SCHISM: The Final Fortnight

(Signal and Clutter as Highly Independent Structured Modes)

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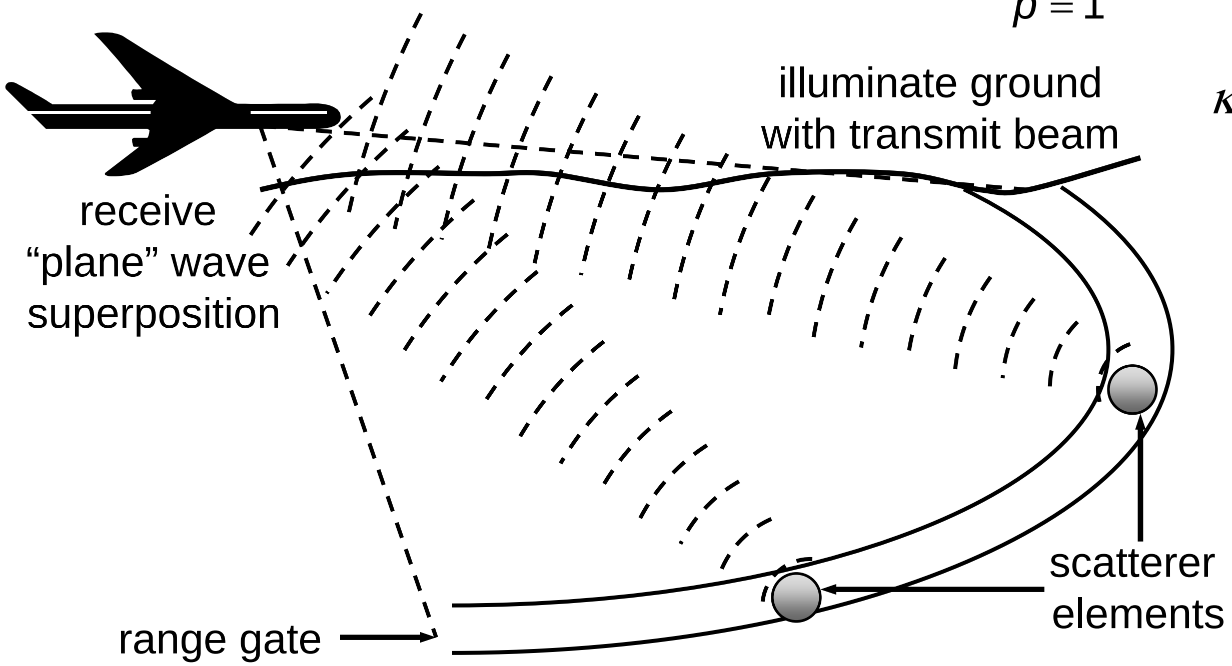
Overview of Presentation

- Brief review of SCHISM approach
- KASSPER Data Set 3 CPI 17
  - Cal-on-clutter datacube focusing results
  - Description of focusing procedure
  - Two target detection methods: omit or include “noise”
- KASSPER Data Set 3 CPIs 1-30
  - Target detection
- Single CPI of KASSPER Data Set 4
  - Cal-on-clutter datacube focusing results
  - Target detection performance
- Comments

SCHISM: Physics-Based Airborne GMTI Signal Model

- Prior knowledge: radar return is a superposition of near-ideal plane-waves
- Estimate (**A**,κ,ω) to fit the data, $y_{n,m}(\boldsymbol{A},\kappa,\boldsymbol{\omega}) \equiv \sum_{p=1}^{P} A_p \cdot \exp\left[j \cdot \left(\kappa_p \cdot n + \omega_p \cdot m\right)\right]$



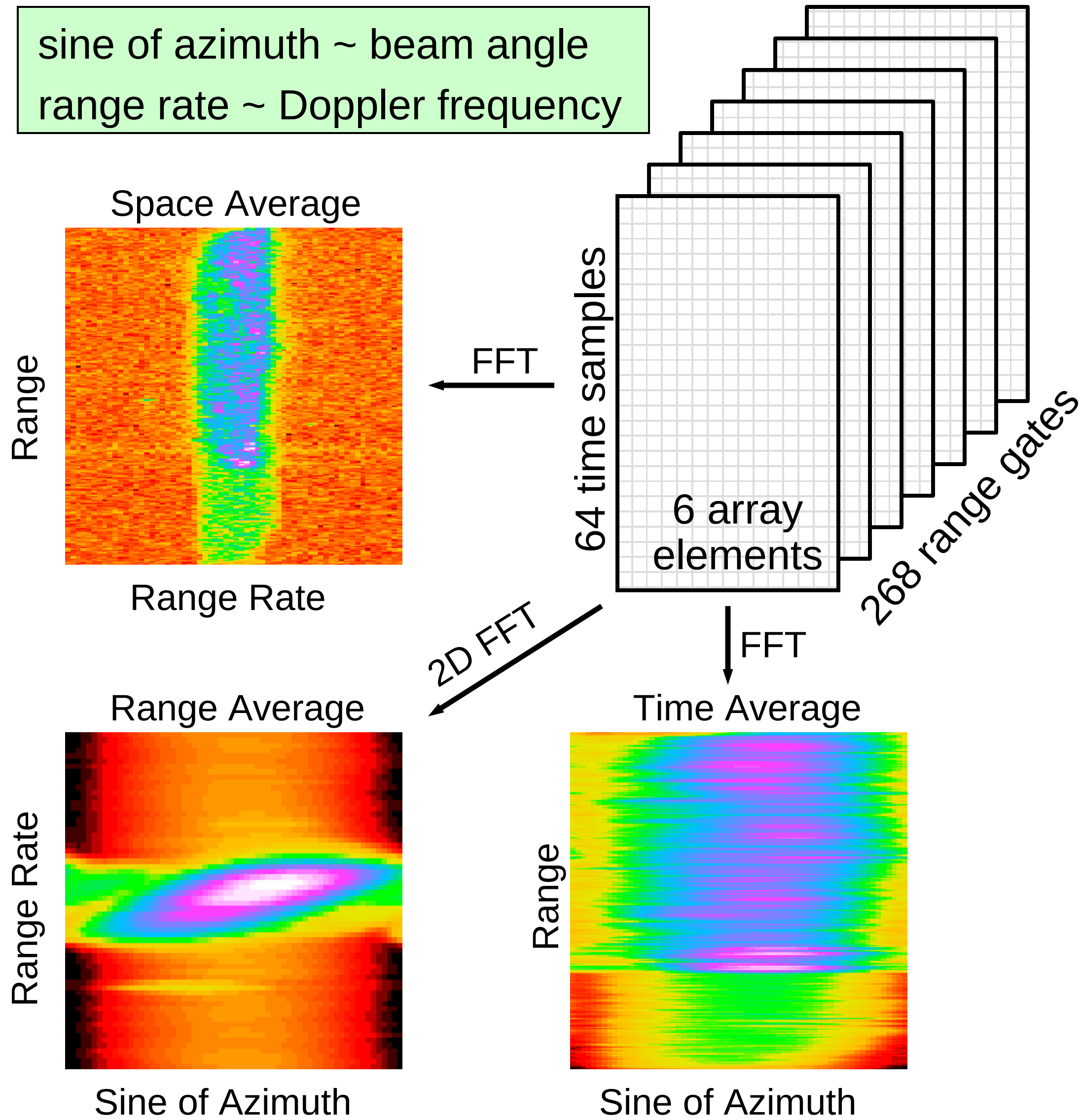
$$\kappa_p \equiv \frac{2\pi \sin(\theta_p)}{\lambda} \Delta x$$

$$\omega_p \equiv 2\pi f_p \Delta t$$

- Concise: scatterers are independent blobs only in beam-Doppler domain
- Deterministic: no covariance matrix needed (high C/N ⇒ precise model)
- Parallel processing: independent estimate for each range gate

KASSPER Data Set 3
(ISL simulation based on real SAR images)

sine of azimuth ~ beam angle
range rate ~ Doppler frequency



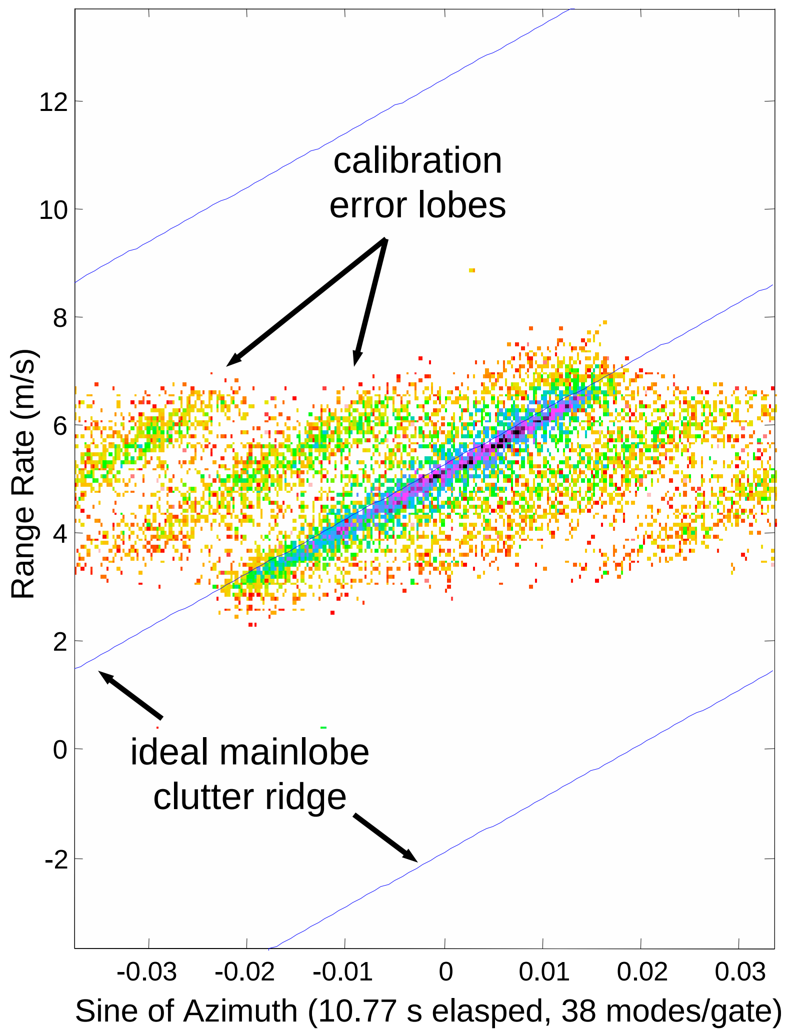
All Data Set 3 results based on entire [6,64,268] datacube.

Simulation Parameters

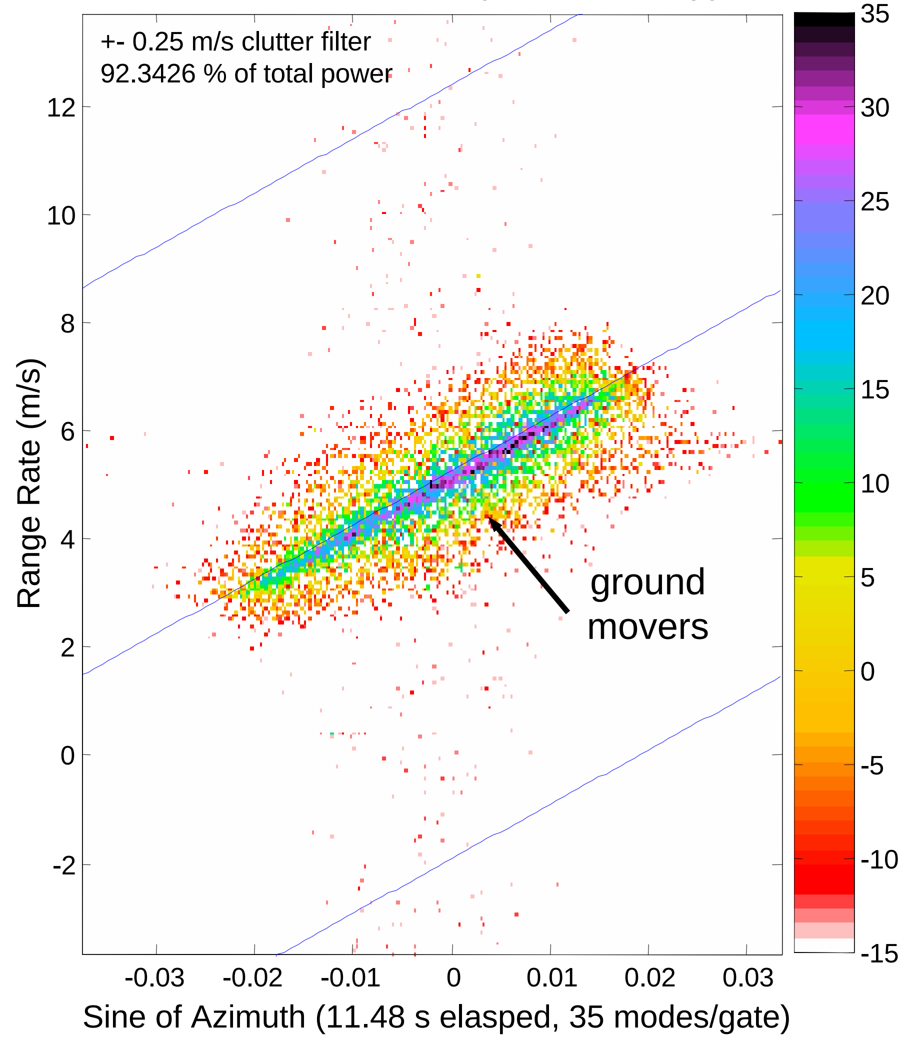
carrier frequency	8.6 GHz
bandwidth	20 MHz
PRF	1 kHz
range	51-53 km
platform speed	100 m/s
platform height	10 km
crab angle	3°
subarray spacing	14 λ
30 CPIs separated by 5 sec	

KASSPER Data Set 3 CPI 17
SCHISM Before and After Focusing

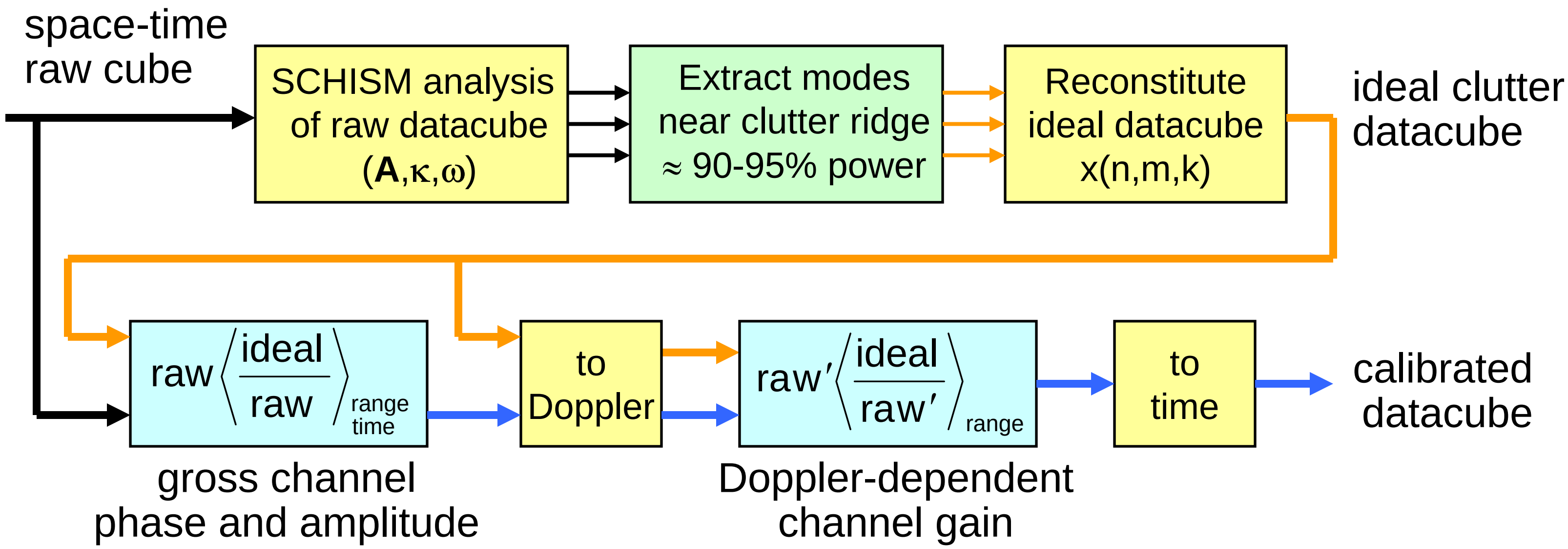
3-17 Unfocused Modes (dB, 15 dB stop)



3-17 Focused Modes (dB, 9 dB stop)

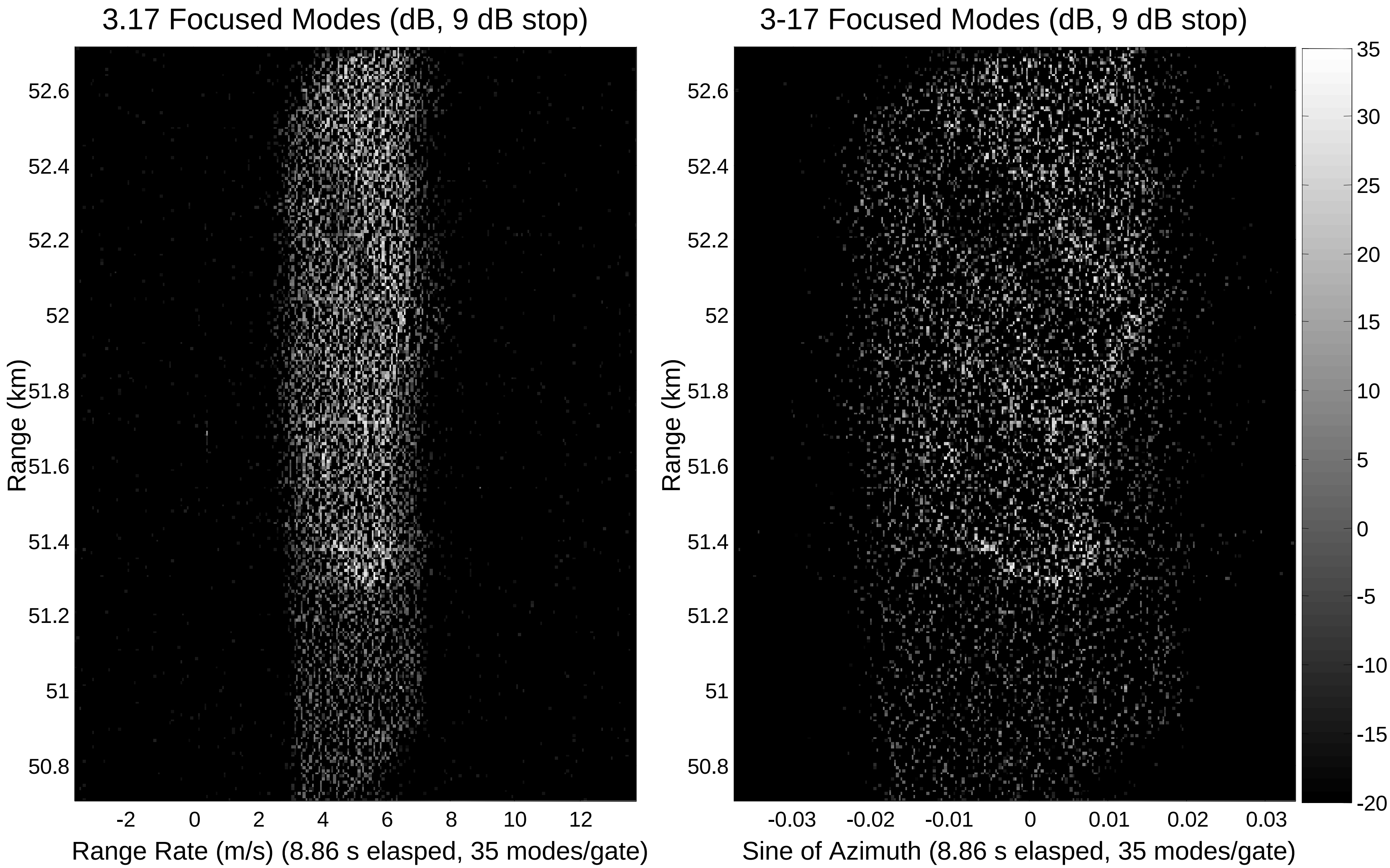


SCHISM Cal-on-Clutter Focusing Procedure



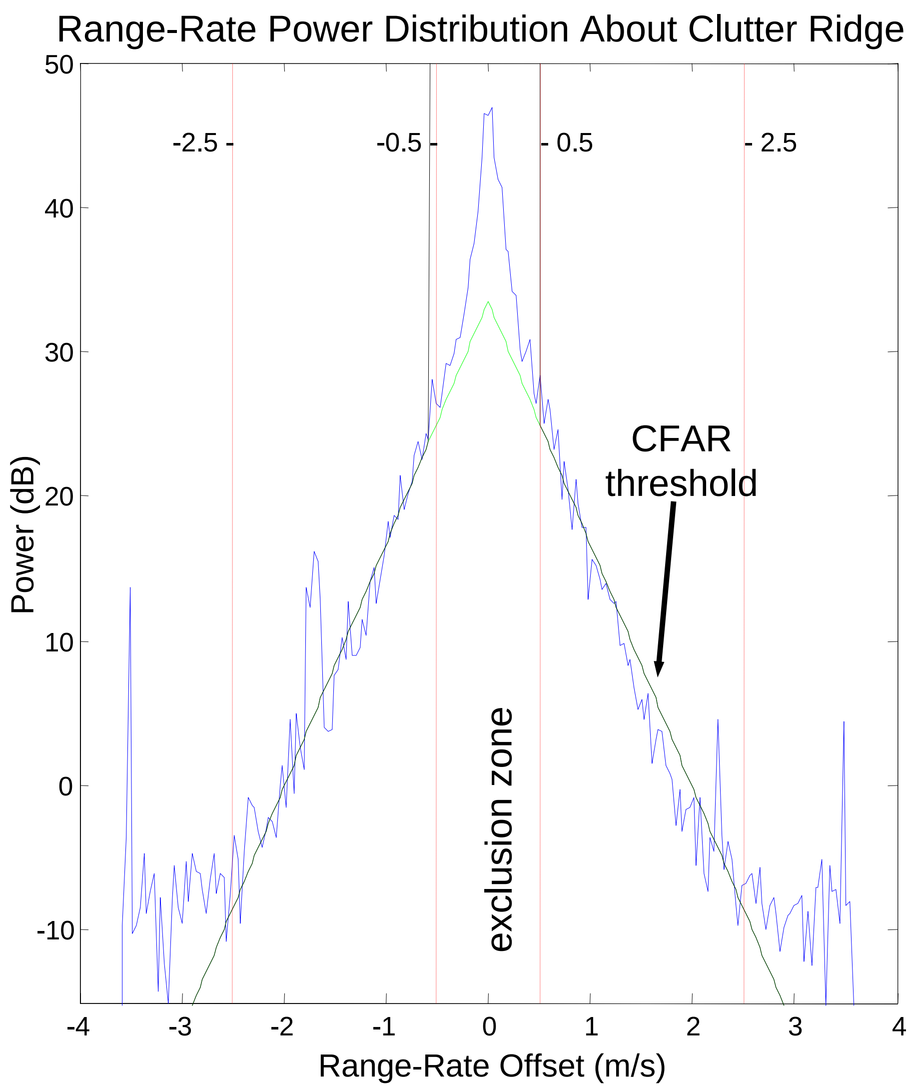
- Exploits structure of dominant beam-Doppler clutter ridge
- Clutter Doppler frequencies are associated with unique beam angles
- Doppler-dependent channel calibration corrects angle-dependent errors
- Averaging process modified to avoid dividing by small numbers
- Moving average smoothes Doppler dependence (n degrees of freedom)
- Assumes ideal time measurements (could correct timing drift if necessary)

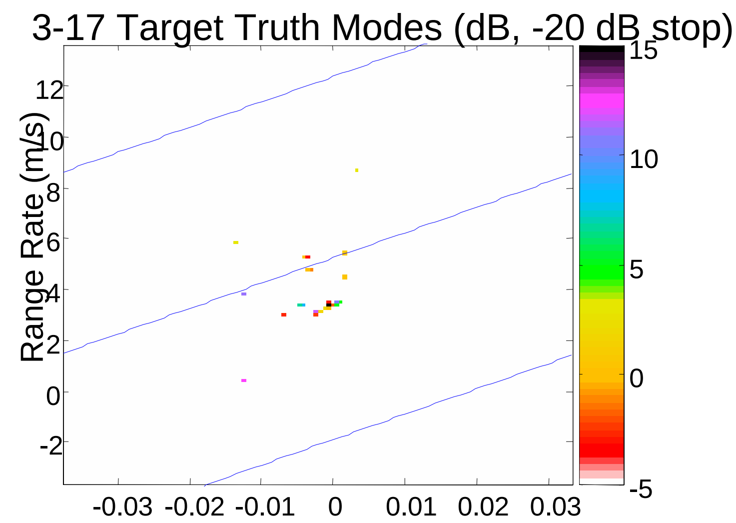
KASSPER Data Set 3 CPI 17
Doppler-Range and Beam-Range

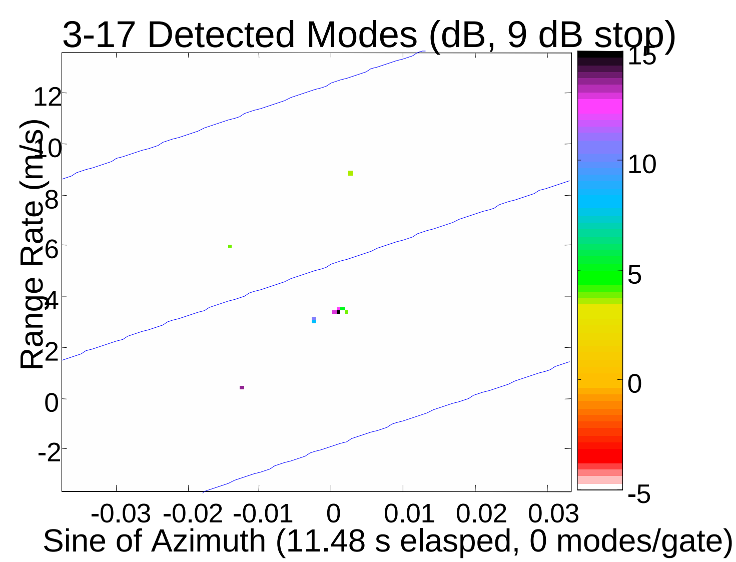


High C/N ⇒ precise scatterer angles

Clutter Distribution, CFAR Threshold, True and Detected Modes (Set 3-17)

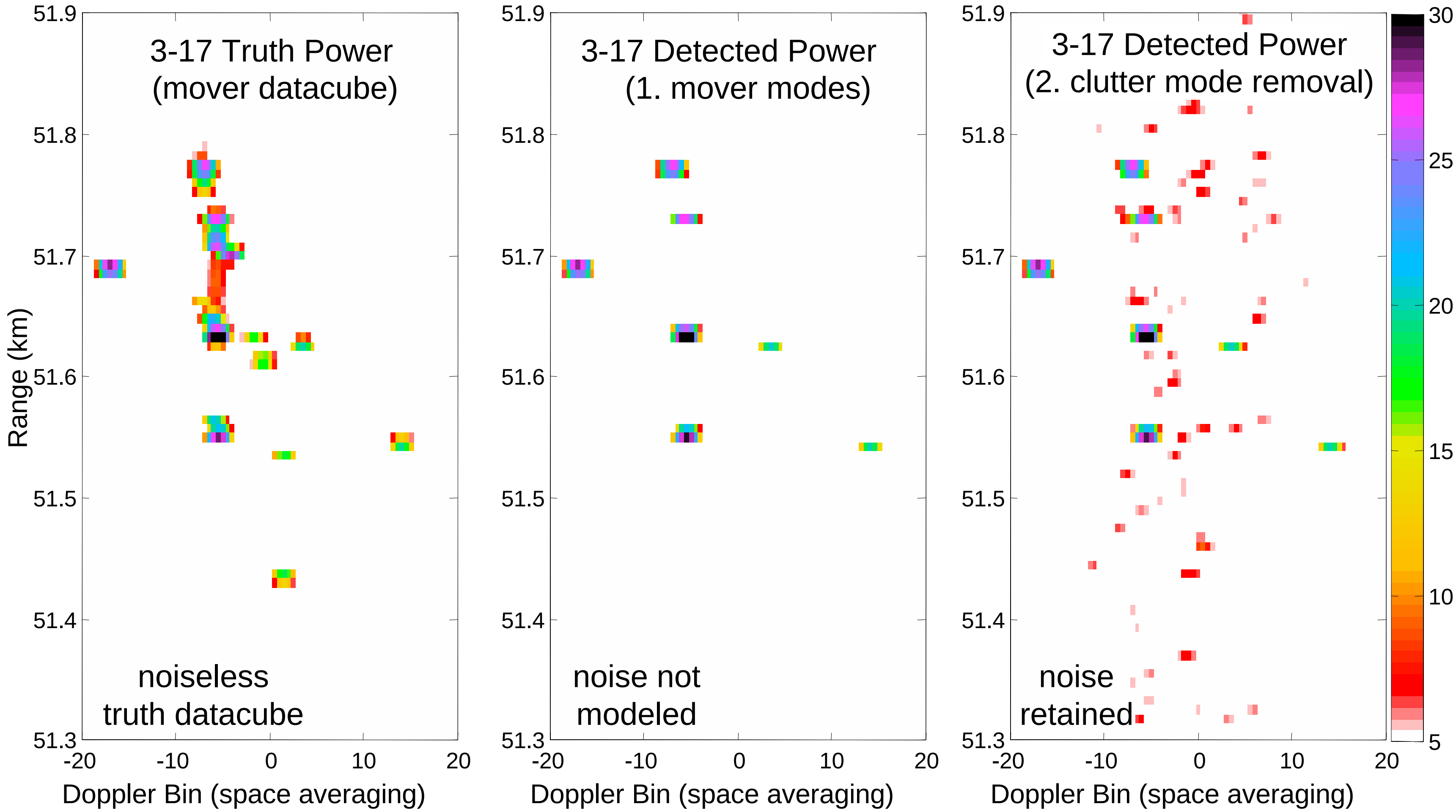






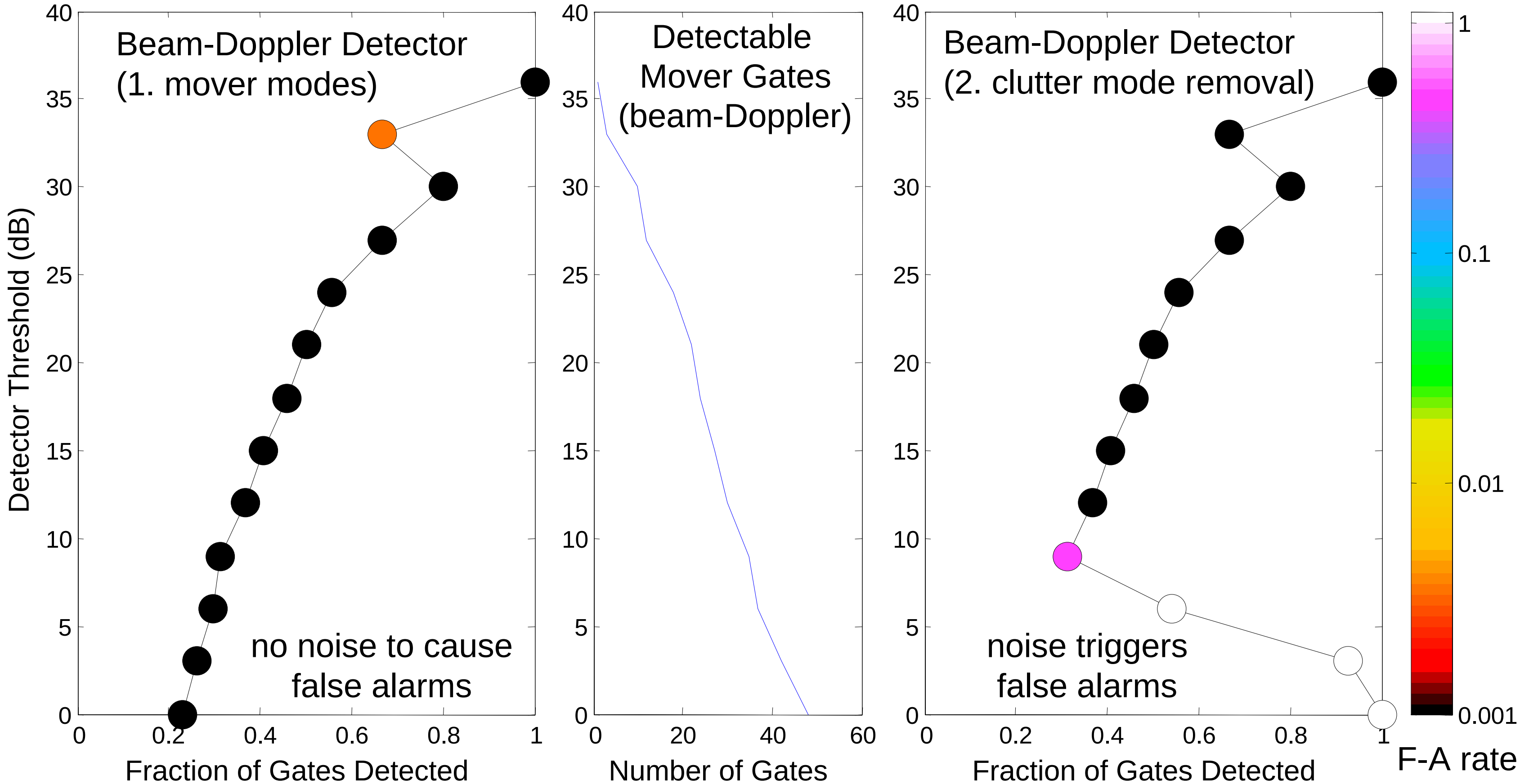
Two SCHISM Detection Methods

1. Model to noise floor, detect mover modes, reconstitute mover datacube
2. Model strong clutter modes, reconstitute clutter, remove from datacube

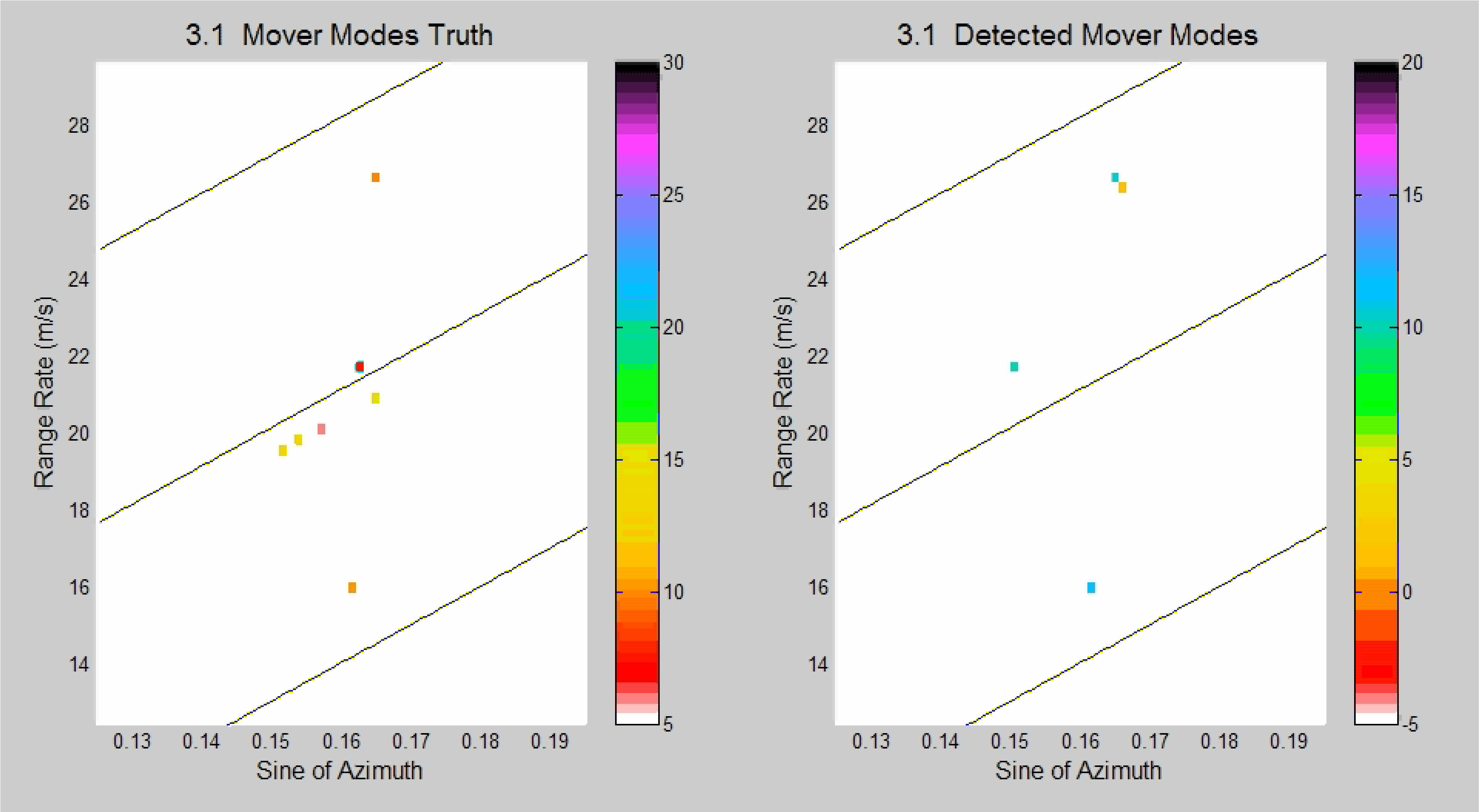


KASSPER Data Set 3 CPI 17 Detector Performance

- Target-only datacube allows comparison with ideal performance limit
- If detection within 1 b-D cell of truth, declare hit for that range gate
- If b-D cell detection in non-target gate, declare false alarm for that gate



KASSPER Data Set 3 CPI 1-30 Detected Beam-Doppler Modes



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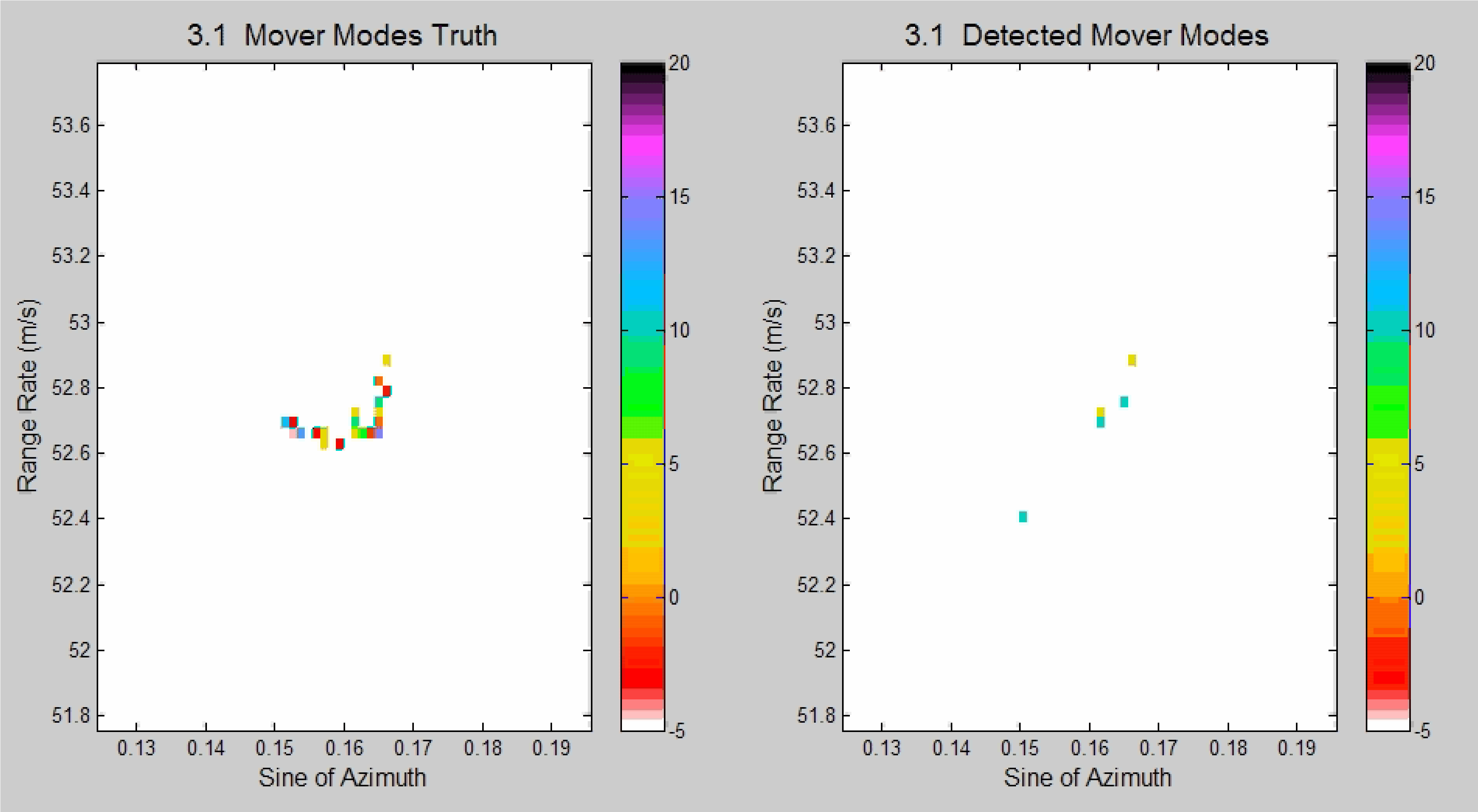
Click on Image to Play

KASSPER Data Set 3 CPI 1-30 Detected Beam-Range Cells



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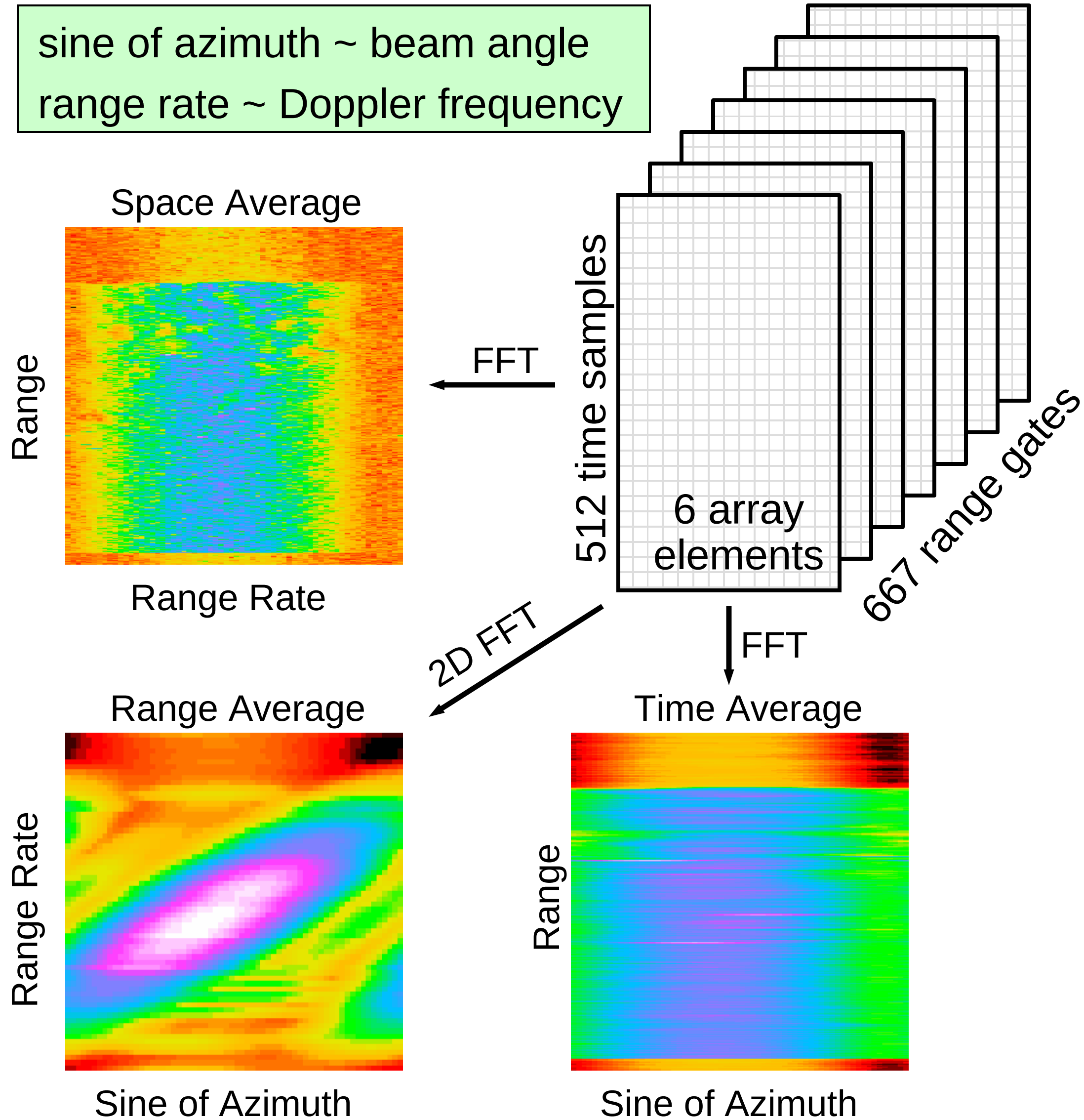
KASSPER Data Set 4
(ISL simulation based on SCATS)

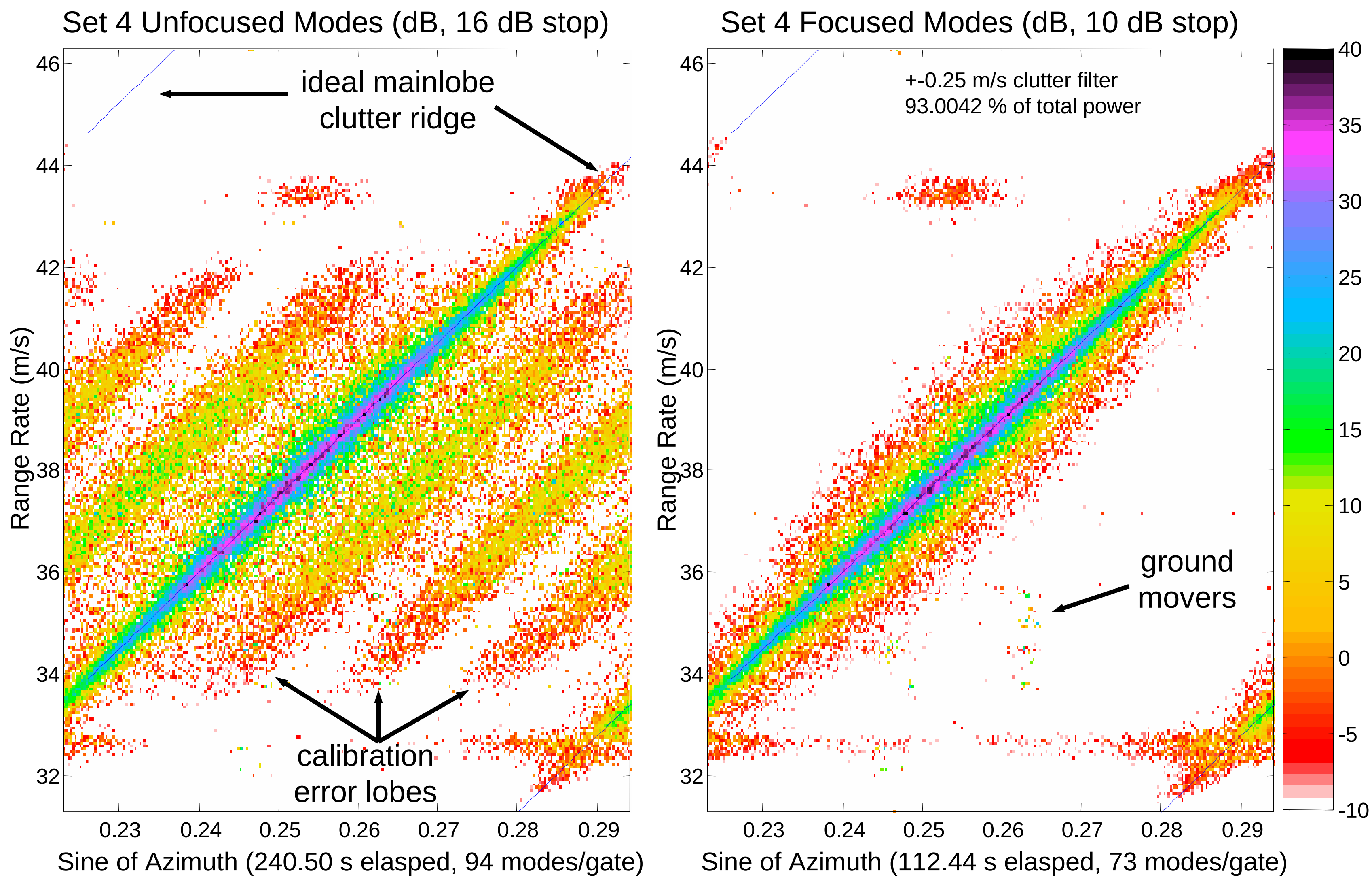
sine of azimuth ~ beam angle
range rate ~ Doppler frequency



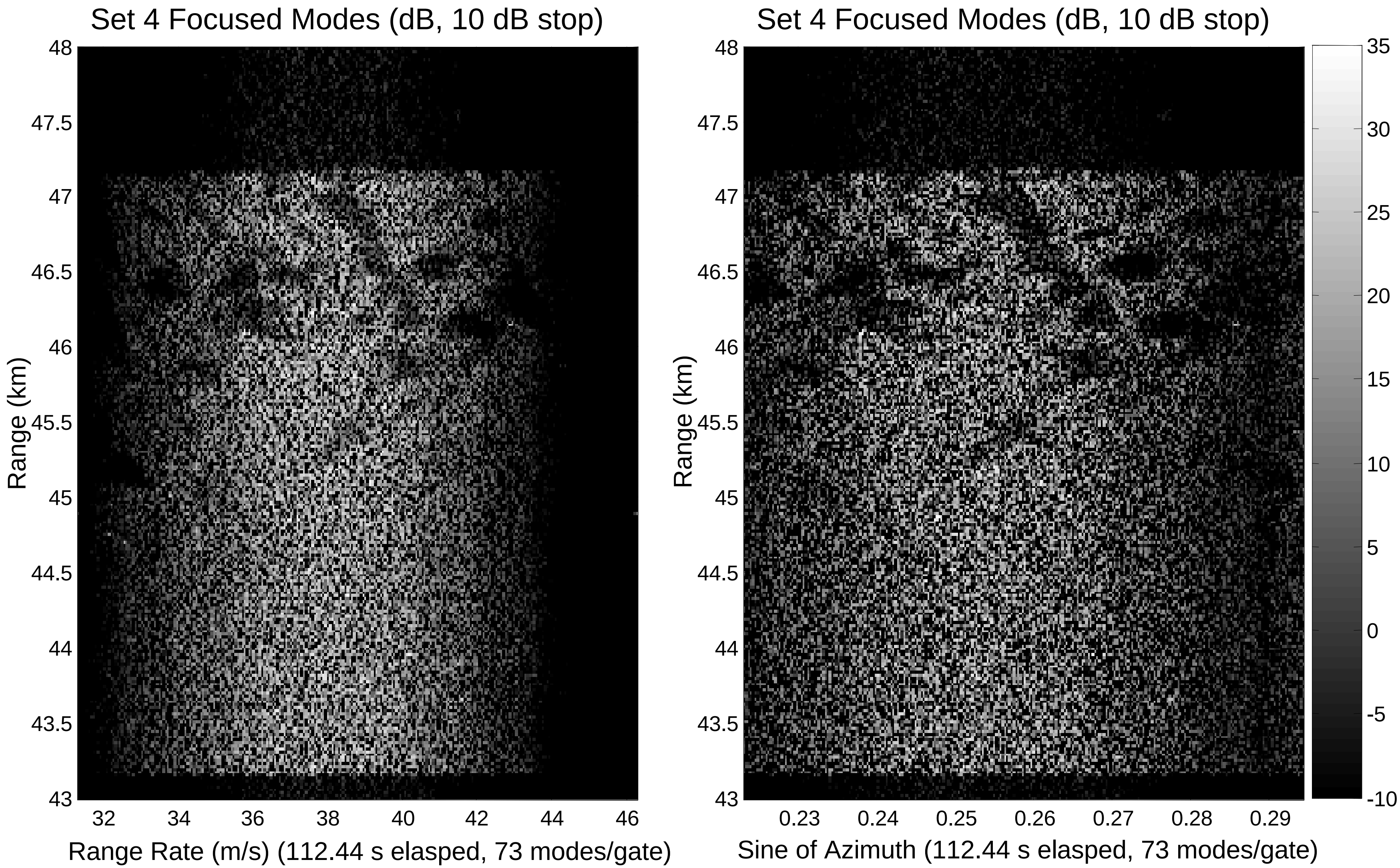
All Data Set 4 results based on partial [6,64,667] datacube.

Simulation Parameters	
carrier frequency	10 GHz
bandwidth	20 MHz
PRF	1 kHz
range	43-48 km
platform speed	150 m/s
platform height	10 km
crab angle	0°
subarray spacing	14 λ
single CPI (512 ms dwell)	

KASSPER Data Set 4 (64/512 subset) SCHISM Before and After Focusing

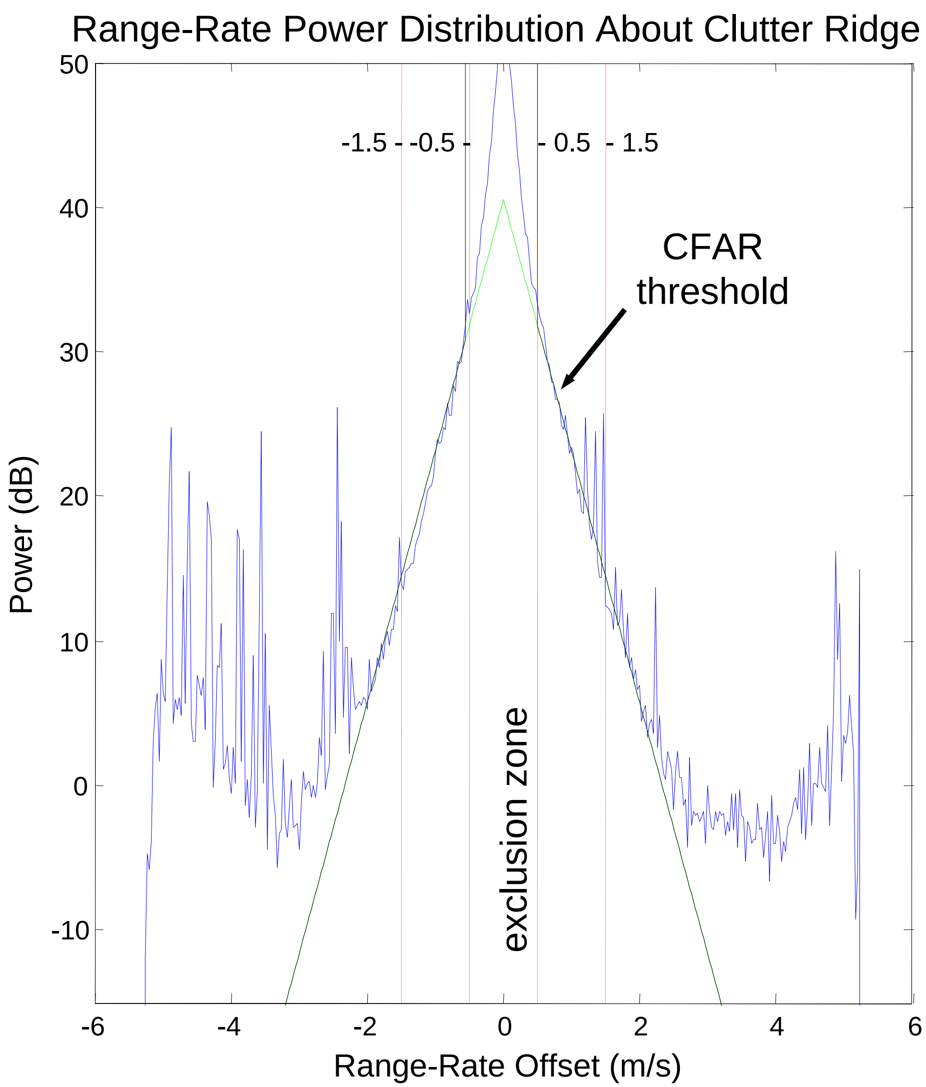


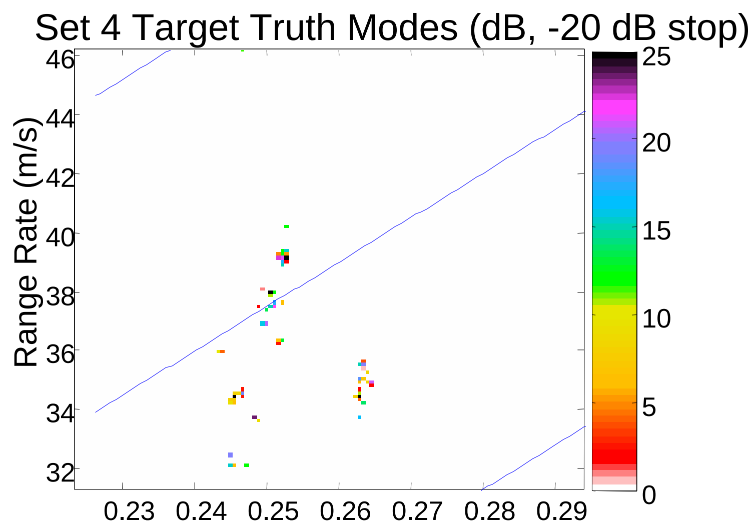
KASSPER Data Set 4 (64/512 subset)
Doppler-Range and Beam-Range

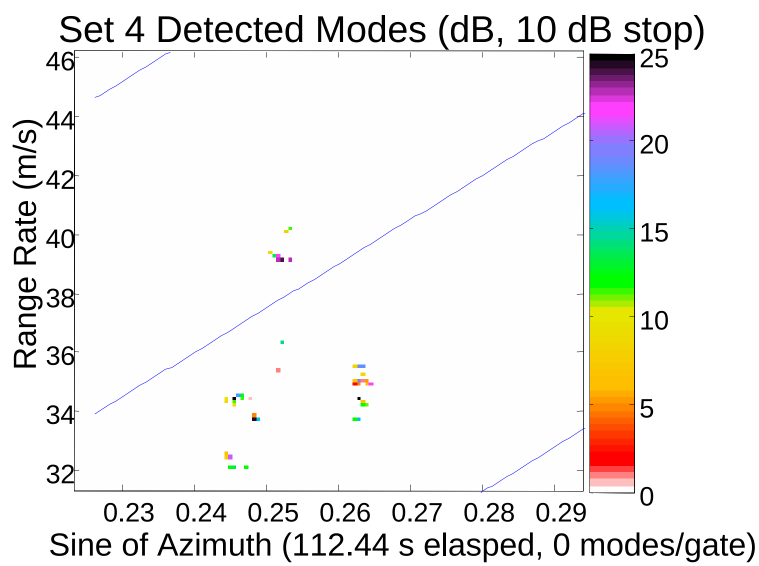


High C/N ⇒ precise scatterer angles

Clutter Distribution, CFAR Threshold, True and Detected Modes (Set 4)







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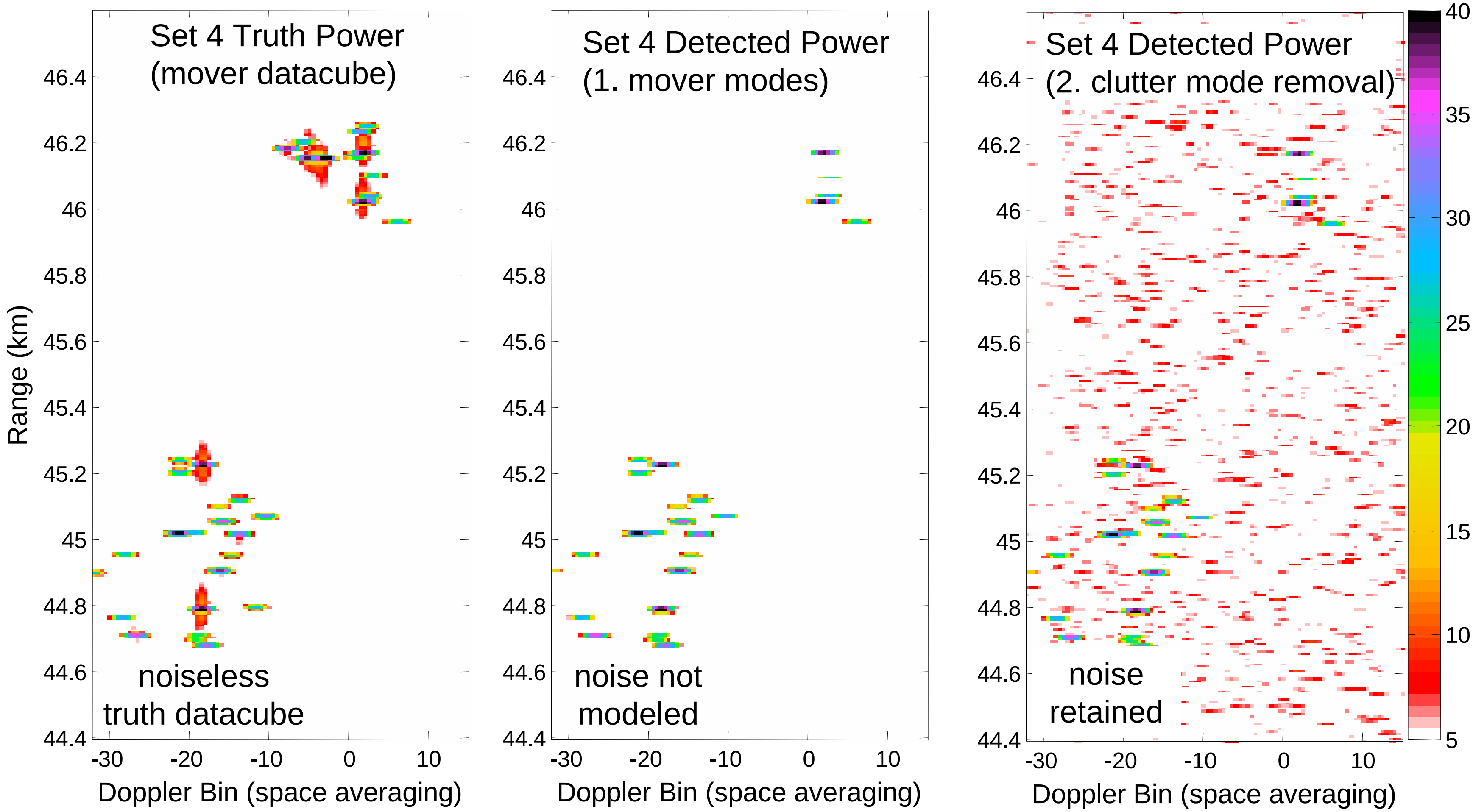

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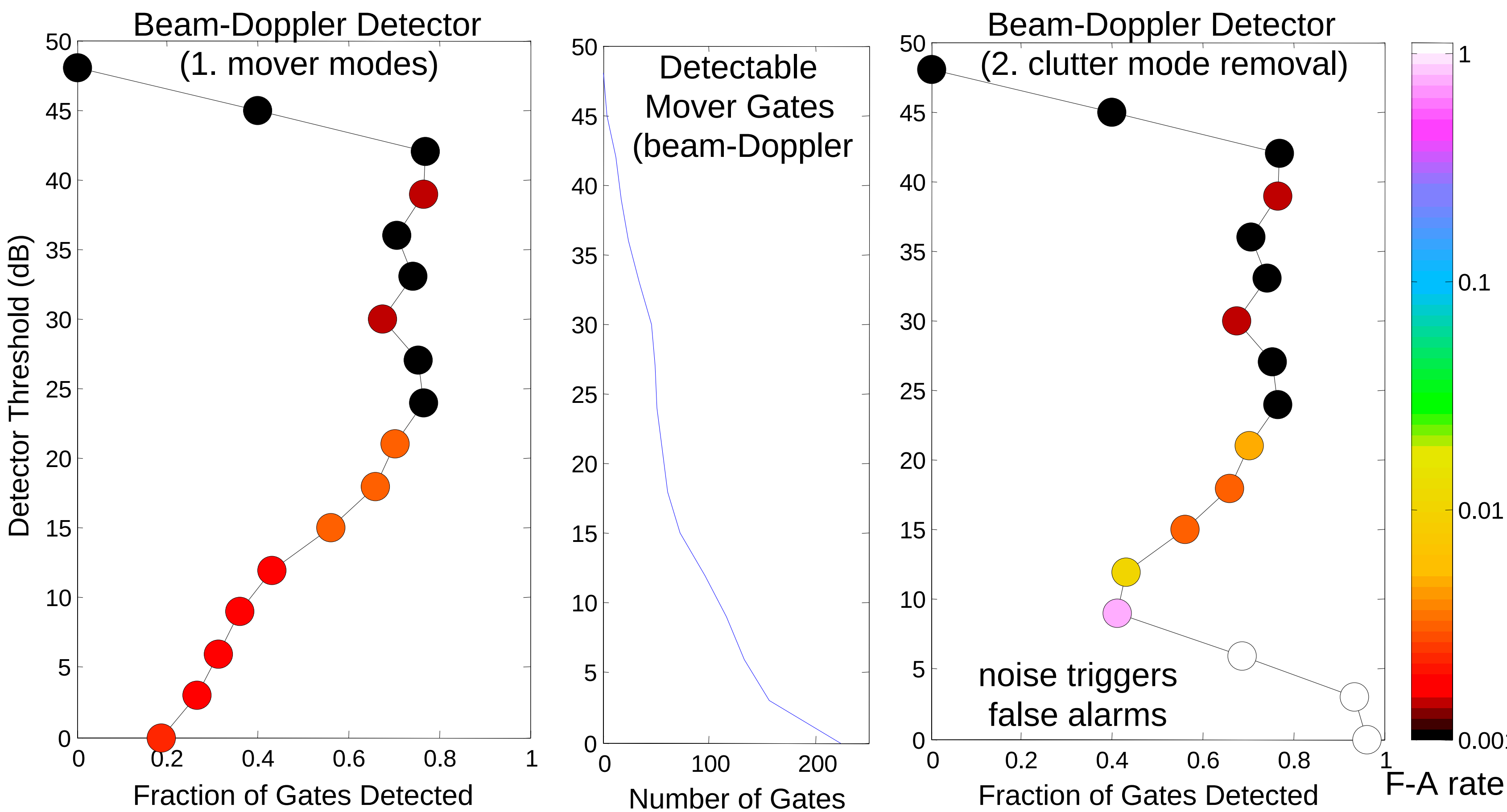


Detection Method Comments

- Mover mode detection when targets above noise floor
  - Datacube is compressed to a mover mode list
  - Built-in noise threshold reduces size of mover mode list
- Use clutter mode removal detection when movers are buried in noise or just need to get rid of strong clutter
  - Retain noise-like movers for tracking filter
  - SCHISM much faster if only strong modes are modeled
  - multi-beam SAR processing (piecewise-linear phasefronts)
- Precise SCHISM beam-Doppler frequencies may help tracker distinguish movers from ICM & speckle
  - Mover modes should persist with consistent range-angle-walk

Final Comments: Parametric vs Adaptive

- Prior knowledge: Distant radar scatterers produce near-ideal plane waves localized in compact regions of beam-Doppler-range space
  – ideal signal for parametric modeling and array calibration
- Airborne GMTI radar $\Rightarrow$ strong clutter "iceberg" effects, inhomogeneity
  – STAP is degraded by large scatterers with non-stationary statistics
  – Parametric modeling and cal-on-clutter is improved by high C/N
- Large space-time apertures improve S/N, resolution, and MDV, but see ICM, array flexing, terrain elevation details, strong targets, etc.
  – Many degrees of freedom greatly complicate STAP (saffron conjecture)
  – Added spatial degrees of freedom $\Rightarrow$ calibration woes
  – More space-time samples help parametric modeling and calibration

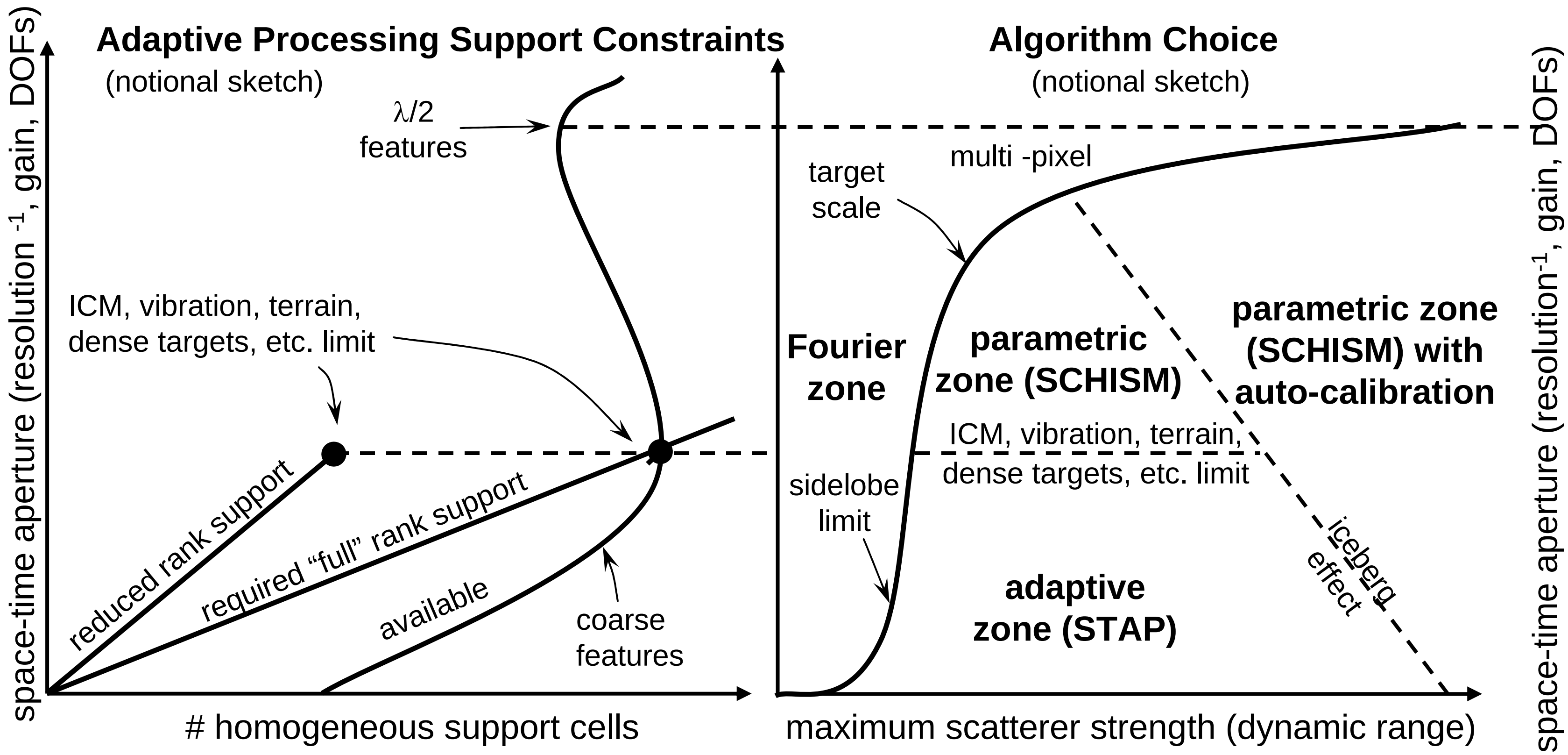
Non-stationary, highly-structured, high C/N $\Rightarrow$ use parametric model

Backup Slides

- Motivation: STAP is Very Difficult in Urban Enviroments and Rough Terrain
- SCHISM and STAP Comparison
- SCHISM Algorithm Block Diagram
- SCHISM Cal-on-Clutter Focusing Procedure

Motivation: STAP is Very Difficult in Urban Enviroments and Rough Terrain

- Target-rich and/or highly inhomogeneous urban and mountainous environments **require larger** airborne GMTI radar **space-time apertures**.
- More STAP sample support is required for larger apertures, but highly-resolved, target-rich, urban and mountainous clutter exhibits **insufficient homogeneity**.

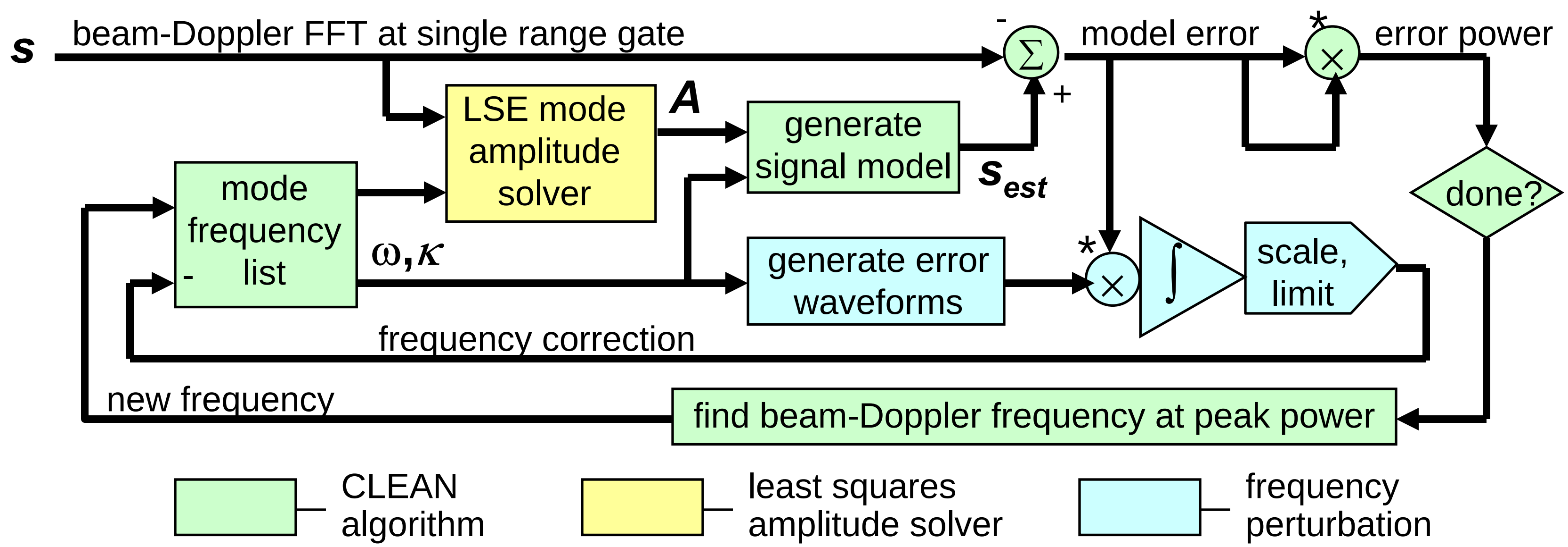


SCHISM and STAP Comparison

SCHISM	Typical STAP
Independent estimate for each range gate. No covariance matrix needed.	Covariance matrix based on nearby gates/cells and tends to widen nulls.
Precise signal frequency estimation based on beam-Doppler peaks.	Precise clutter nulling is implicit form of precise frequency estimation.
LSE estimate of all mode amplitudes.	Clutter mode amplitudes not found.
Target modes exhibit precise beam-Doppler frequency. Steering vector approach optional for weak targets.	Steering vector is matched filter for targets. Precise target beam-Doppler requires MUSIC, etc.
Physical signal model can be used to correct calibration errors or steering vectors, motion compensation, etc.	Adaptive nulling can automatically correct calibration errors. Steering vector may still need correction
Favors large space-time apertures that sample highly-structured signals. Provides needed precise calibration.	Large space-time aperture gain aggravates “iceberg” effect. Larger support invites inhomogeneity.

SCHISM Algorithm Block Diagram

Special Projects Office



Repeat until modeling error power < desired threshold (e.g. noise floor + 9 dB).

- Radically fewer modes than CLEAN (16 vs 260 average per range gate).
- Much faster than CLEAN (10 ms vs 259 ms per range gate, XP1900+).
- Tricky business (limited data support, nonlinear frequency estimation)
  - non-unique solutions: many models can fit the data with equal precision.
  - mode frequencies are generally not orthogonal.
  - error modes can be linear combination of regular modes.

Back to Agenda