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Selex ES/Academic Collaboration in SAR-MTI:
Using PicoSAR in Research to get to the Real World Faster

Stuart Kennedy

UDRC Industrial Day
Heriot-Watt University, Friday 27th June 2014

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Introduction

EPSRC
Engineering and Physical Sciences Research Council

Selex ES

- Engineering Doctorate student at The University of Edinburgh with Prof Bernie Mulgrew
- Based full-time with Selex ES as Industrial Sponsor
- Supported by EPSRC
- Additional support from the Royal Commission for the Exhibition of 1851
- Research topic:

  “Slow-moving target detection in SAR”
- Perfectly suited for industrial/academic collaboration

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Scope

- Engineering Doctorate as a vehicle for collaboration
  - What is an EngD?
  - What advantageous does it offer?
- Brief introduction to moving objects in Synthetic Aperture Radar
- Radar trials data with PicoSAR
- Case study: Slow-moving SAR-MTI
  - How industry is essential
  - Adaptive channel alignment for clutter cancellation
  - PD-STAP
  - Detection by focusing

Engineering Doctorate

- PhD-equivalent research in industry with commercial focus
- Focus on practical applications and implementation
- Examined differently with less focus on publications and novelty
- Additional taught element including part-MBA

- Flexibility and research-focus of academia
- Practical experience and resources of industry

An Aside: Royal Commission for the Exhibition of 1851

- Victoria and Albert's Great Exhibition of 1851
  - Crystal palace
  - "Confirm Great Britain's position in the world"
- Great success
  - 6 million visitors, £21m profit (inflation adjusted)

- Charged by royal charter with:

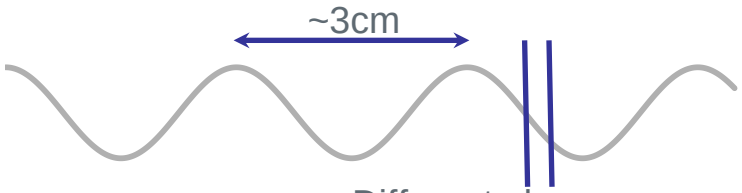
  "increasing the means of industrial education and extending the influence of science and art upon productive industry"

- Bought land in Kensington
- Now award £2m each year
- Nobel laureates:

  John Cockcroft
  Alexander Todd
  Ernest Rutherford
  John Cornforth
  Peter Higgs

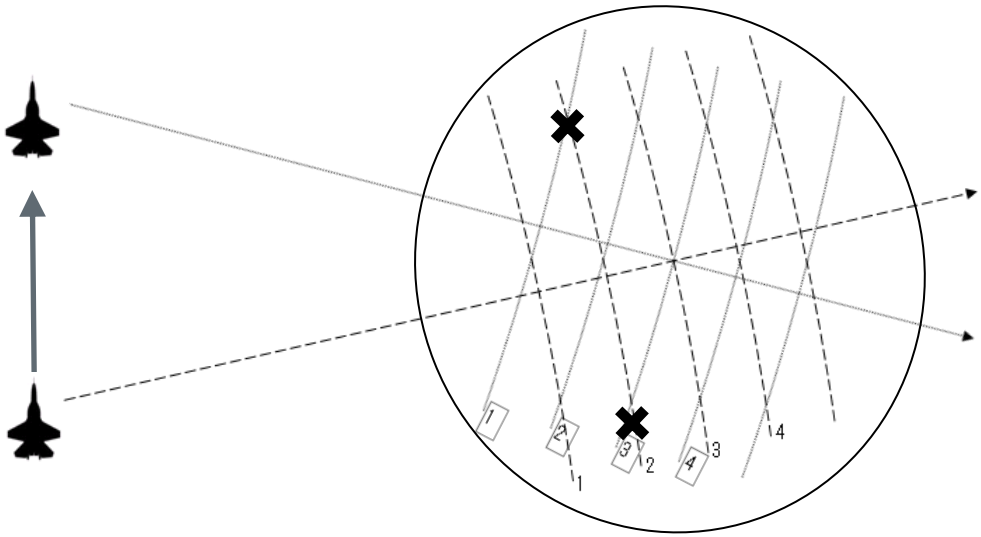
Synthetic Aperture Radar

- Synthesises a huge aperture utilising the aircraft motion
  - Bigger aperture = better azimuth resolution
- Each pulse gives a slightly different range measurement from phase



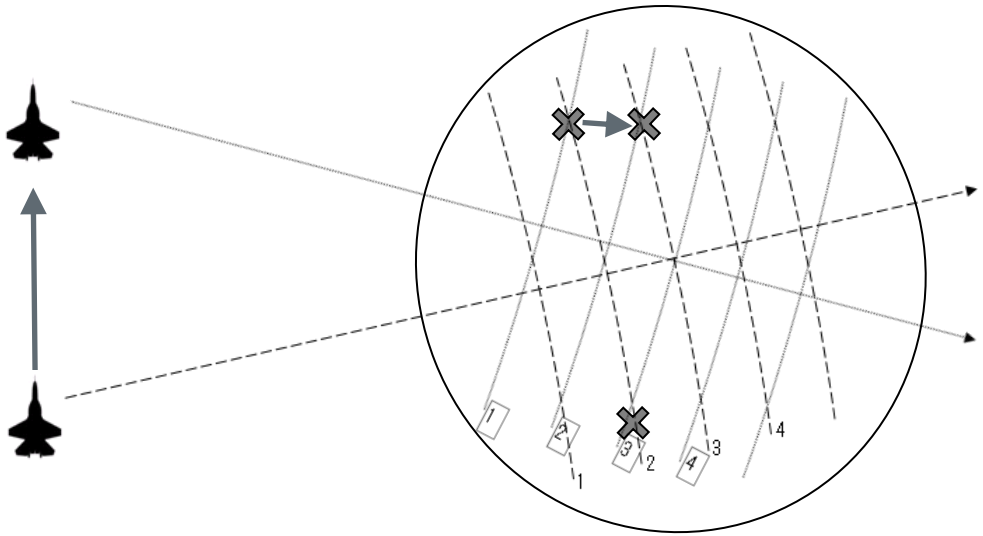
Different phases: wave travelled different distance

- Reflectors further from the scene centre move more between pulses



Moving Targets in SAR

- Moving targets have a different change in distance
- SAR processing images as if everything is stationary



- So moving targets are imaged in the wrong place
- Displacement is proportional to velocity (position from Doppler)
- Varying velocity gives varying displacement (a smear)

- Phase difference between two separate spatial channels gives independent (Doppler-free) measurement of angle

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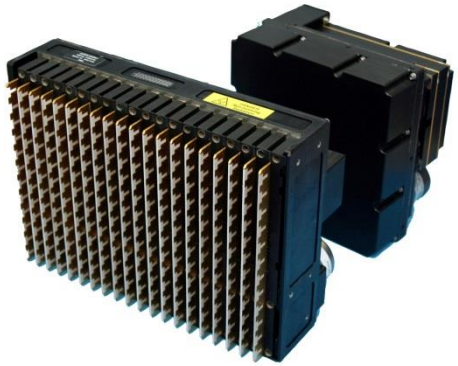
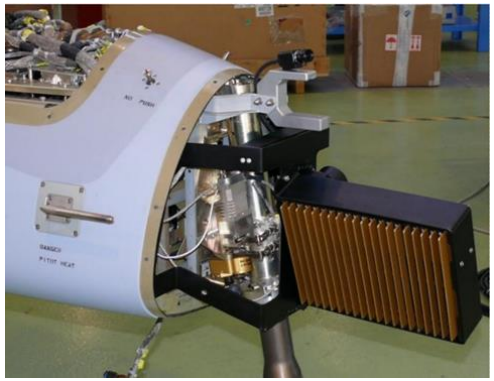
PicoSAR

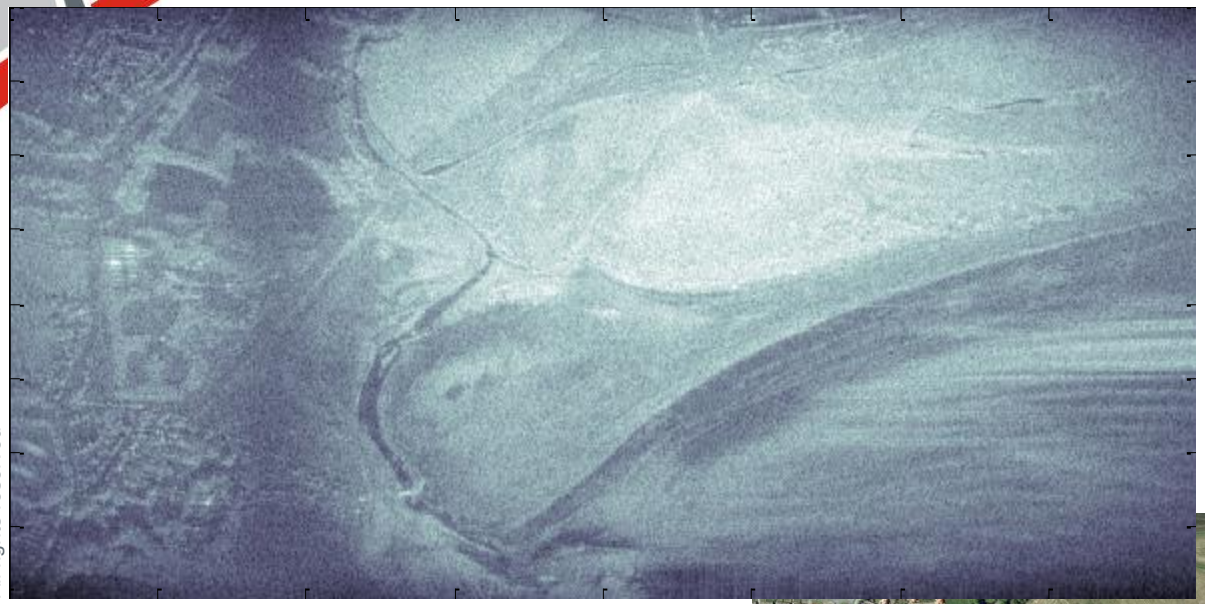
Lightweight, low-cost AESA system





- Low-cost system
- Lightweight at only 10kg
- **Dual-channel** capabilities
- On-board inertial navigation
- On-board image formation
- Data storage

Example Trials Scenario



- PicoSAR mounted on helicopter
- Beach scene
- Walking targets with ground-truth
  - No RCS enhancement
- Varied clutter
  - Sea, sand, grass, buildings
- Matlab processing

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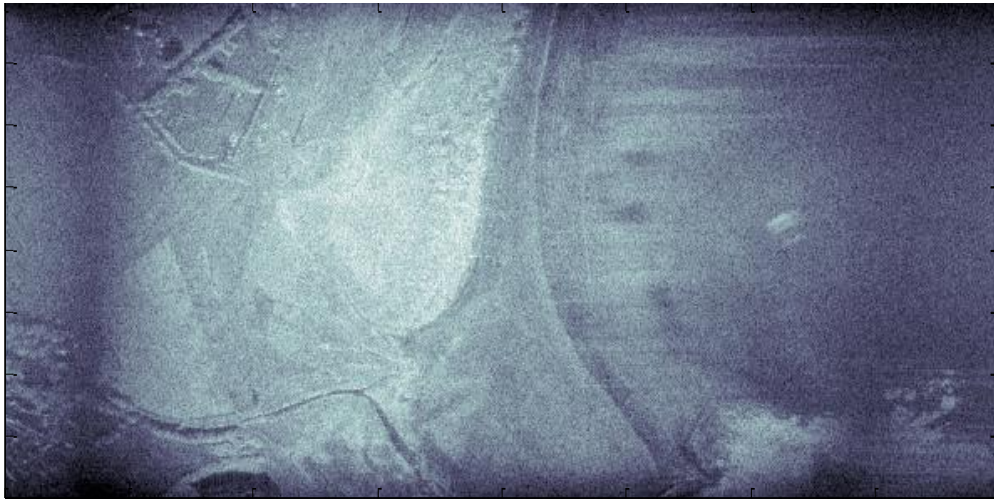
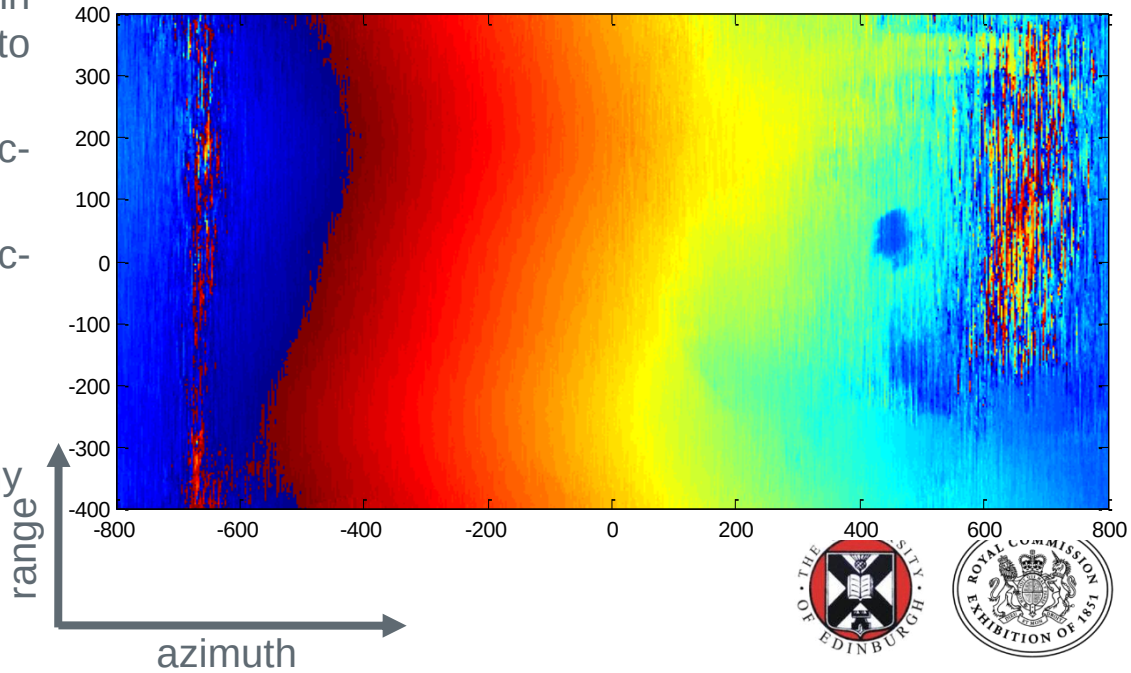
Adaptive Channel Alignment (ACA)

Channel Calibration

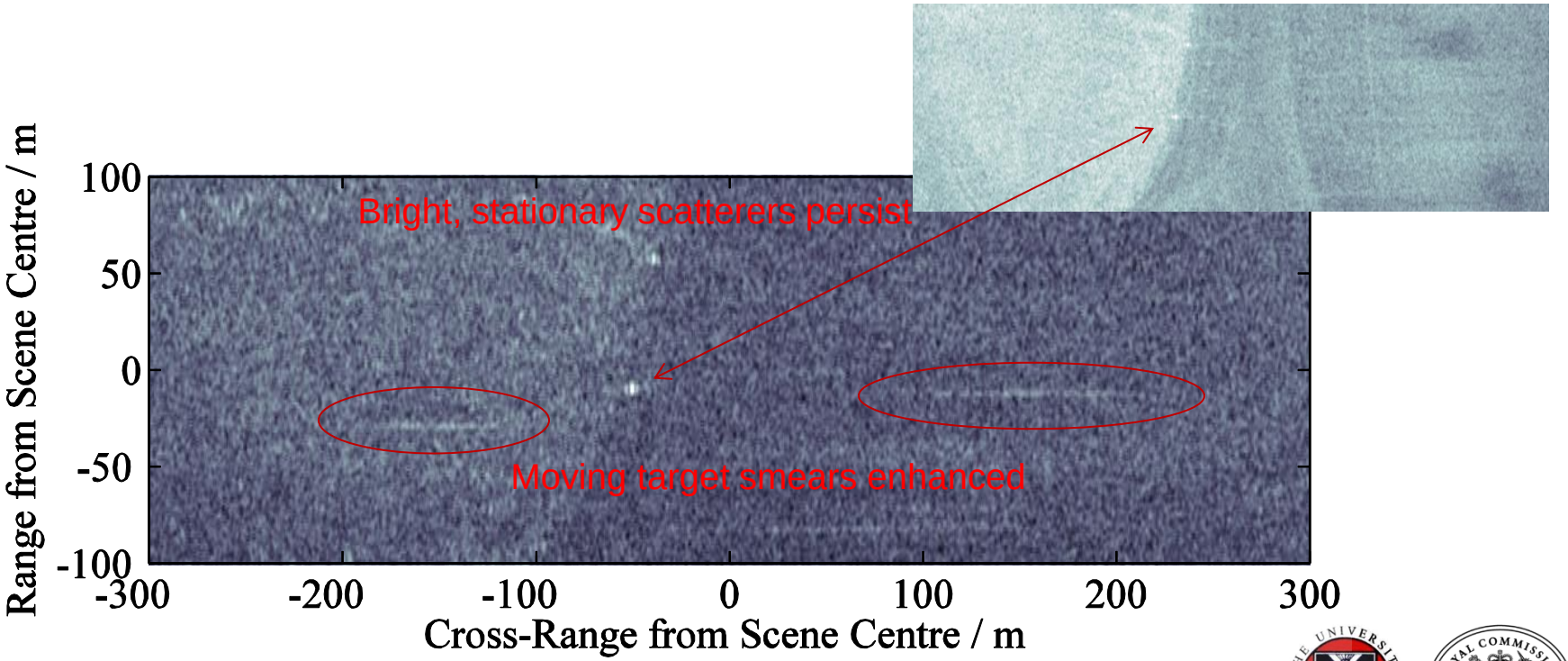
- Channels have to be aligned
- The necessary phase delay can be determined from geometry
  - Needs additional calibration
- OR: adaptively measure delay from images
  - Implicitly handles calibration and many other errors
- Determine correlation in neighbouring range gates to estimate phase difference
  - Smooth variation is included in measurement
  - Sharp variation is not included
- Offset due to mismatch
- Linear variation due to DoA
- Additional pattern from topology





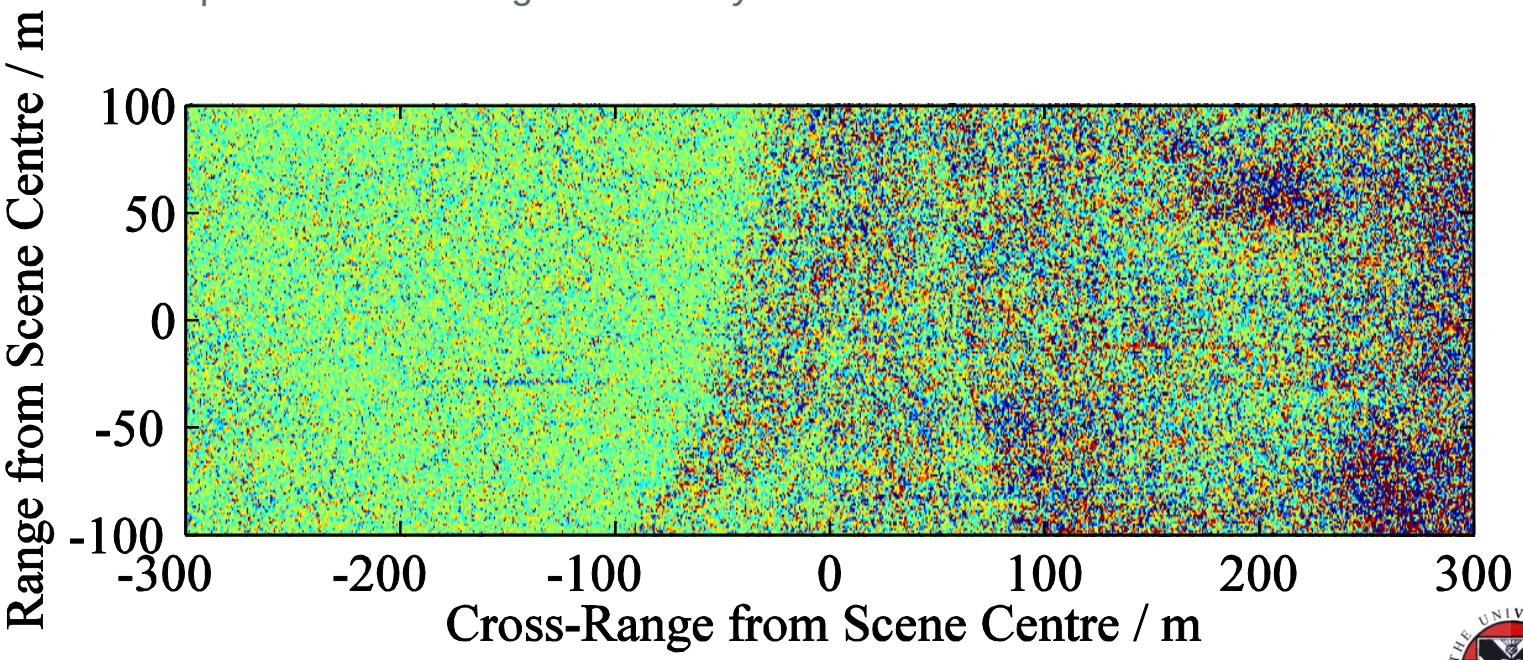
Displaced Phase-Centre Antenna (DPCA)

- Subtracts channels
- Traditionally: Arrange PRF so that trailing antenna mimics position of the lead antenna on the previous pulse
- Or: Phase delay can be introduced to remove the hardware constraint
- ACA far superior to derivation of delay from geometry



Along-Track Interferometry (ATI)

- Calculates the phase difference between two aligned channels through conjugate multiplication
- Phase difference gives true azimuth position from which velocity can be derived
  - Although this can be corrupted by coincident clutter
- Improved by ACA
- Poor performance in dark areas due to dominance of phase noise
- No problems from bright stationary scatterers



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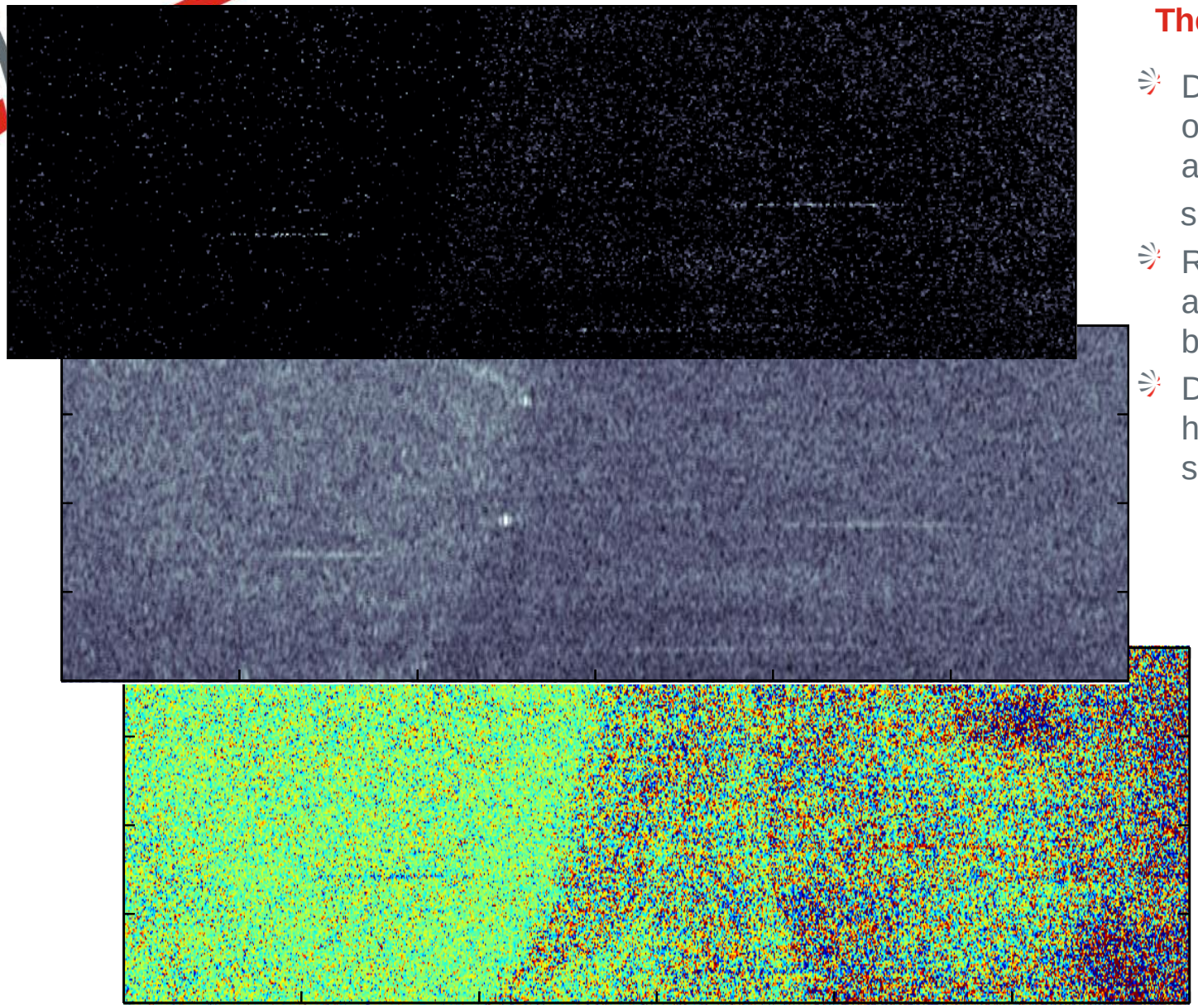
Hybrid DPCA/ATI Combination

The Perfect Blend



- DPCA and ATI have opposing strengths and weaknesses:

  so combine them.
- Resulting smears are very distinct over background
- Detection algorithms have proved to be successful

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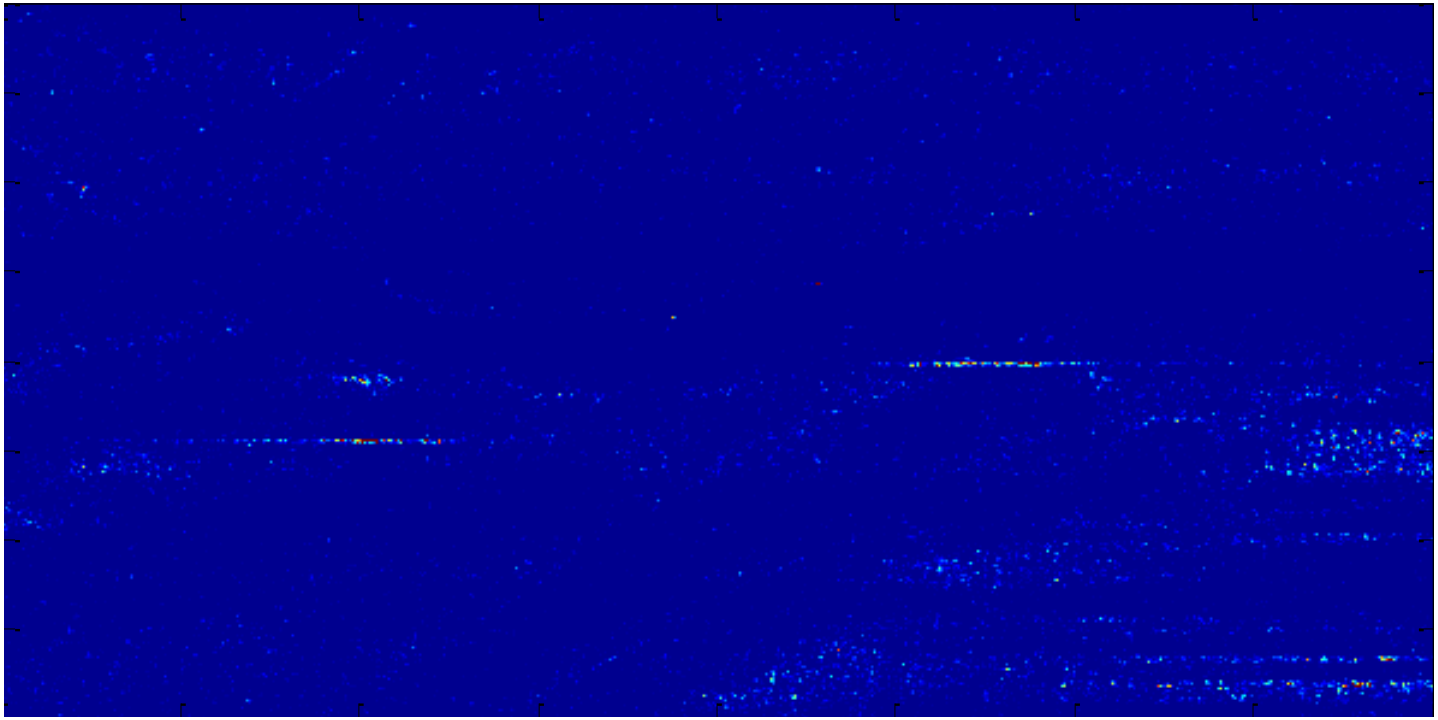
Post-Doppler STAP

Coastal trial after clutter removal

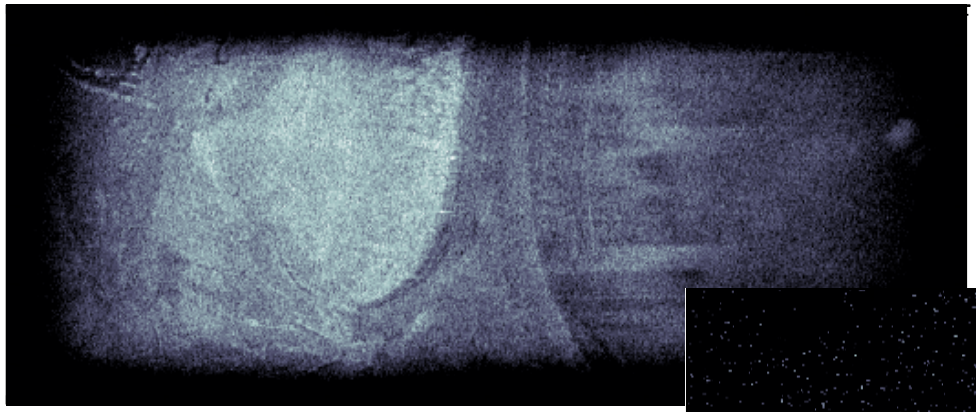
- Post-Doppler STAP offers slight improvement against hybrid DPCA/ATI
  - Far greater computational cost
  - More susceptible to clutter statistical variations
- Research aware of practical limitations within industry

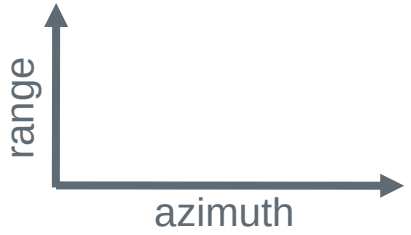


Coastal helicopter trial

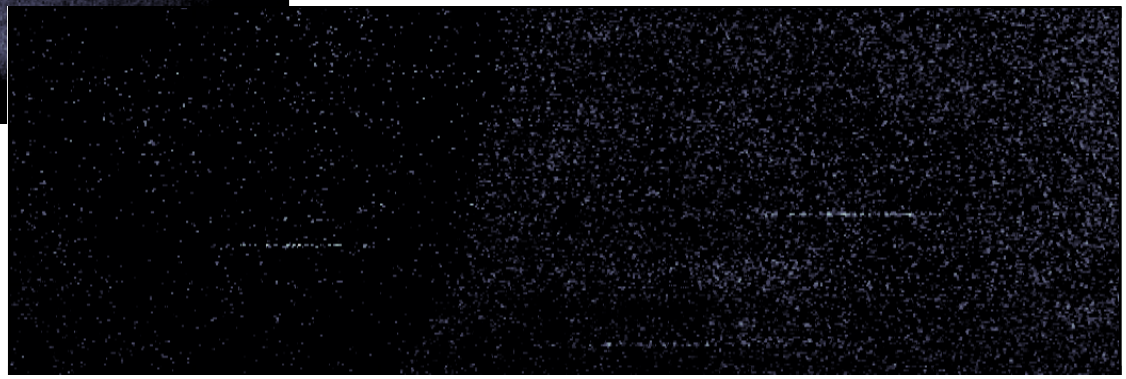
PD-STAP Clutter Suppression and Hybrid DPCA/ATI Comparison

Original Image

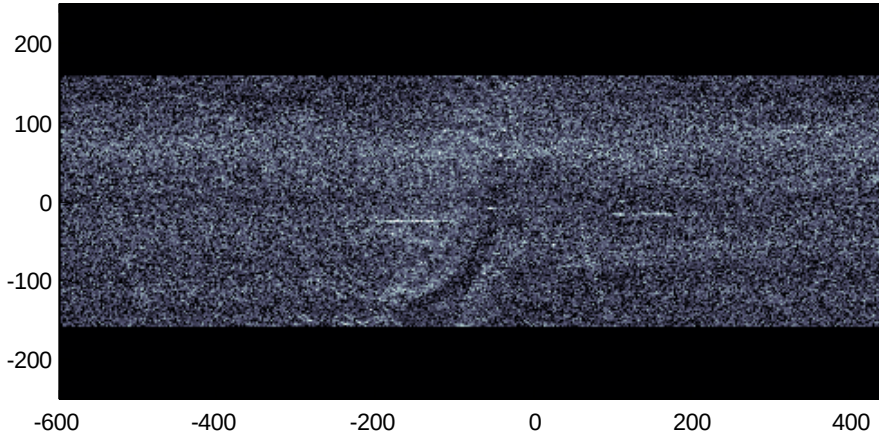




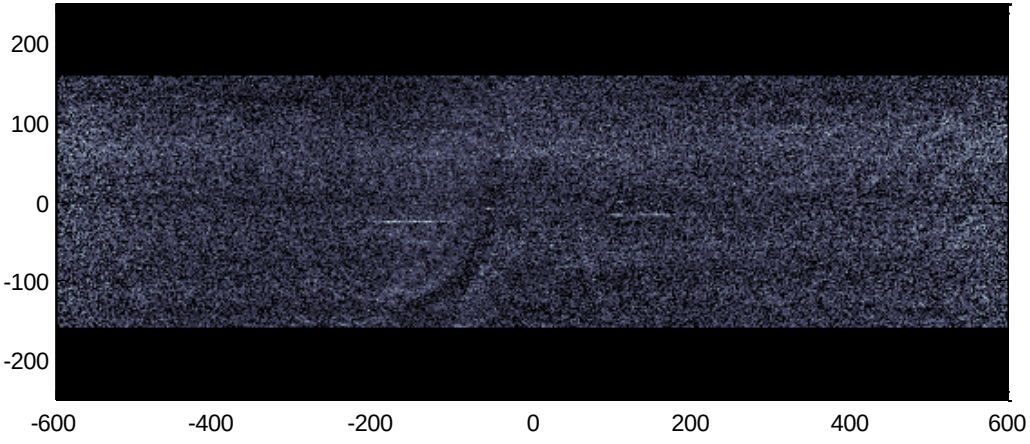
Hybrid DPCA/ATI



STAP Suppression



STAP Suppression weighted by Original Intensity



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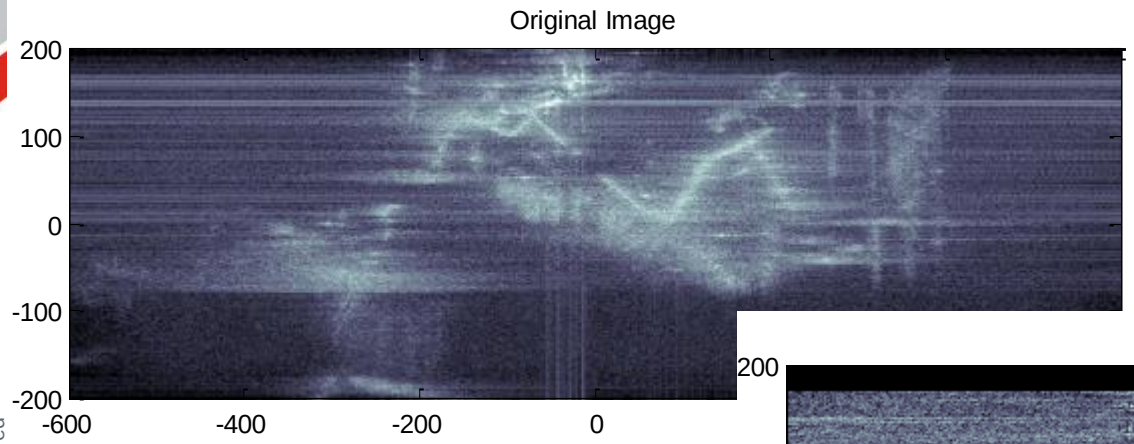
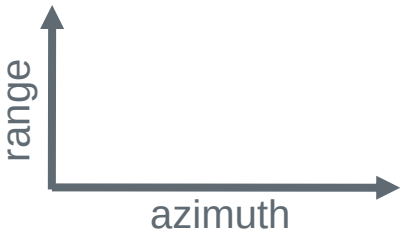
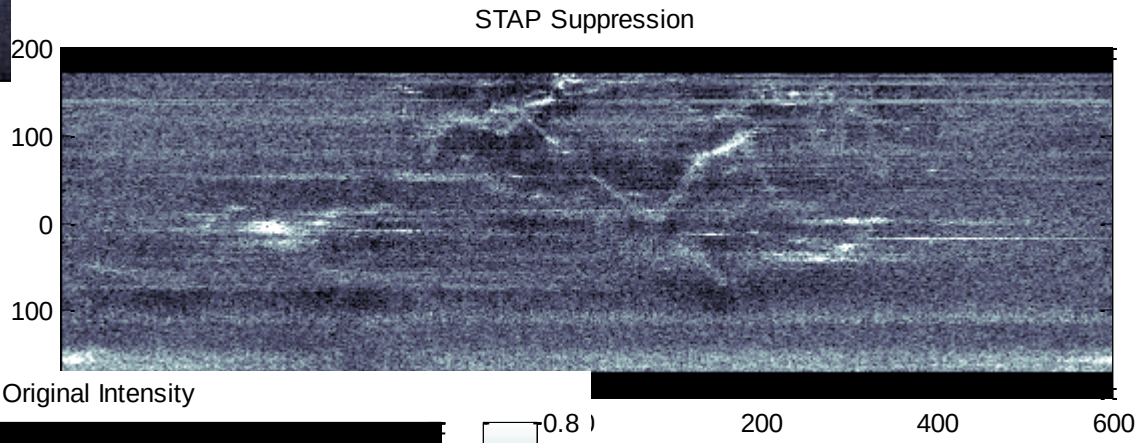
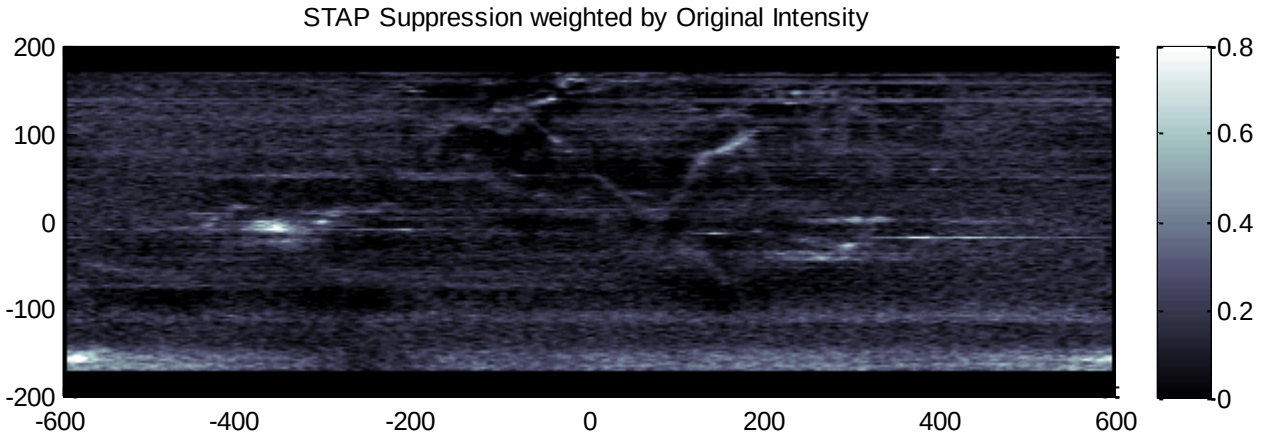
PicoSAR in a Van

PD-STAP Clutter Removal on Farm Trial



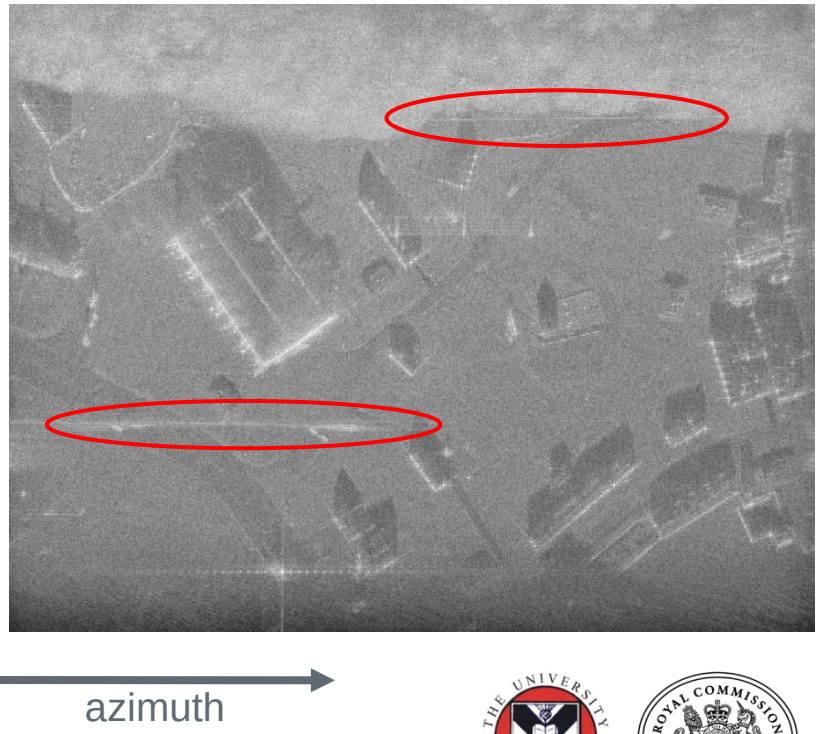






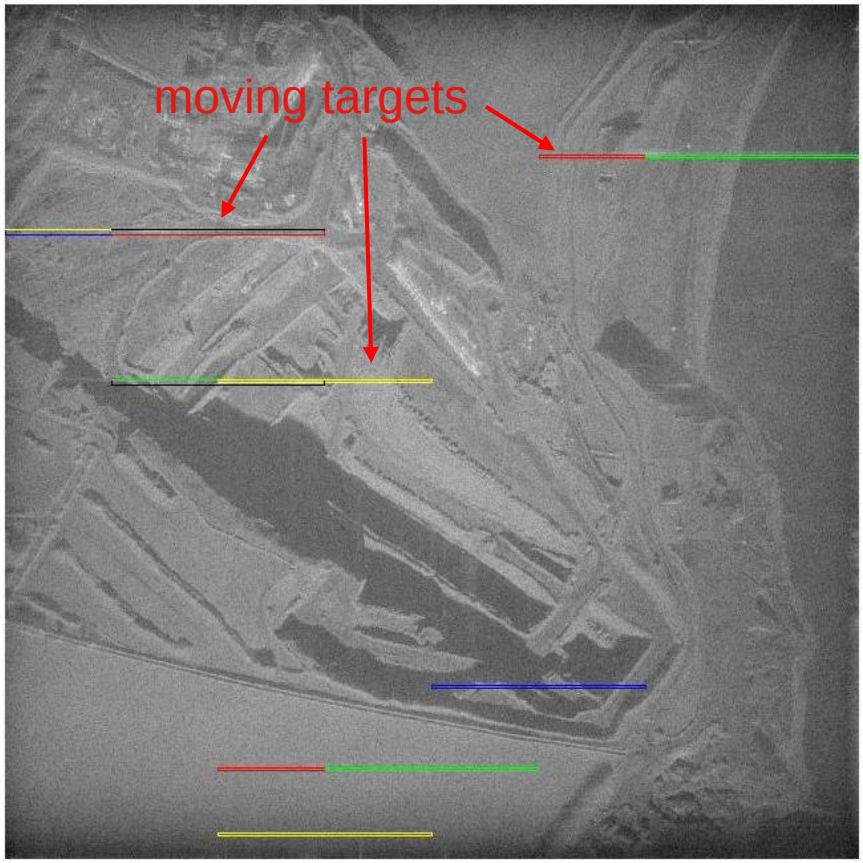
MTI by Focusing

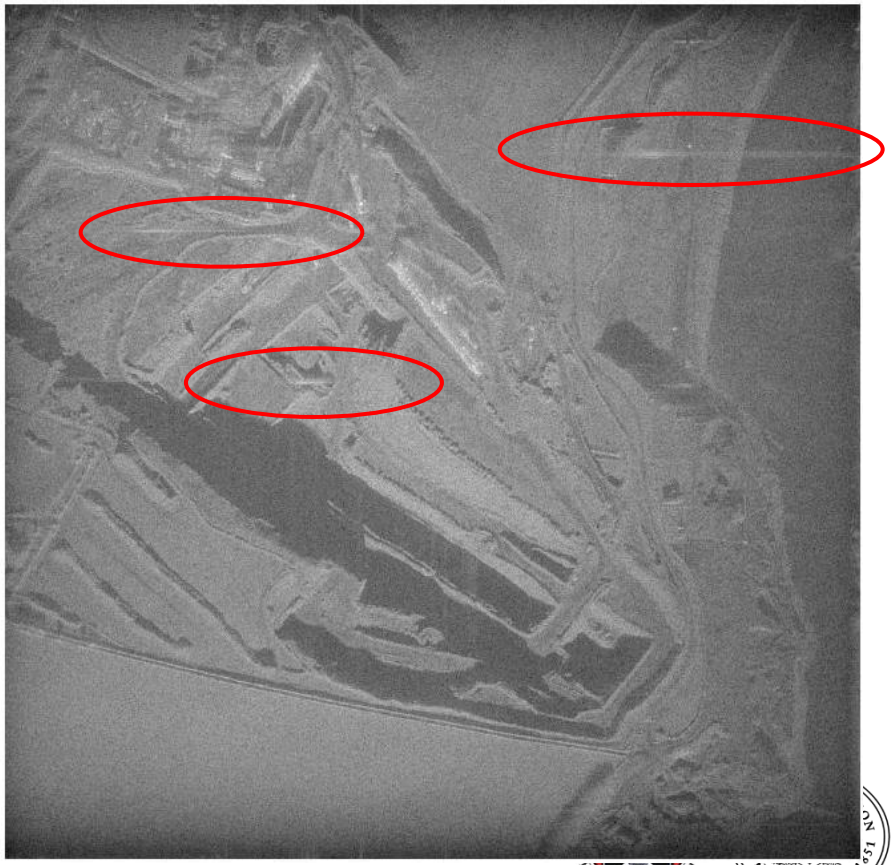
- Utilises autofocus which is currently used in PicoSAR
  - Applies the same correction to the entire image; correcting errors that are constant across the entire scene from unknown platform motion
  - Autofocus does not focus anomalous phase errors arising from moving targets
- This SAR-MTI method is post-processing
  - Easier to add to existing systems
- Splits the image into patches
  - Patches are narrow in range, long is azimuth to match expected smear
- Autofocus is then applied to each patch in turn
- Those patches which show an improvement in sharpness after PGA contain a moving target
  - Static patches will have been focused by the global PGA and will show limited improvement



Results – Quarry

- Good detection
  - Patches with moving targets identified in coloured boxes in left image
- Very large, bright moving targets



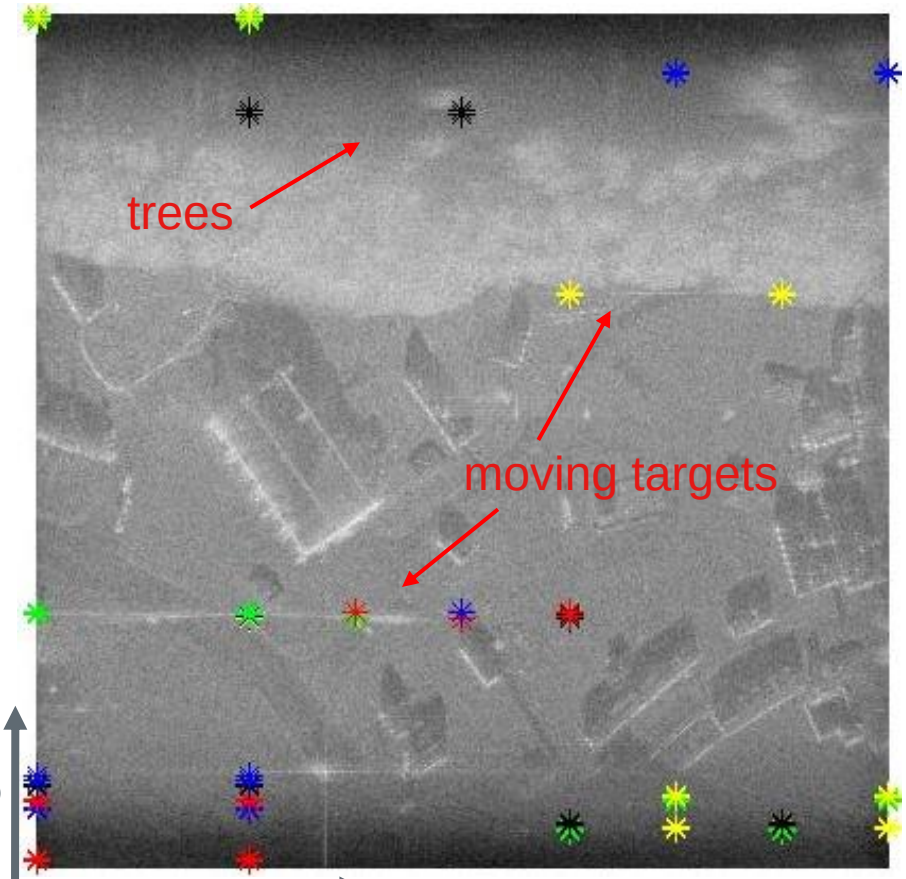


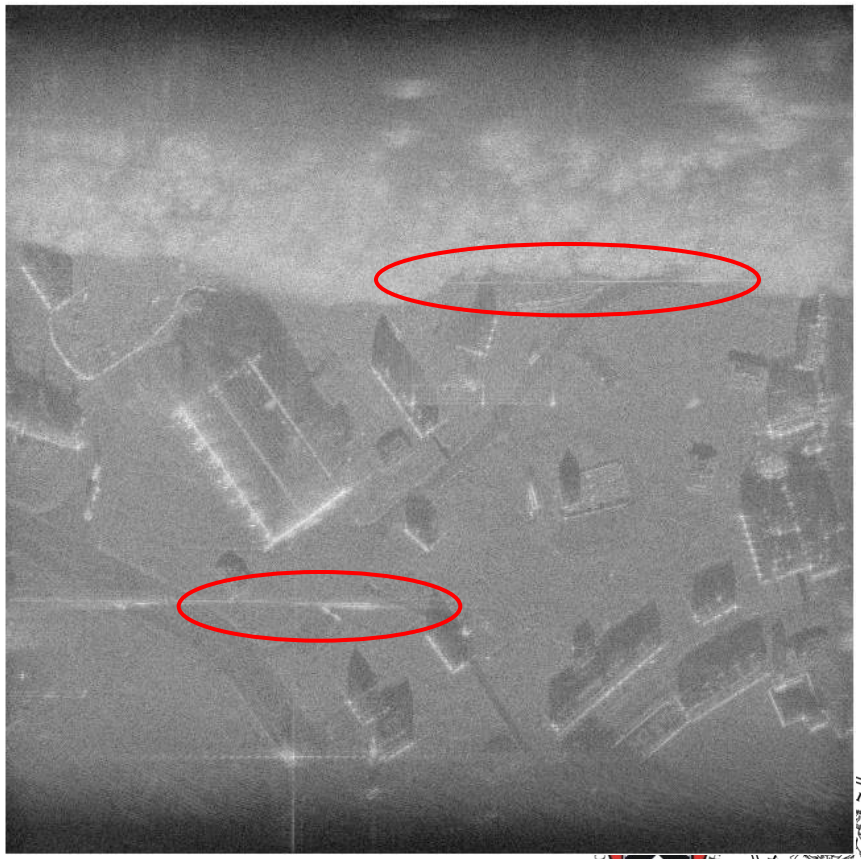
range

azimuth

Results - Airfield

- Targets seemingly identified but high number of suspected false alarms

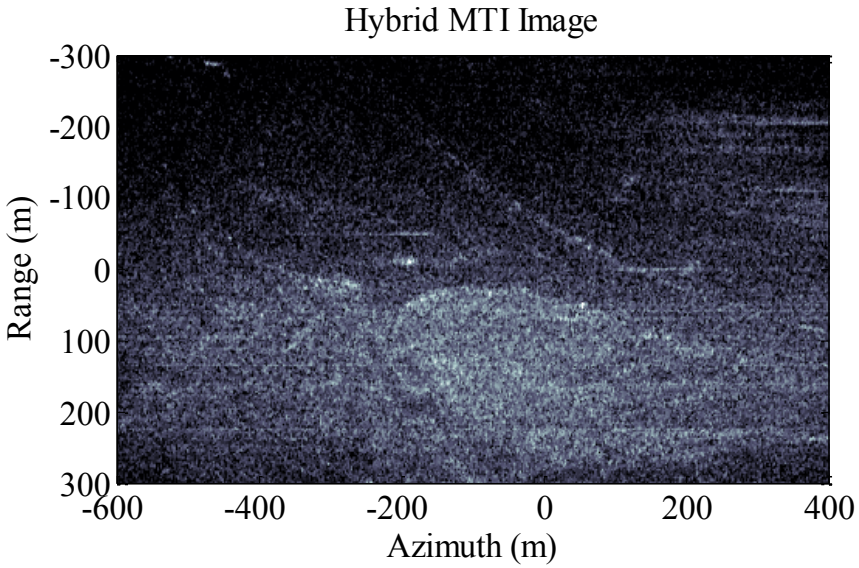


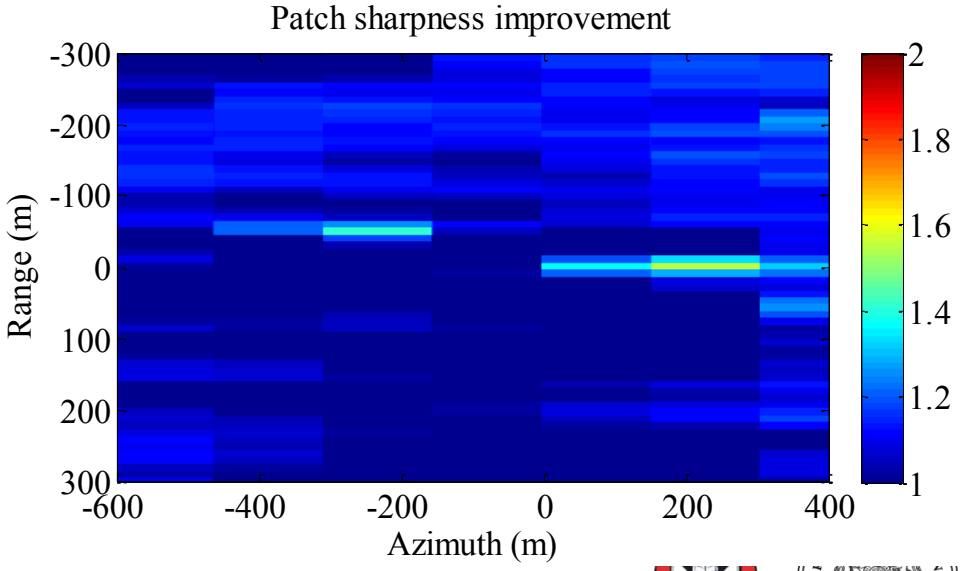


Current Limitations

- Many false alarms due to crude thresholding of sharpness improvement
  - Phase error not always from moving objects of interest, eg. foliage (exclude clusters of patches?)
- Moving targets have to be in image to be detected
  - Will not detect fast moving targets outwith background Doppler-spread
  - Will not detect targets buried under strong clutter

- Excellent detector after clutter suppression





Close

- Engineering Doctorate
  - Bernie Mulgrew at The University of Edinburgh
  - David Greig at Selex ES
- Industrial involvement in academia
- Academic involvement in industry
- Detecting moving targets in SAR images by enhancing traditional techniques
  - DPCA
  - ATI
  - Hybrid combination
  - STAP
  - MTI by patch-specific focusing
- Research facilitated throughout with Selex ES data

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