Multi-target tracking using Probability Hypothesis Density (PHD) filters for whistle contour detection

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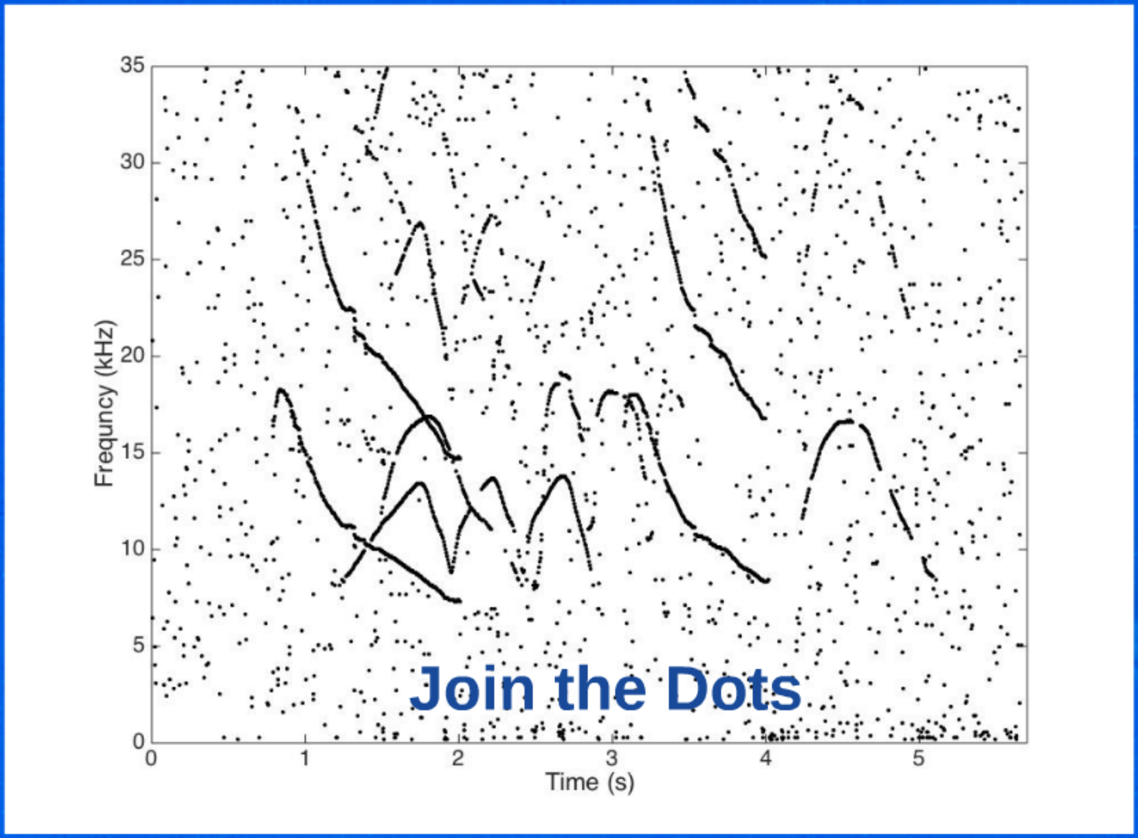
Overview

- Target tracking
  - Single target tracking
  - Multi-target tracking
- PHD filter – GM-PHD filter
- GM-PHD application to synthetic and real data
- Challenges
- Conclusions

Problem description



Target tracking

Target: anything whose state is of interest
State: contains all information about the system under observation at a particular time
Measurement: output from a sensor (target + clutter)

Target tracking = the process of estimating a target's state from noisy measurements and linking together the detections from one source

2 models required

System (dynamic) model

$$x_k = Fx_{k-1} + Qv_{k-1}$$

Describes transformation of the state (x_k) with time

Measurement (observation) model

$$z_k = Hx_k + Rw_k$$

Describes how what we measure (z_k) relates to the state (x_k)

State space model for dolphin whistles

State

$$x_k = [f \;\; \alpha]^t$$

Current whistle frequency

Current whistle chirp rate

System model

$$x_k = \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix} x_{k-1} + v_{k-1}$$

Time between segments

System noise

Measurement model

$$z_k = \begin{bmatrix} 1 & 0 \end{bmatrix} x_k + w_k$$

We only measure frequency

Measurement noise

Single target tracking

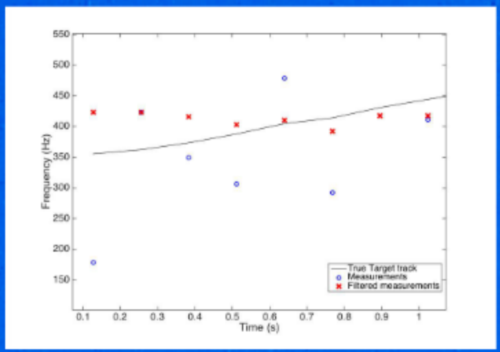
- One target present, all measurements generated by target
- **Kalman filter**

$$x_k = F x_{k-1} + Q v_{k-1} \qquad z_k = H x_k + R w_k$$

state

measurement

Strict assumptions: linear models, Gaussian noise



$$\hat{\boldsymbol{x}}_{\boldsymbol{k}} = F \boldsymbol{x}_{\boldsymbol{k-1}}$$

Predict state estimate

$$\hat{\boldsymbol{P}}_{\boldsymbol{k}} = Q + F \boldsymbol{P}_{\boldsymbol{k-1}} F^T$$

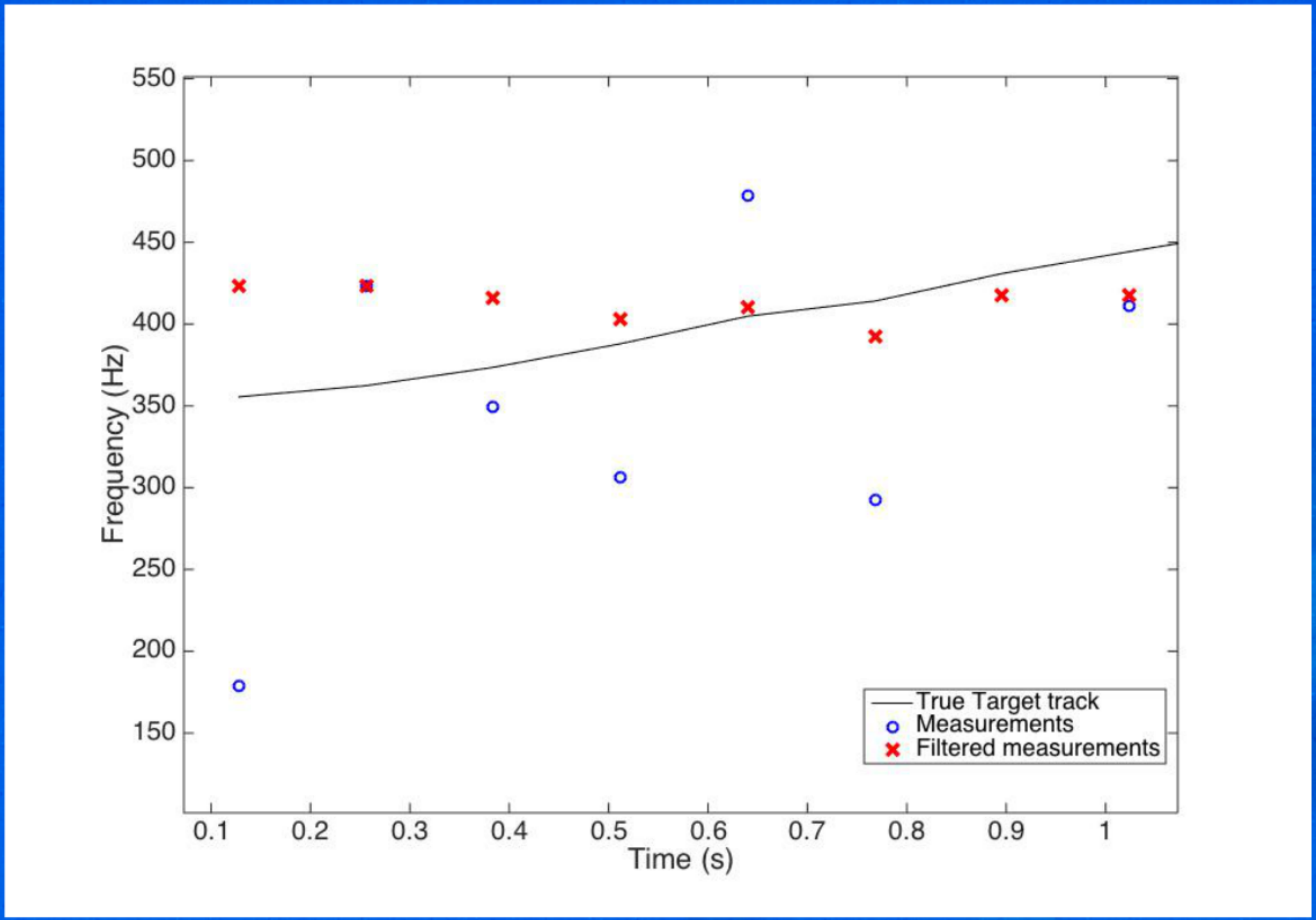
$$K = \hat{\boldsymbol{P}}_{\boldsymbol{k}} H^T (H \hat{\boldsymbol{P}}_{\boldsymbol{k}} H^T + R)^{-1}$$

Kalman gain

$$x_k = \hat{\boldsymbol{x}}_{\boldsymbol{k}} + K(\boldsymbol{z} - H \hat{\boldsymbol{x}}_{\boldsymbol{k}})$$

Update state estimate (refined)

$$\boldsymbol{P}_{\boldsymbol{k}} = (\boldsymbol{I} - KH) \hat{\boldsymbol{P}}_{\boldsymbol{k}}$$

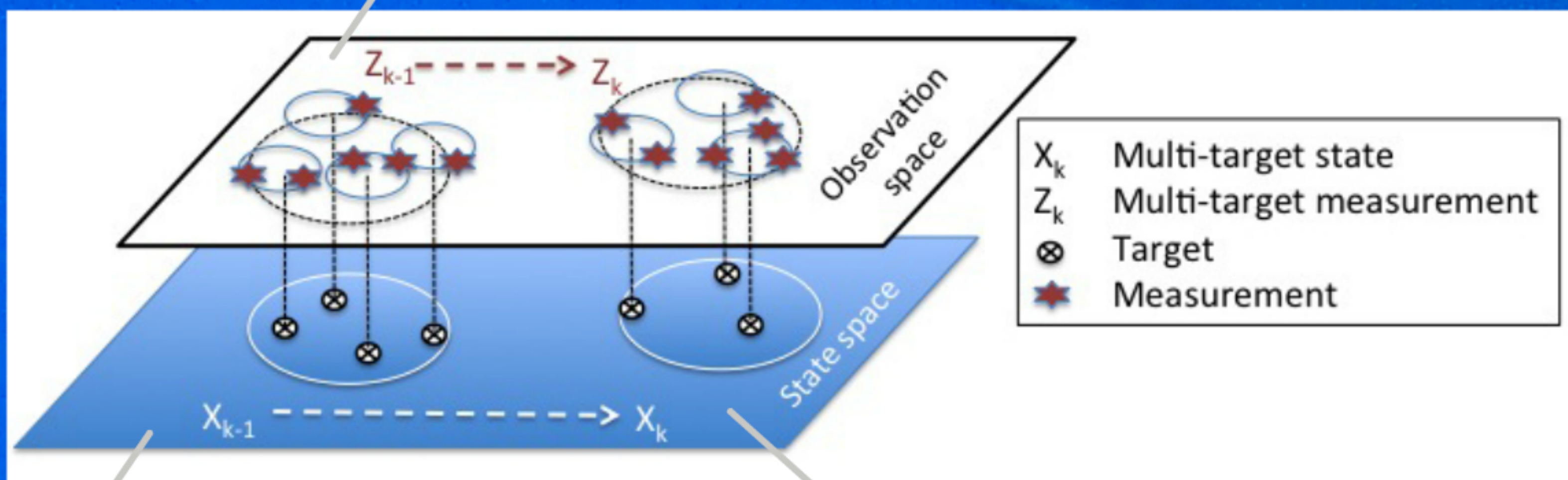


550
500
450
400
350
300
250
200
150
Frequency (Hz)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (s)
True Target track
Measurements
Filtered measurements

Multi-target tracking

Goal: jointly estimate the number of targets and their states from noisy measurements.

measurements (targets + clutter)



multiple targets / no targets

number of targets change

Traditional approaches: NN, GNN, JPDA, MHT; others: FISST (PHD filters)

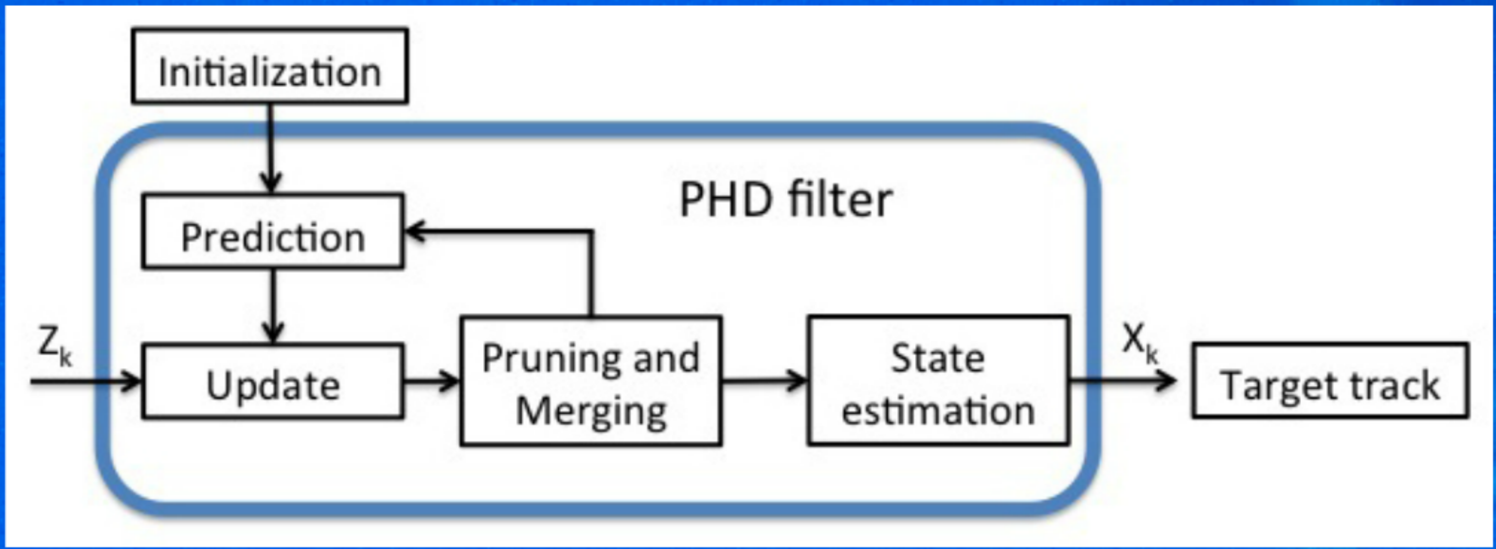
Probability Hypothesis Density (PHD) filters

- Based on Finite Set Statistics (FISST)

  multi-source, multi-target problem

  single-source, single-target problem

- Propagates first-order statistical moment (intensity function/PHD) – strategy analogous to Kalman filter



Gaussian Mixture PHD filter [1]

- Approximates PHD filter
- Recursive algorithm, propagates intensity function or PHD that is represented by a sum of weighted Gaussian components

Each target ≈ Gaussian component

Means and covariances predicted & updated with Kalman filter equations

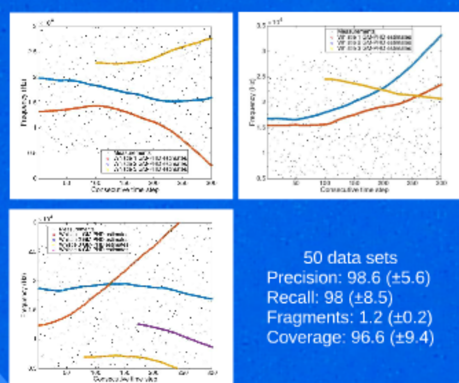
Weights predicted & updated with PHD equation

- Assumptions: linear Gaussian system and measurement models

[1] Vo & Ma. IEEE (2006)

GM-PHD filter applications

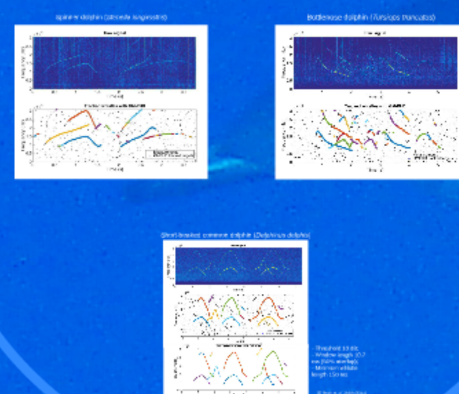
Synthetic data



50 data sets
Precision: 98.6 (±5.6)
Recall: 98 (±8.5)
Fragments: 1.2 (±0.2)
Coverage: 96.6 (±9.4)

Real data

(data taken from MobySound.org)



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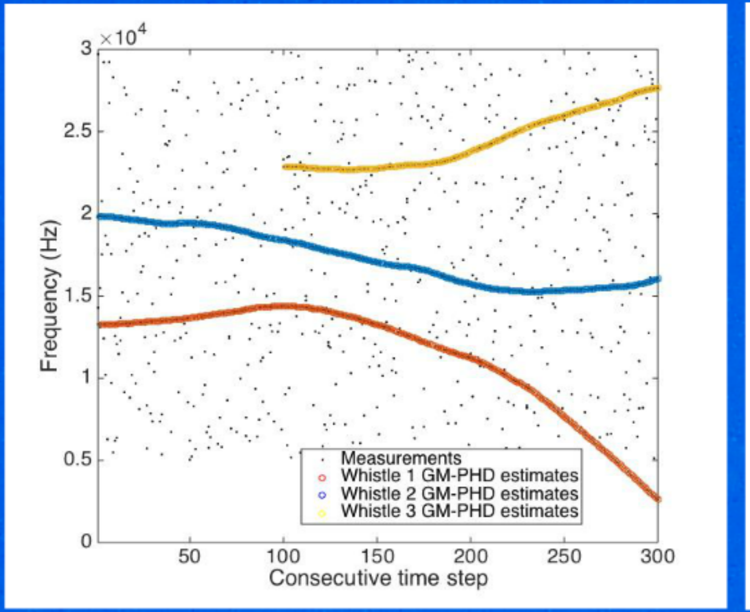

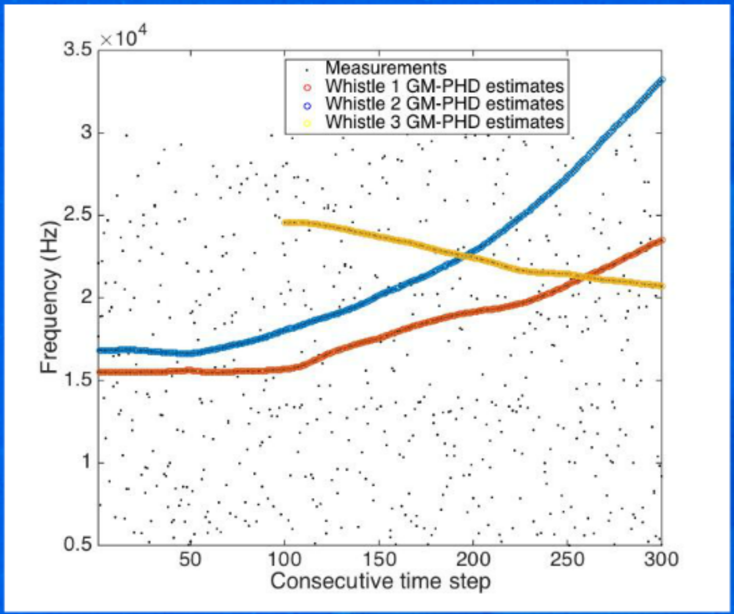

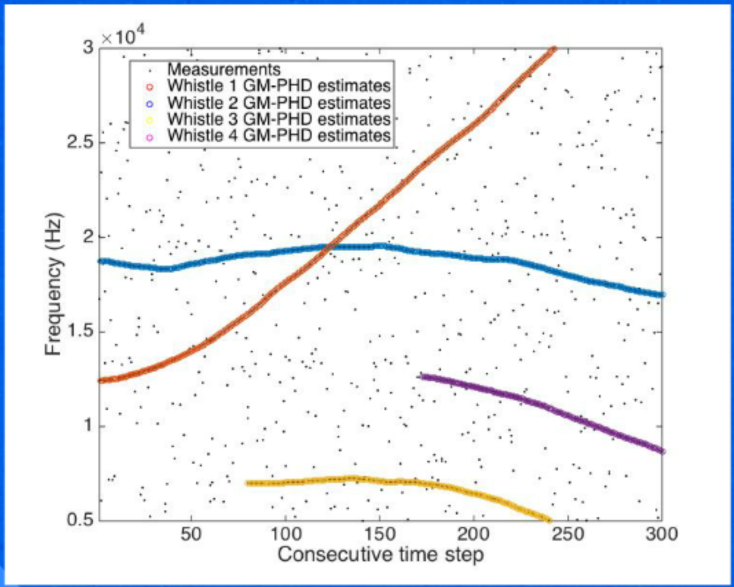

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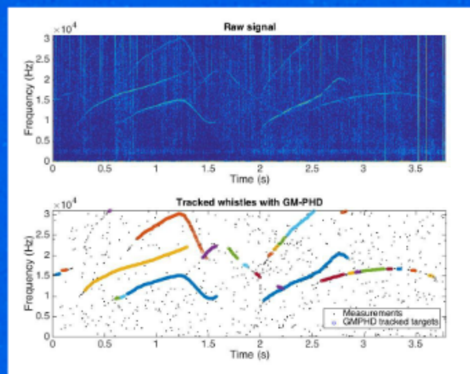
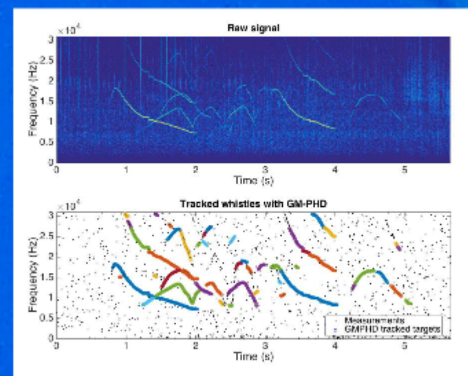
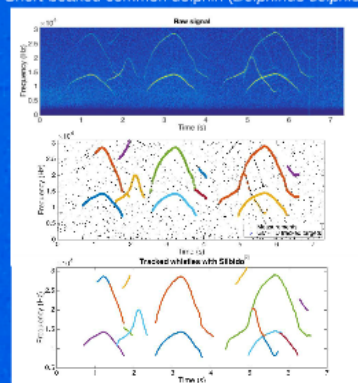
Spinner dolphin (*Stenella longirostris*)



Bottlenose dolphin (*Tursiops truncatus*)



Short-beaked common dolphin (*Delphinus delphis*)



- Threshold 10 dB;
- Window length 10.7 ms (50% overlap);
- Minimum whistle length 150 ms

[2] Roch et al. JASA (2011)

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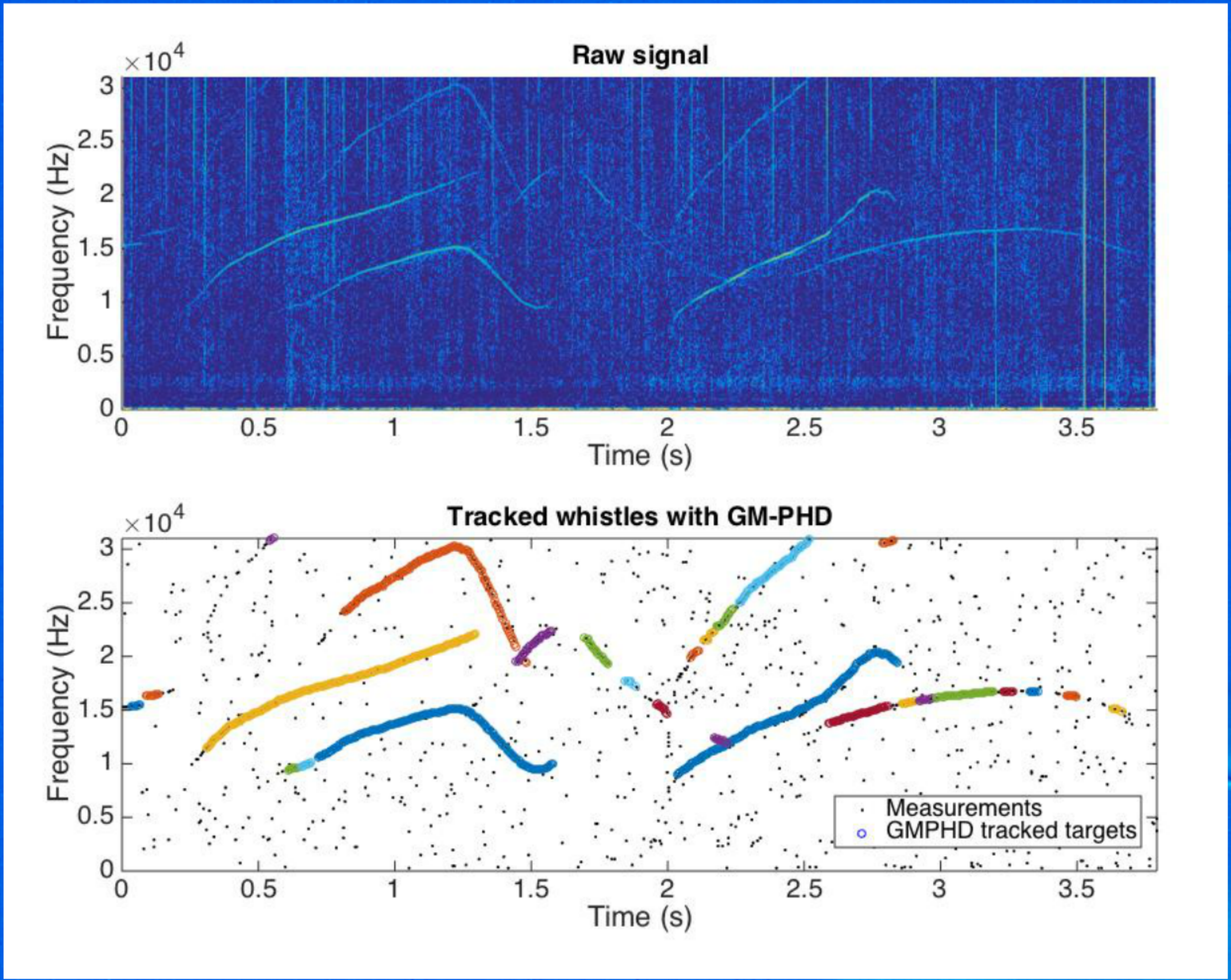

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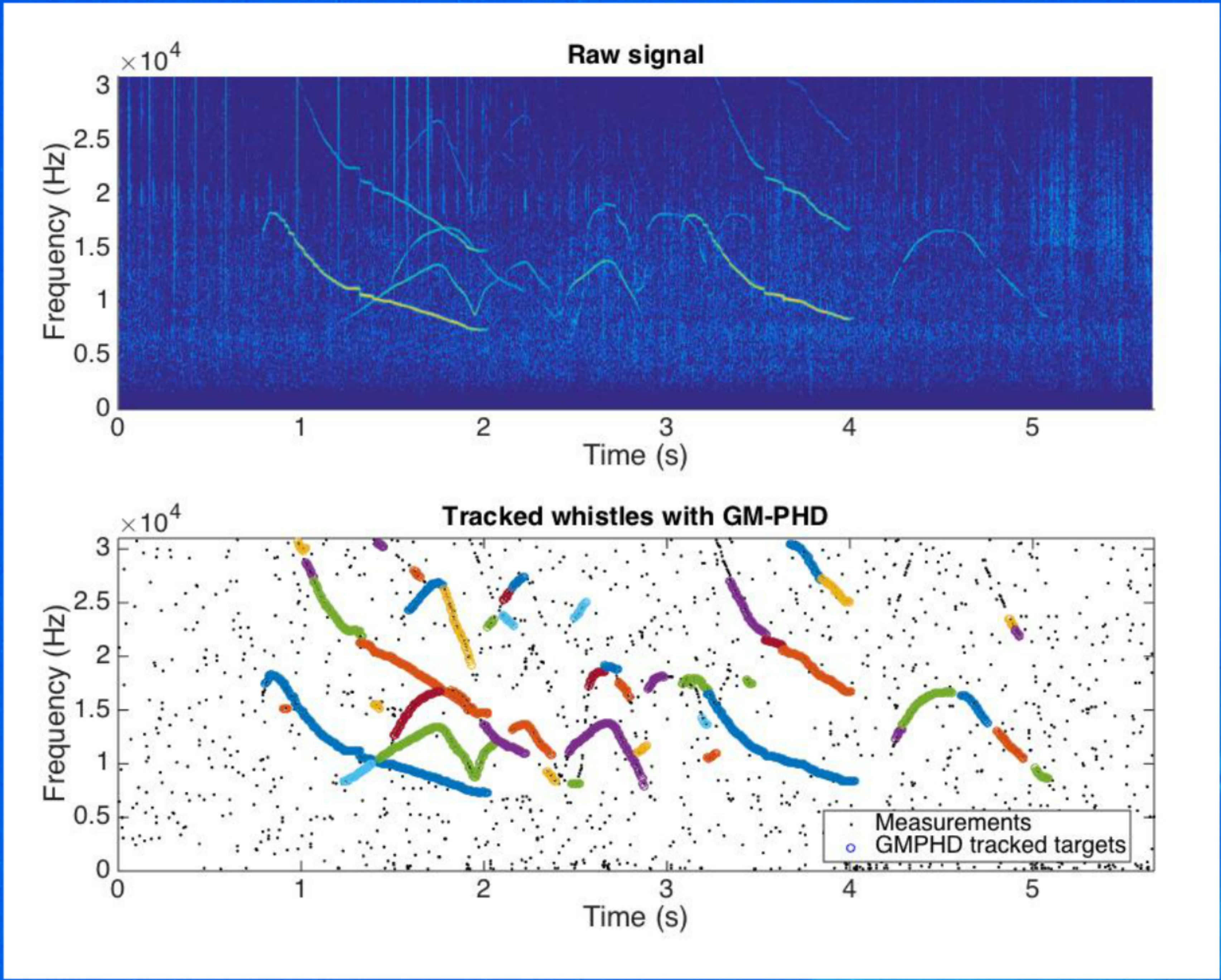

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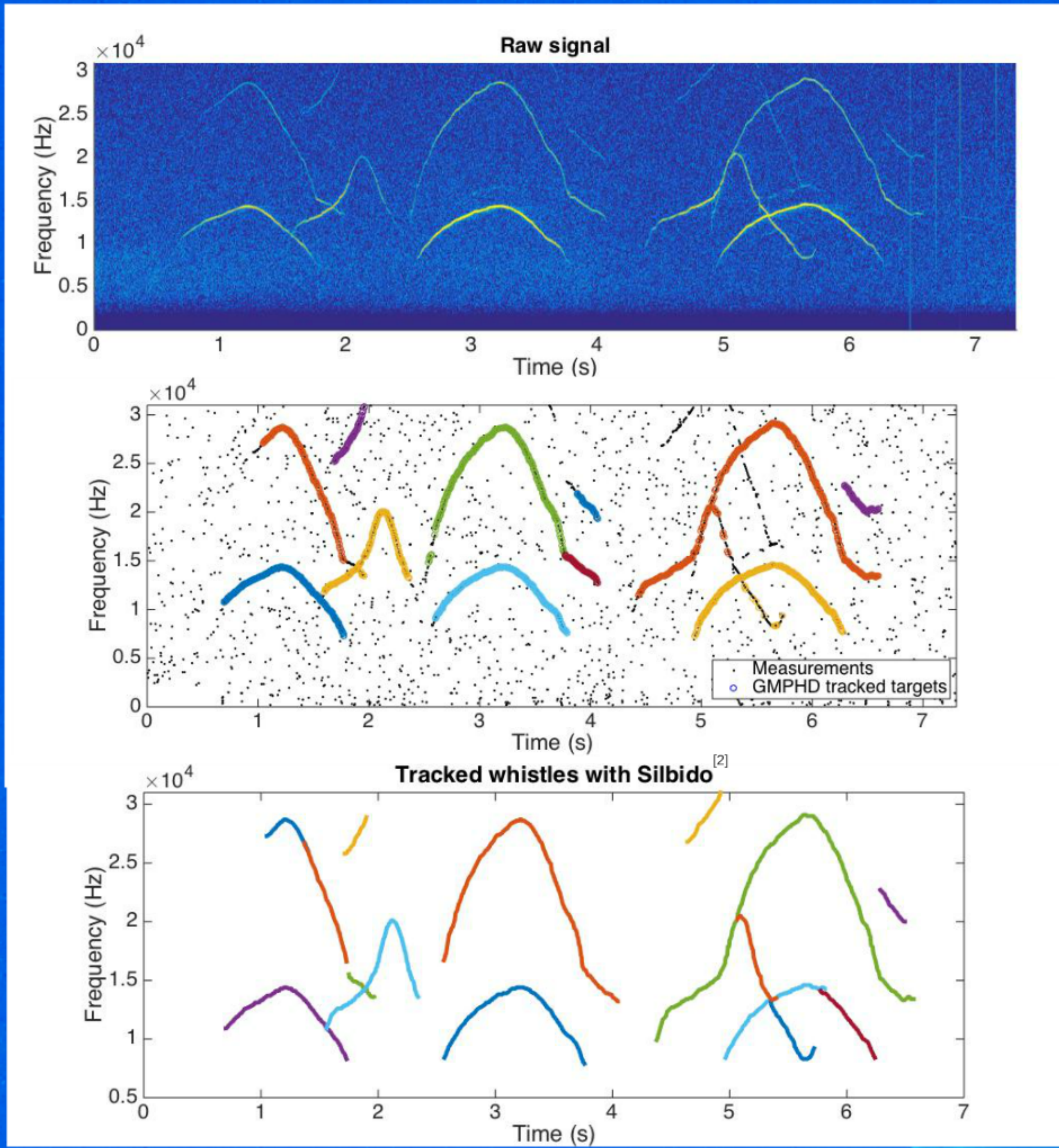

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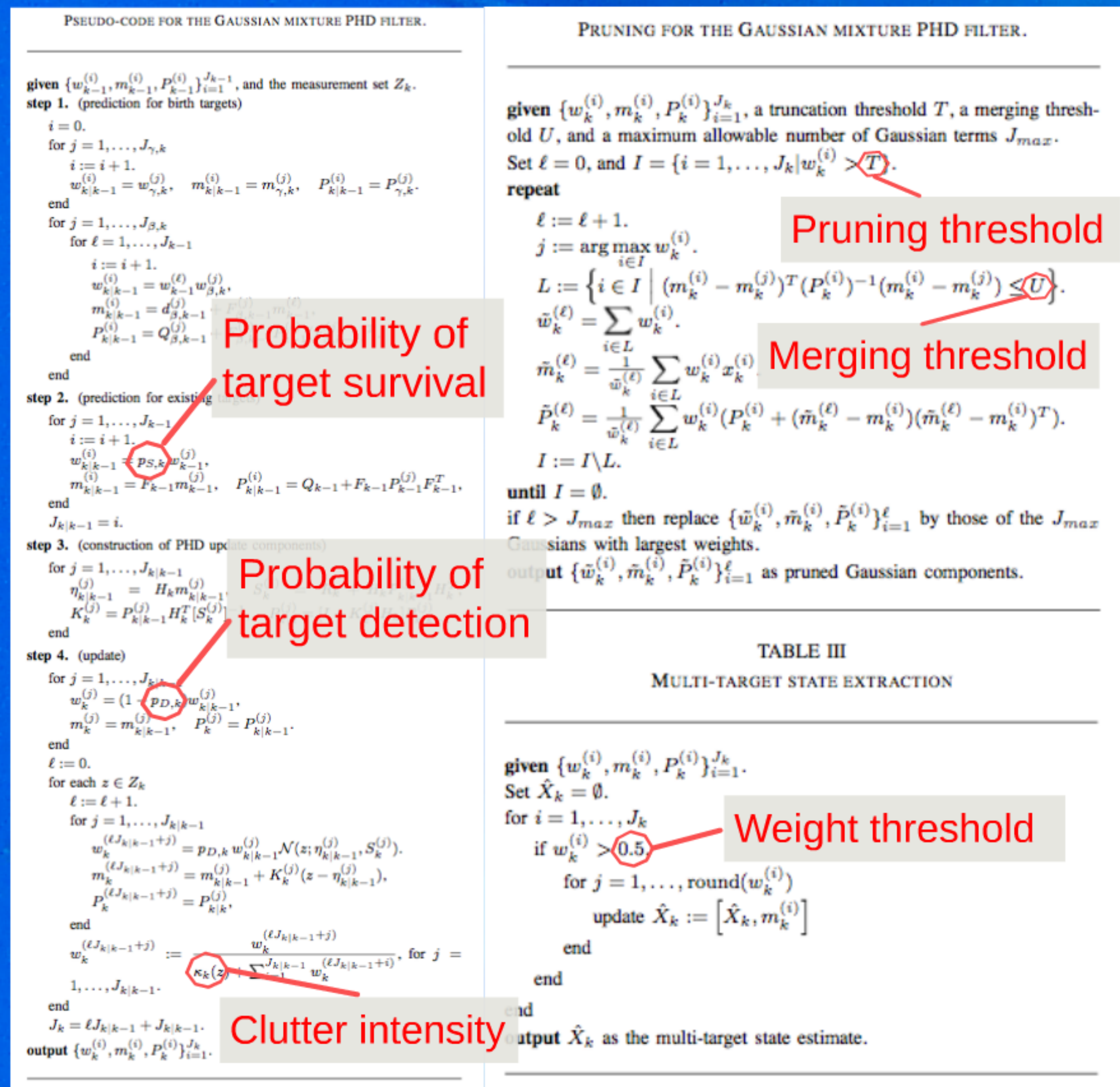
Challenges

- Optimization of GM-PHD filter parameters
- Models (system, measurement, birth and clutter)
- Assumes linear models



Conclusions

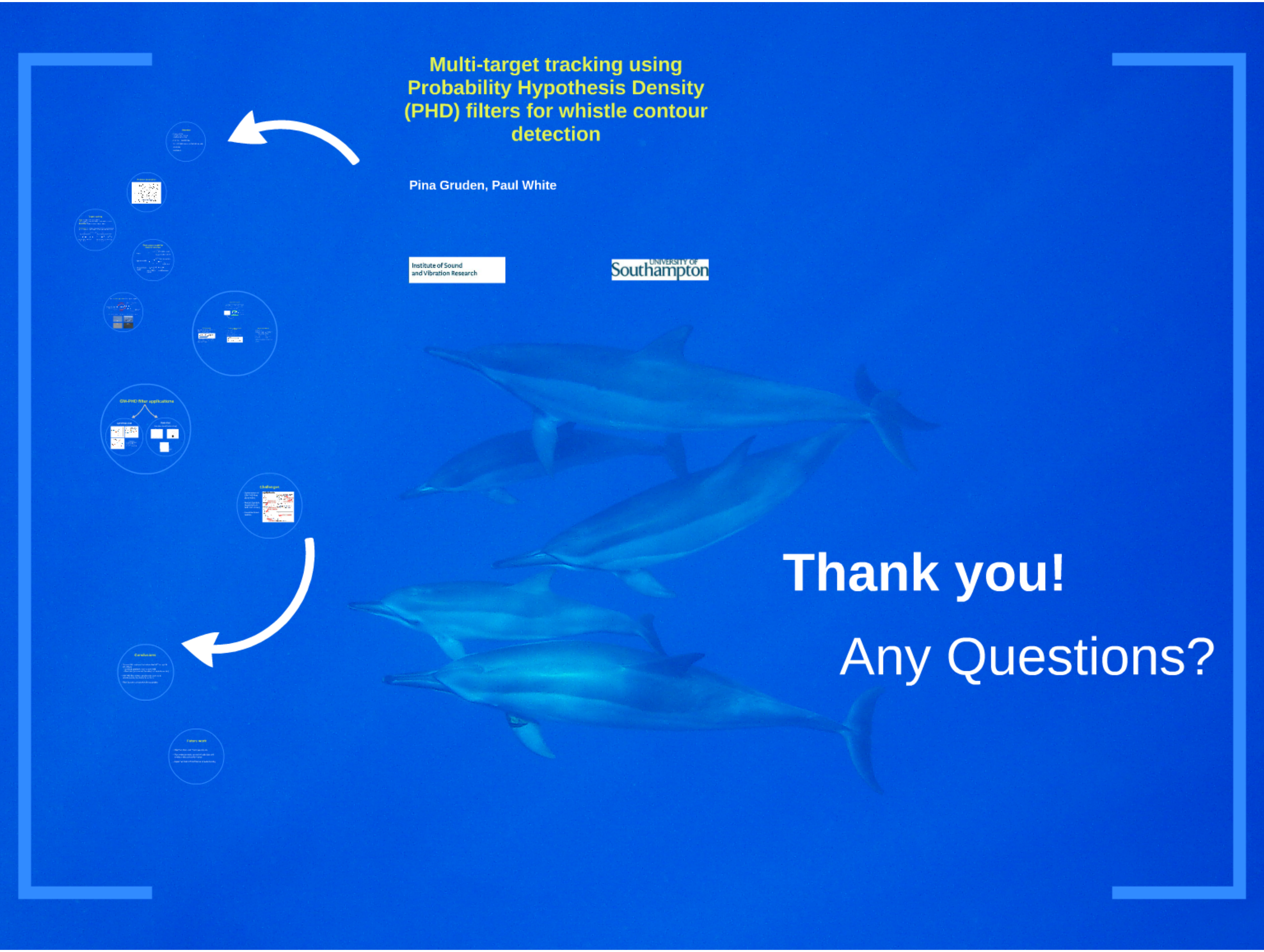
- Successfully implemented automated MTT using GM-PHD filters
  - Synthetic problems (works very well)
  - Real data (occasional "breaking" of contours occurs)

- GM-PHD filter shows considerable promise to simultaneously track whistle contours

- Filter fast and computationally reasonable

Future work

- Optimize filter and model parameters
- Run extensive tests on real whistle data and evaluate detector performance
- Implement SMC-PHD filter for whistle tracking



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Thank you!
Any Questions?