic angles.

Back to motivation: low-cost vehicles





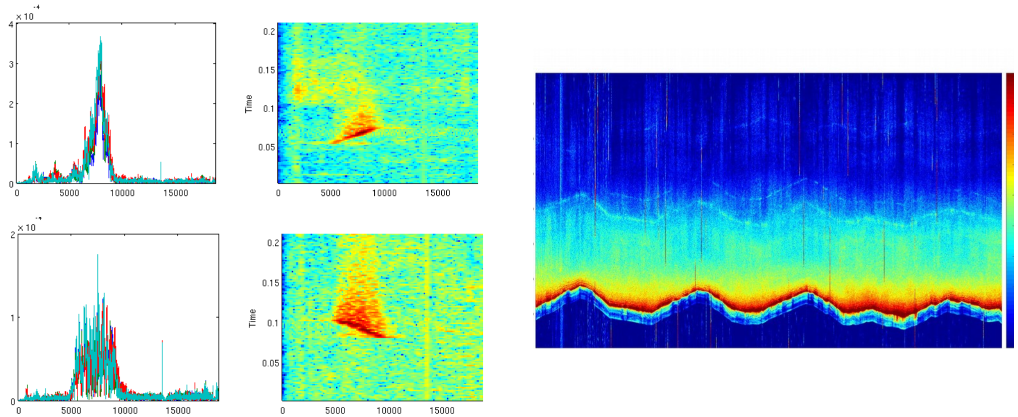
- Use low-cost AUVs/ASVs for target detection/classification.
  - Acoustic data collection systems
  - 3 x SandShark AUVs
  - 2 x JetYak ASVs

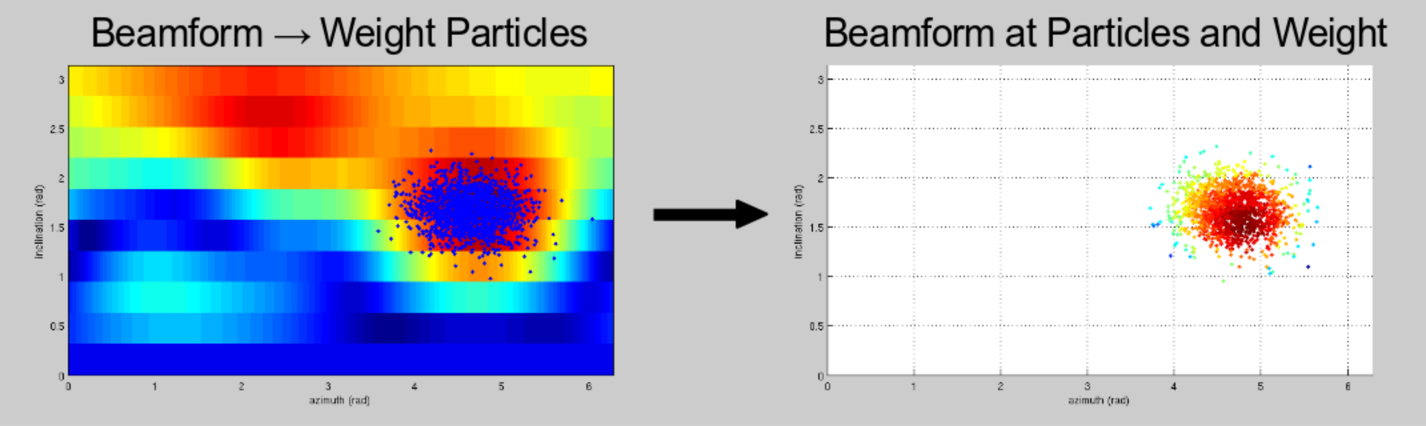
Low-cost micro-UUVs

- 3 x Bluefin SandShark UUVs
- Data collection/processing payload
- Nav/comms challenges

Source-based OWTT iUSBL and scattering target detection for low-cost vehicles

- Use source location for relative navigation
- Use scattering for target detection/classification
- Use waveform for cuing behaviors





Future Work

- Arrays and sources on JetYak ASVs for Multistatic data collection
- SERDP: Bistatic imaging using JetYak ASVs (with Daniel Plotnic APL-UW)
- Line arrays on SandShark AUVs for micro UUV-based target tracking.

Questions?

Overview

1) Bistatic and multistatic radiation patterns
2) Bistatic simulations, scattering experiments, classification
3) Multistatic simulation and classification
4) Navigation and moving to low-cost vehicles
5) Conclusions and suggestions for future work