Spectral coherence applied to vessel tracking

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Wide-band potential

- Recent sensors use wide band signals to achieve metric resolution along slant range.

  ➪ ERS / EnviSAT:

  ✓15MHz —> ~10 m nominal slant range resolution

  ➪ TerraSAR-X / CosmoSkyMed:

  ✓150MHz —> ~1 m nominal slant range resolution

- Wide band can be split into sub-bands to perform spectral analysis.

Split-band processing

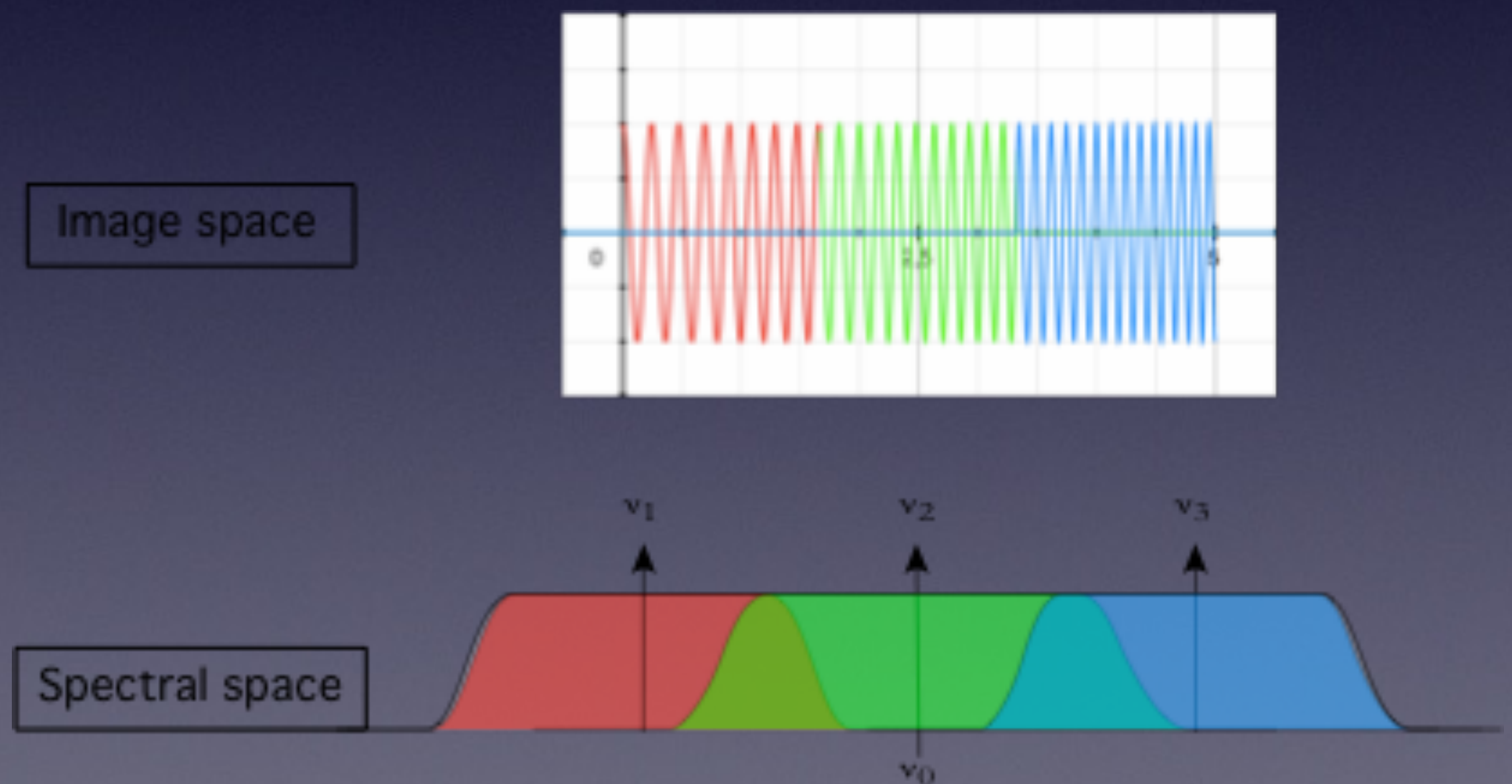
- Split-band processing also known as Multi-Chromatic Analysis (MCA) consist in taking advantage of the spectral diversity offered by wide band SAR sensors to perform a spectral analysis of the observed signal.

- From a single acquisition, one can generate several images of lower resolution centered on slightly different carrier frequency.

Split-band processing

- Three ways to explain split-band processing

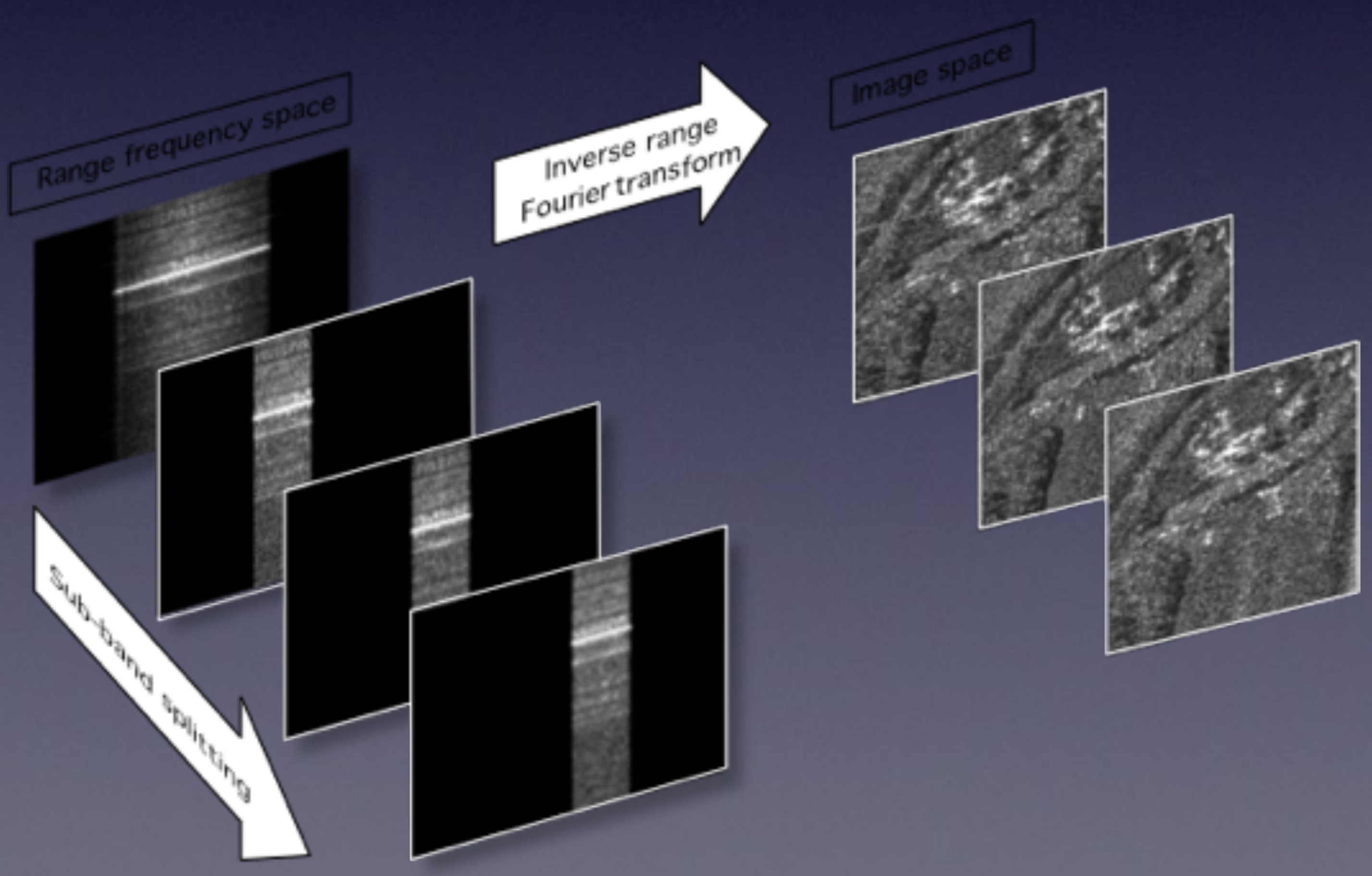
➪ Sensor point of view:



Split-band processing

- Three ways to explain split-band processing

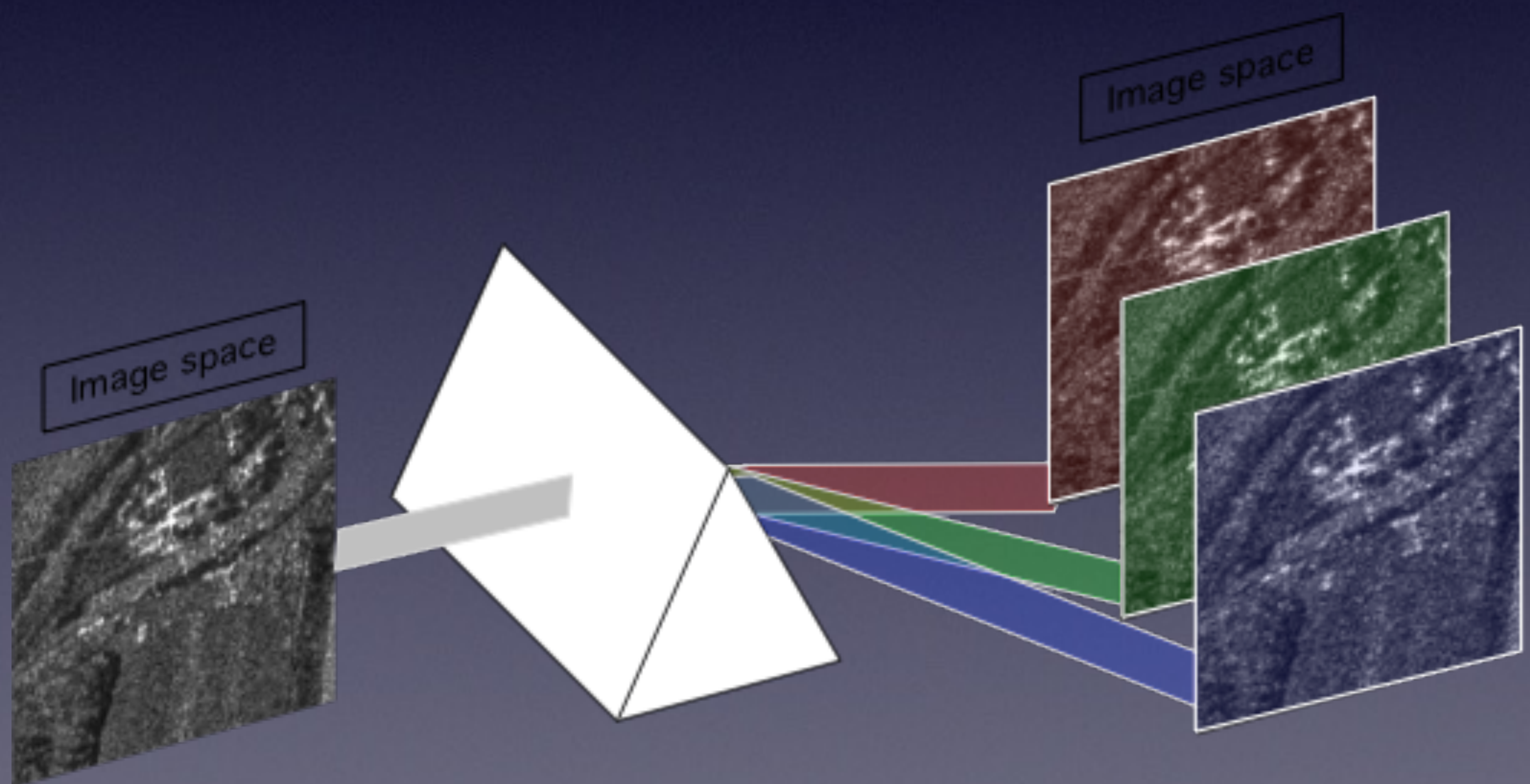
➪ Signal processing point of view:



Split-band processing

- Three ways to explain split-band processing

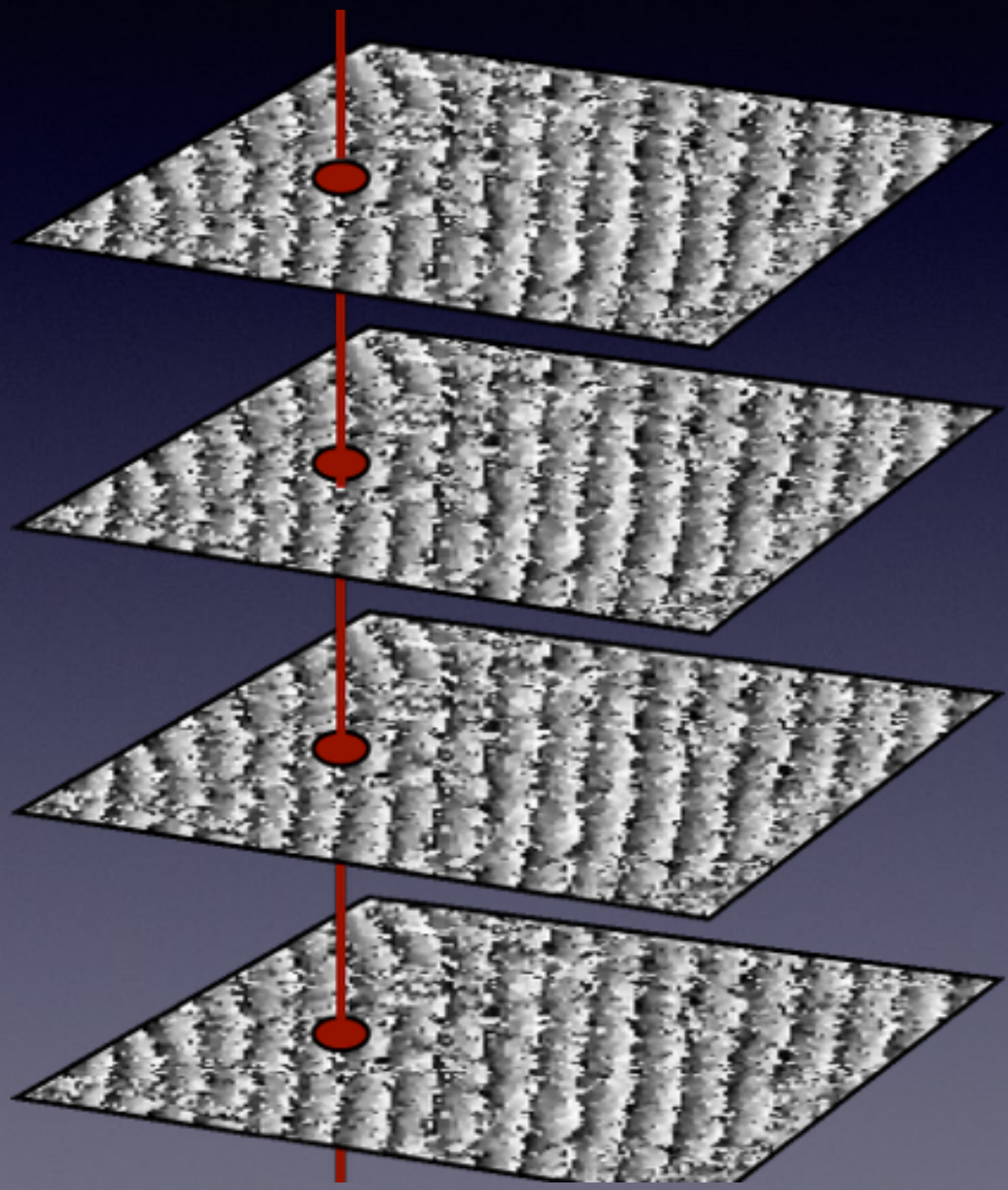
➪ Optical point of view:



SBInSAR

- Split-Band SAR Interferometry (SBInSAR) uses this splitting principle to generate, from a single interferometric pair, several interferograms, each characterized by a slightly different wavelength.

- This lead to a linear phase variation at any point across sub-interferograms

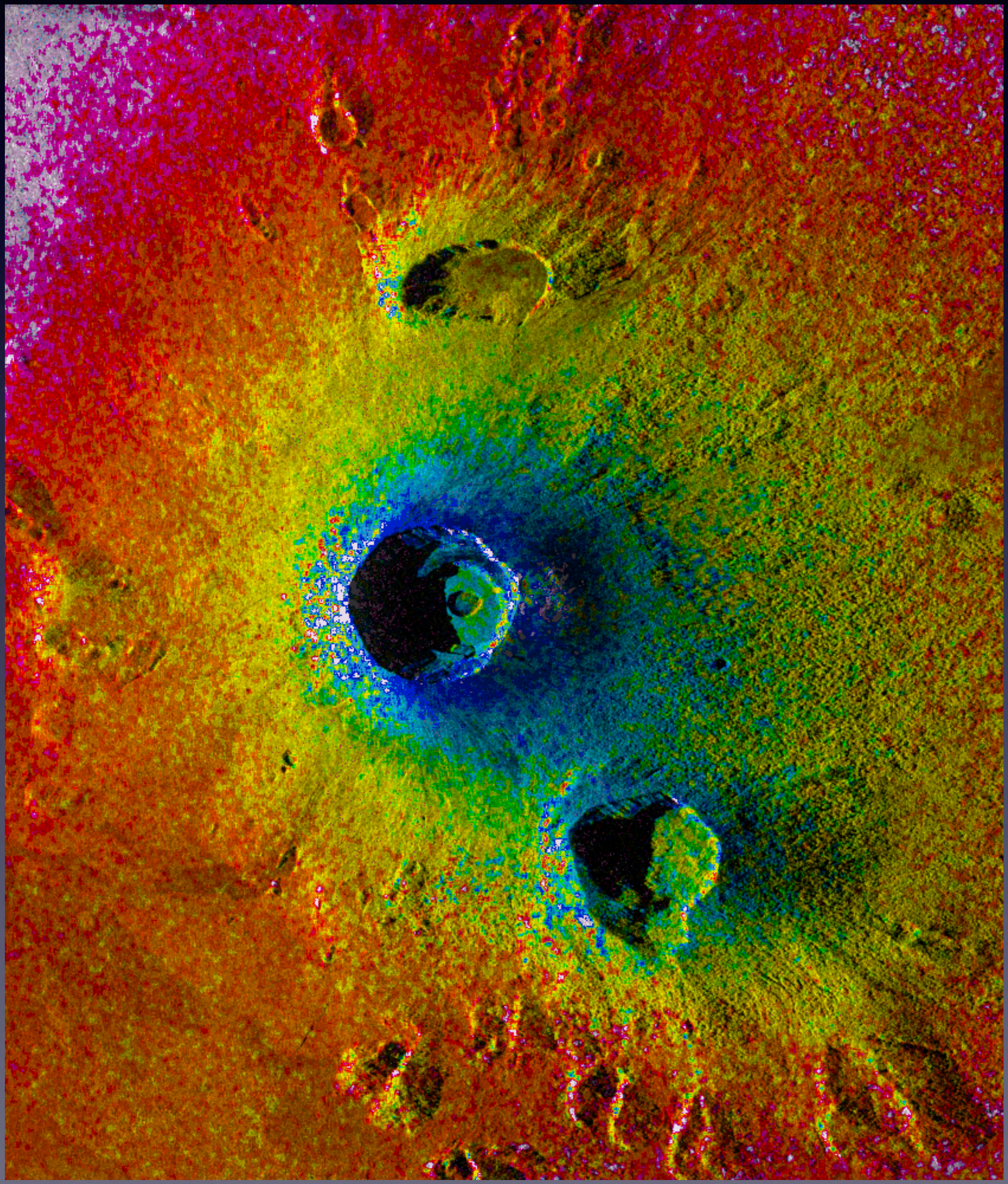


SBInSAR

- Measured linear phase trend is proportional to the absolute phase.

➪ Point-wise phase unwrapping

➪ Example: Nyiragongo crater (TanDEM-X InSAR pair)

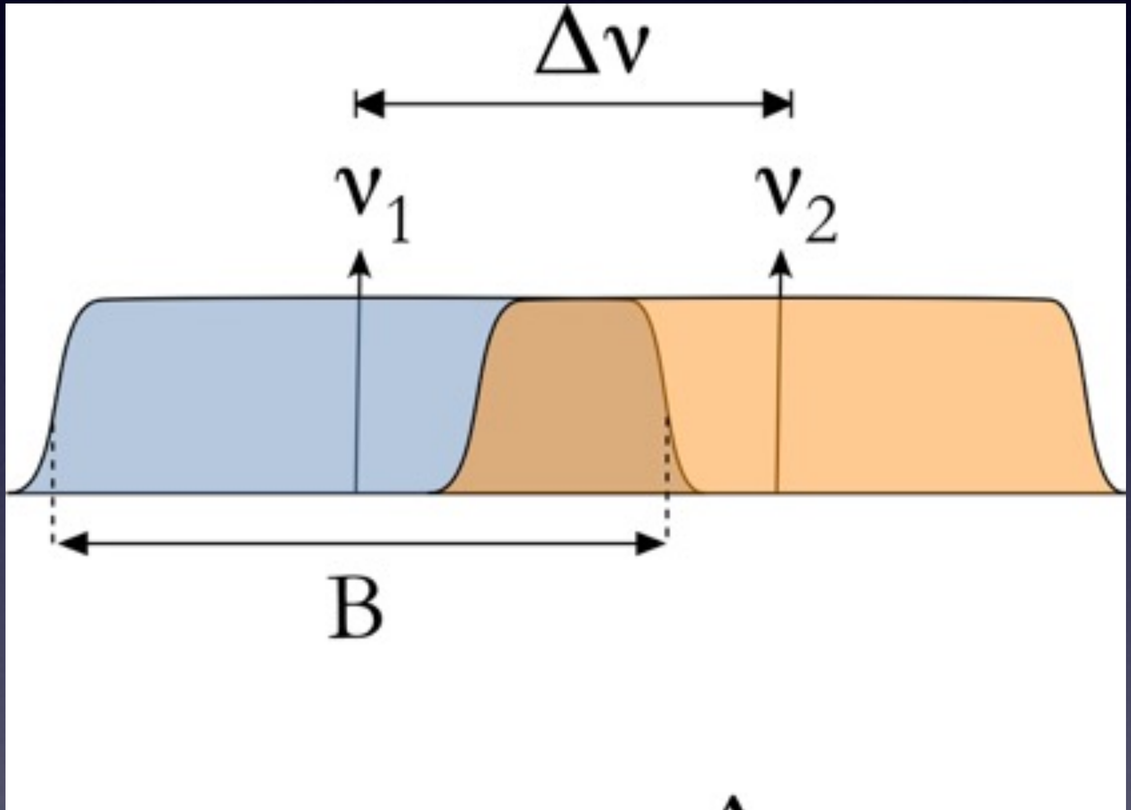


Spectral coherence

- Interferometric coherence between sub-images issued from a single acquisition can be measured.

- For random distribution of surface scatterers, coherence between sub-bands is equal to common sub-band proportion.

  ➪ If sub-bands have no common parts, spectral coherence is null.



$$\gamma = 1 - \frac{\Delta\nu}{B}$$

Spectral coherence applied to vessel tracking

- Hypothesis: Open sea surface can be considered as randomly distributed surface scatterers

- Target that departs from this distribution may preserve a high spectral coherence level

➪ Spectral coherence will be almost totally lost on the sea clutter while it will be preserved on man-made structures.

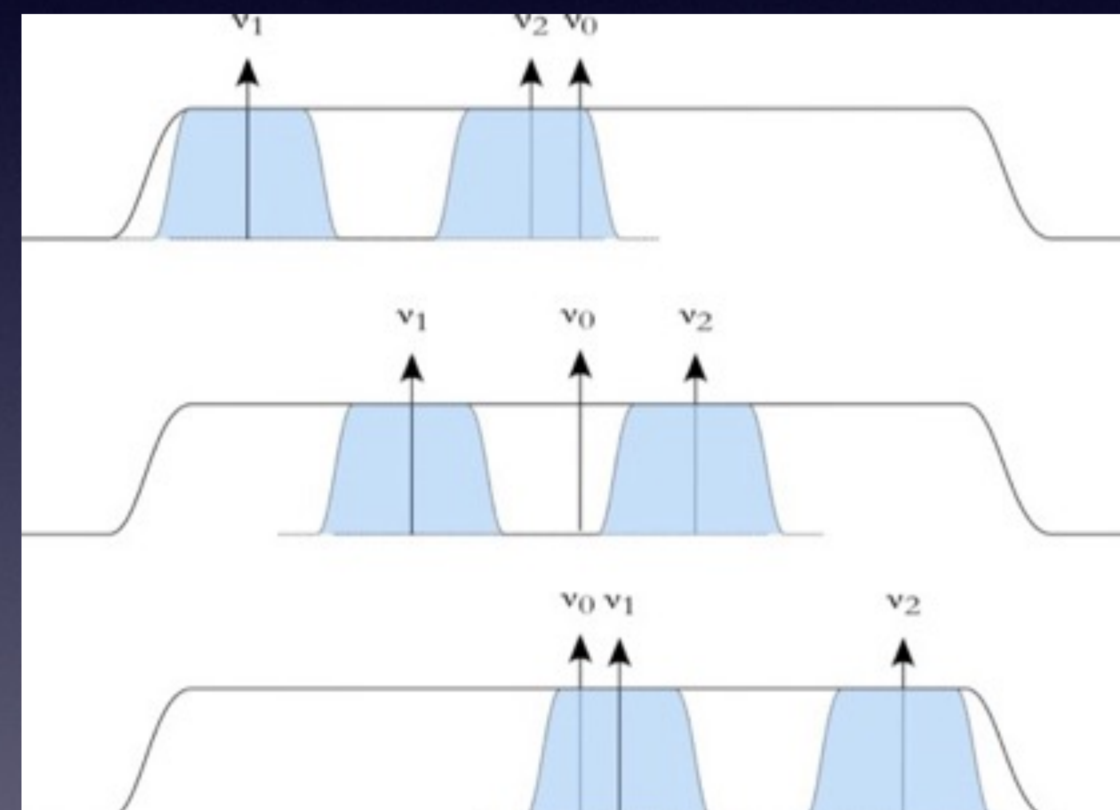
➪ Spectral coherence can efficiently be used in a prescreening process for vessel detection.

Spectral coherence applied to vessel tracking

- Spectral coherence measurement consist in measuring coherence between sub-looks at constant gap

- We are looking for spectrally stable targets on sea clutter.

  ➪ Measurements are averaged to increase signal to noise ratio



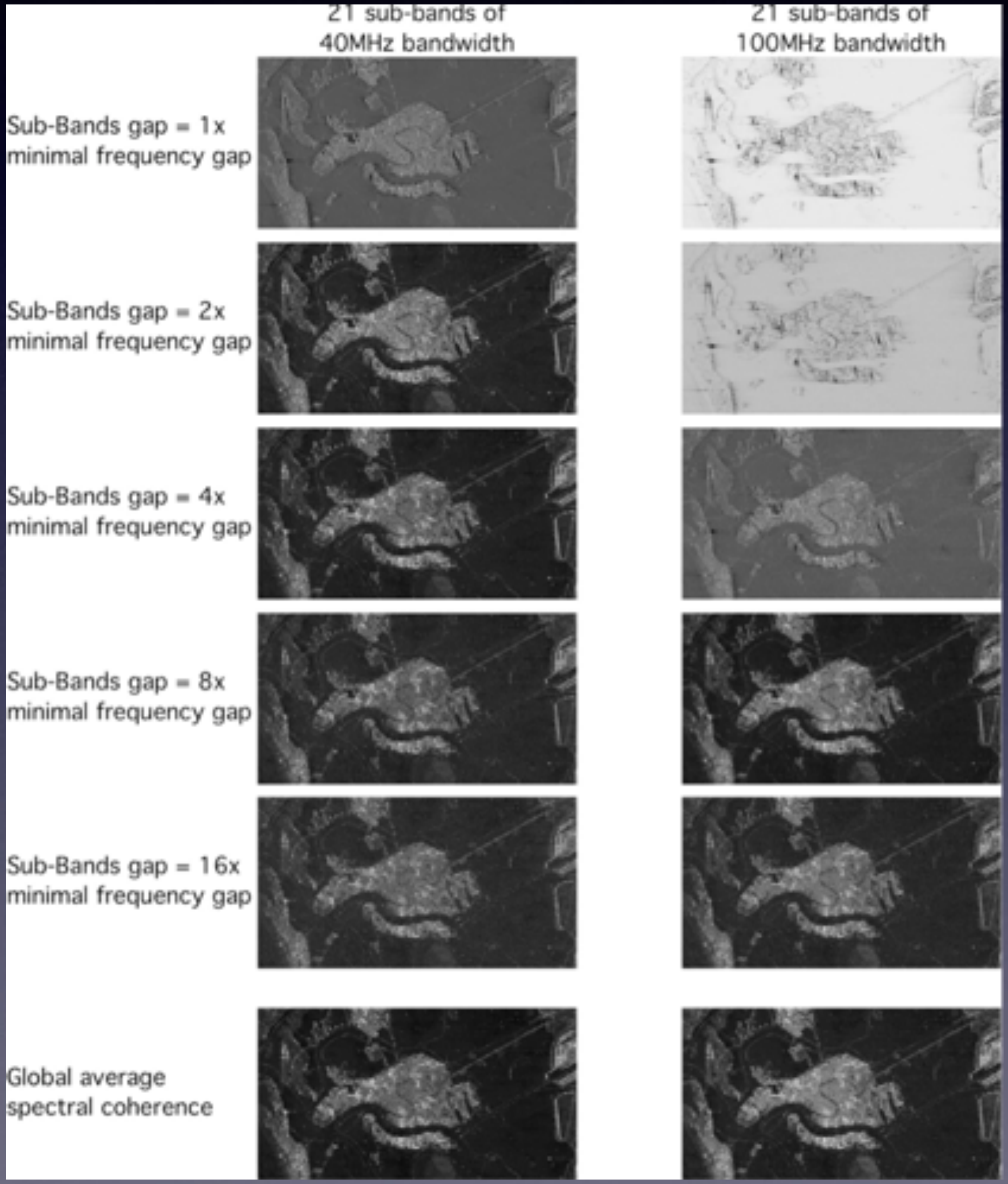
Test site

➪ Spectral coherence measurements where performed on four TSX spotlight acquisitions of the Venice Laguna:

✓ March 14, April 16 and 27 and May 08, 2009

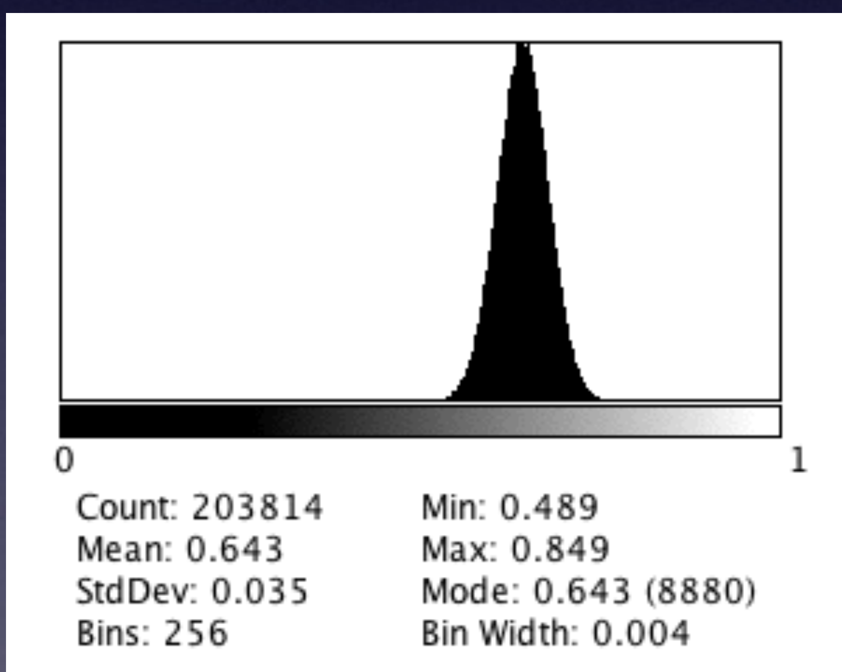
Used splitting scheme

- 21 sub-bands of 40MHz bandwidth:
  - ➪ Explored bandwidth = 260MHz
  - ➪ Minimal frequency gap = 12.3 MHz
- 21 sub-bands of 100MHz bandwidth
  - ➪ Explored bandwidth = 200MHz
  - ➪ Minimal frequency gap = 9.5 MHz

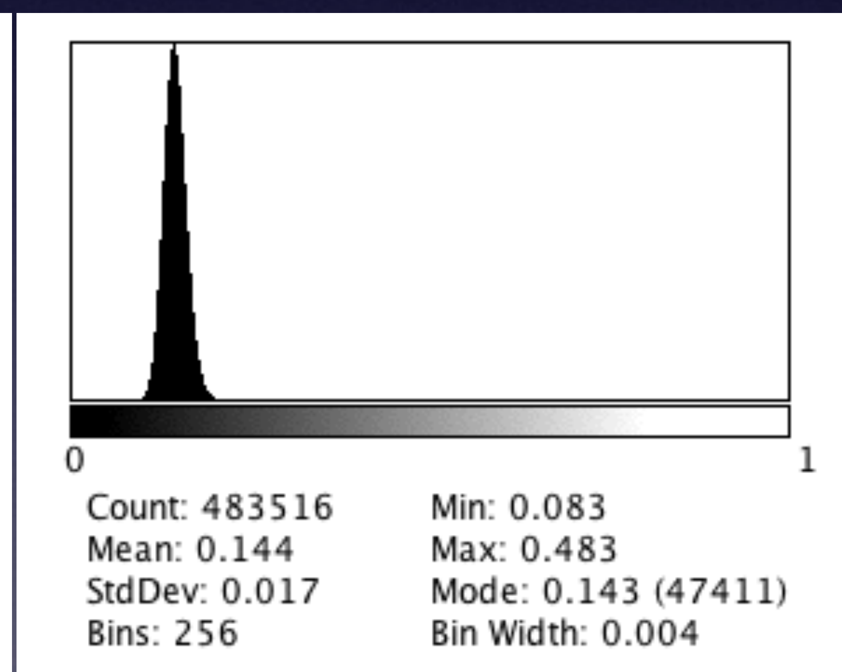


Spectral coherence applied to vessel tracking

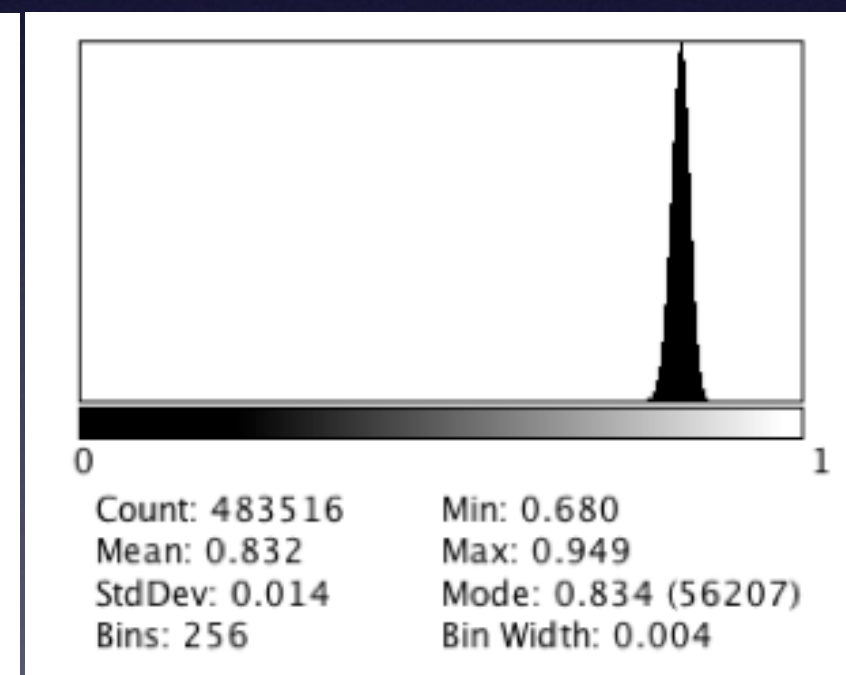
- Spectral coherence model is verified on sea clutter:



40MHz sub-band bandwidth
68% sub-bands overlapping

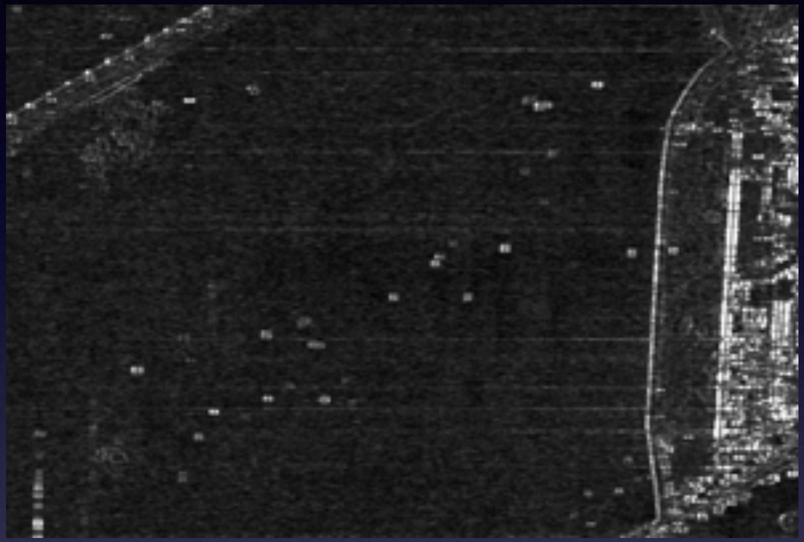


40MHz sub-band bandwidth
0% sub-bands overlapping

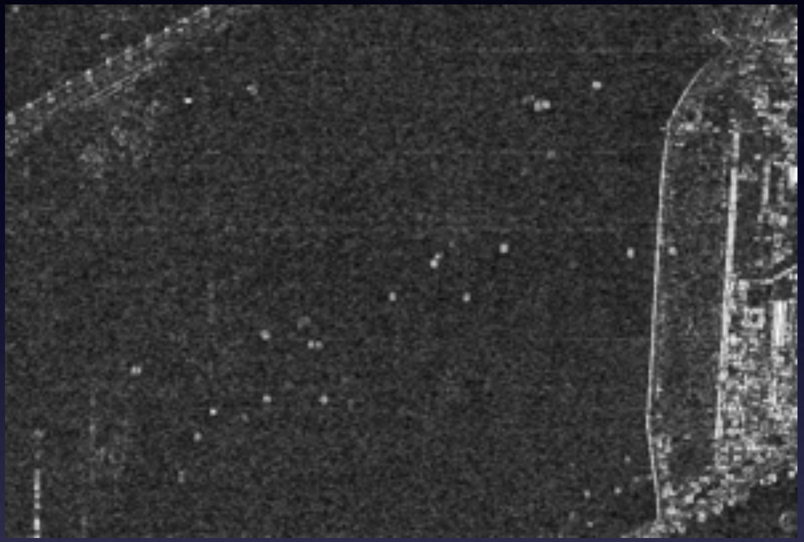


100MHz sub-band bandwidth
82% sub-bands overlapping

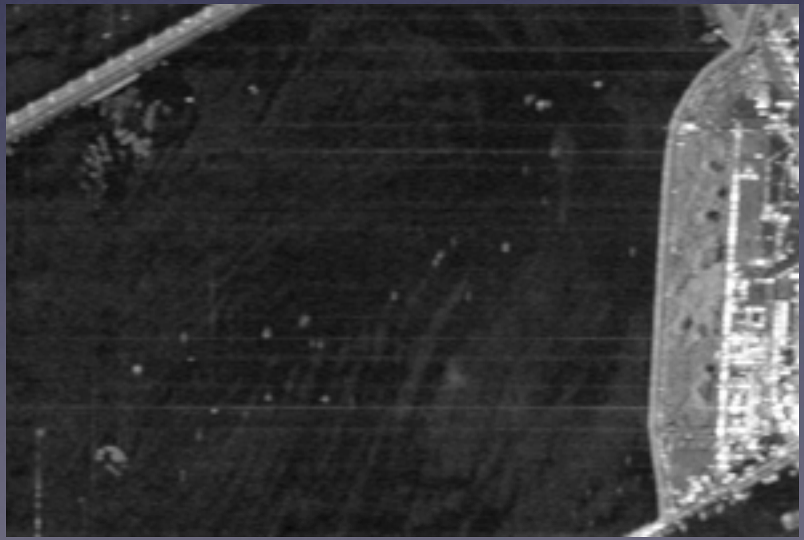
Spectral coherence applied to vessel tracking



Spectral coherence average
40MHz sub-band bandwidth



Spectral coherence average
100MHz sub-band bandwidth



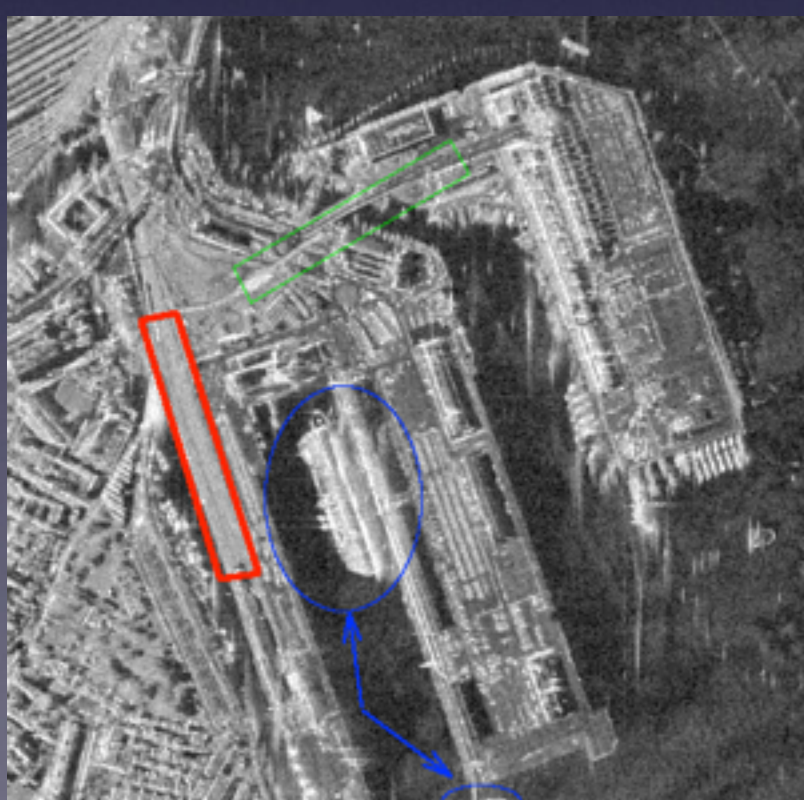
Intensity image

Spectral coherence applied to vessel tracking

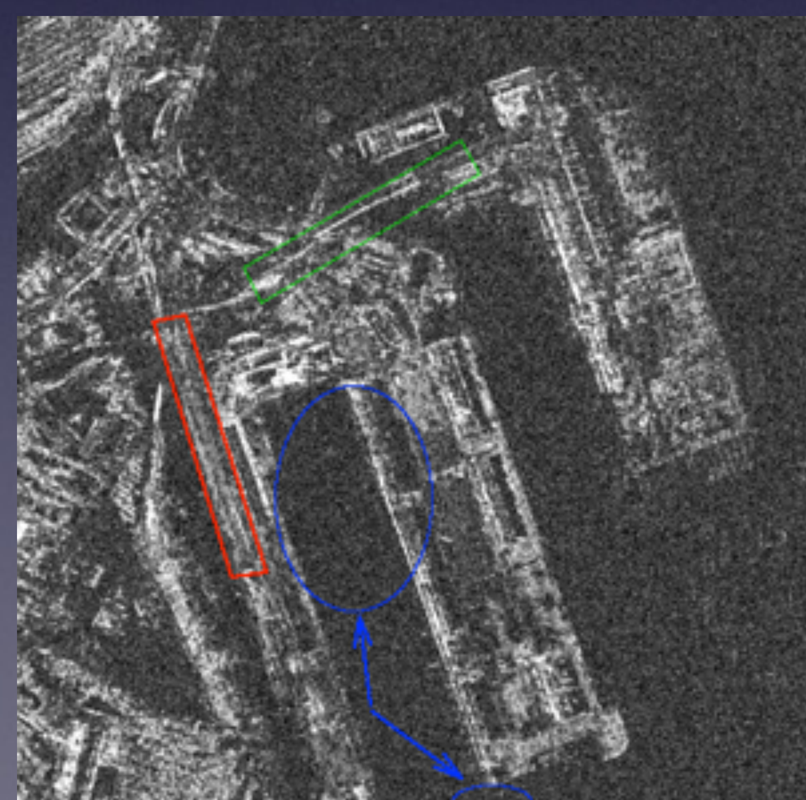
- Observations:
  - ➪ 40MHz sub-band bandwidth spectral coherence average is better contrasted du to the fact that the average contains more uncorrelated (non-overlapping) components.
  - ➪ Most targets visible in the intensity image are visible in the spectral coherence image with different contrasts
  - ➪ Sea surface currents visible in the intensity image are completely wiped out in the spectral coherence image

Spectral coherence versus temporal coherence

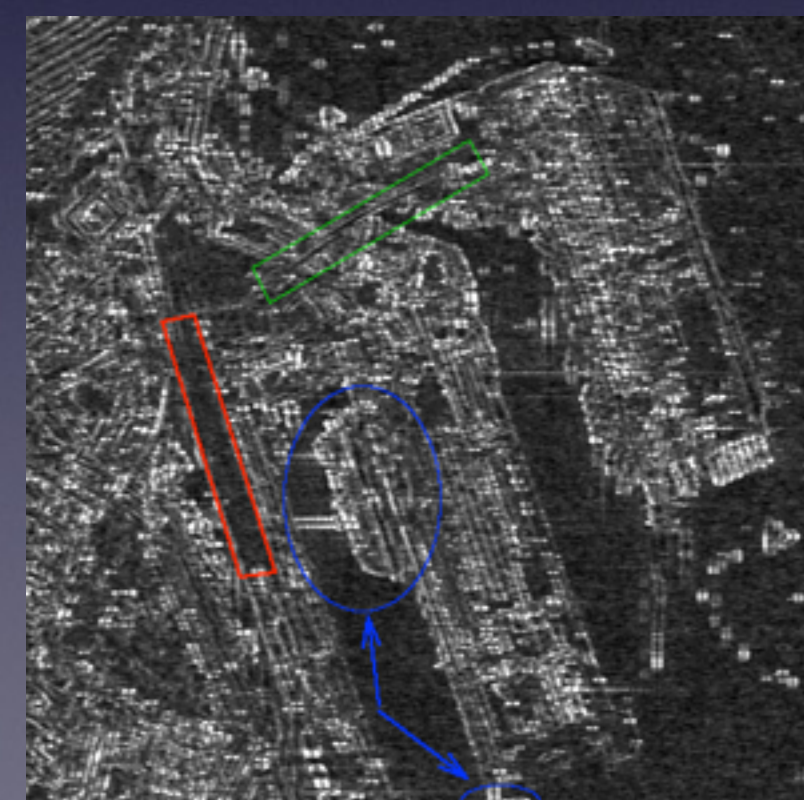
- Spectrally stable scatterers seem to be also temporally stable. However:
  - ➪ Some spectrally stable scatterers disappear in temporal coherence
  - ➪ Some temporally stable scatterers lose spectral coherence
- Spectral and temporal coherence are complementary channels



Intensity



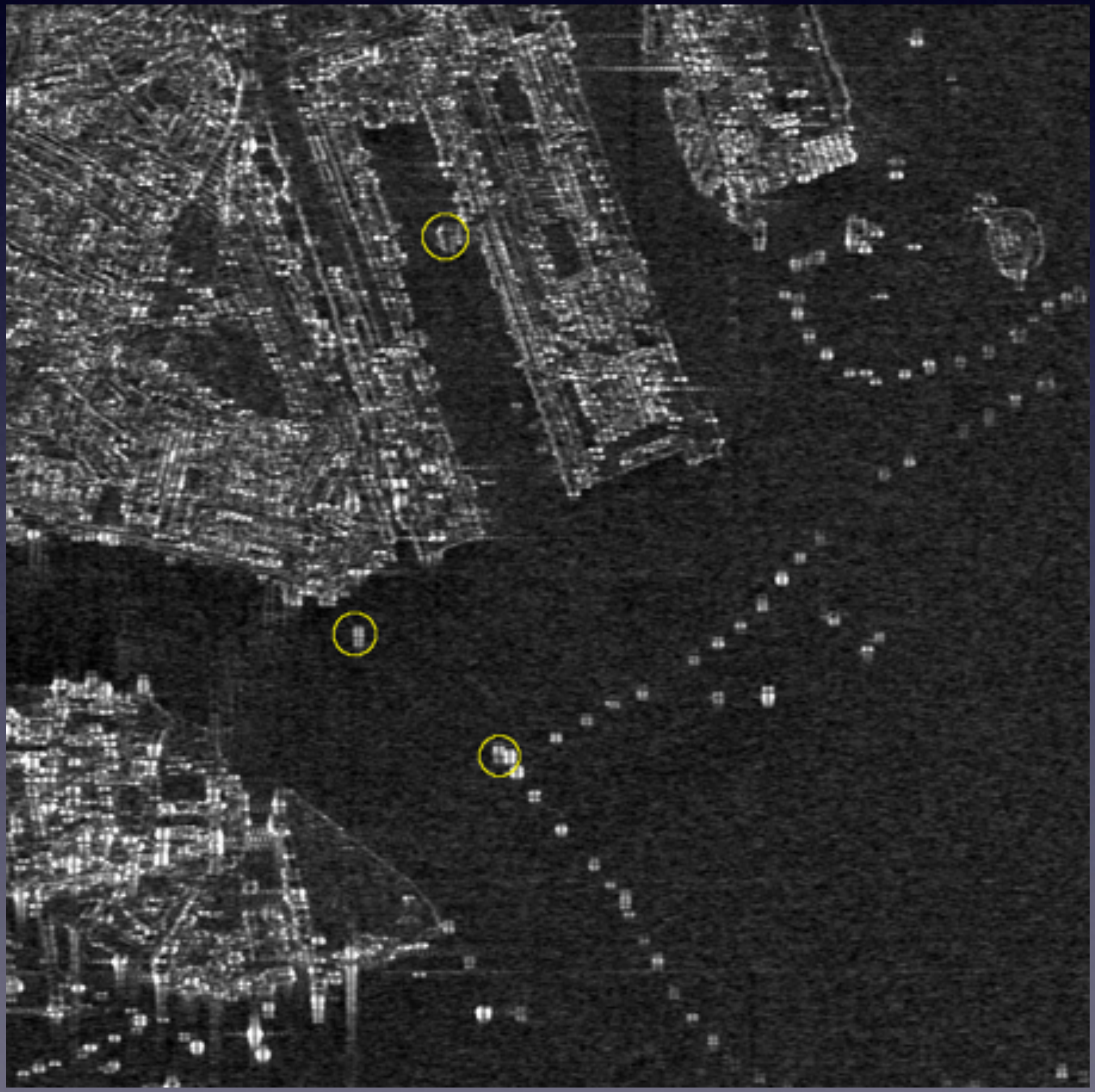
Temporal coherence



Spectral coherence

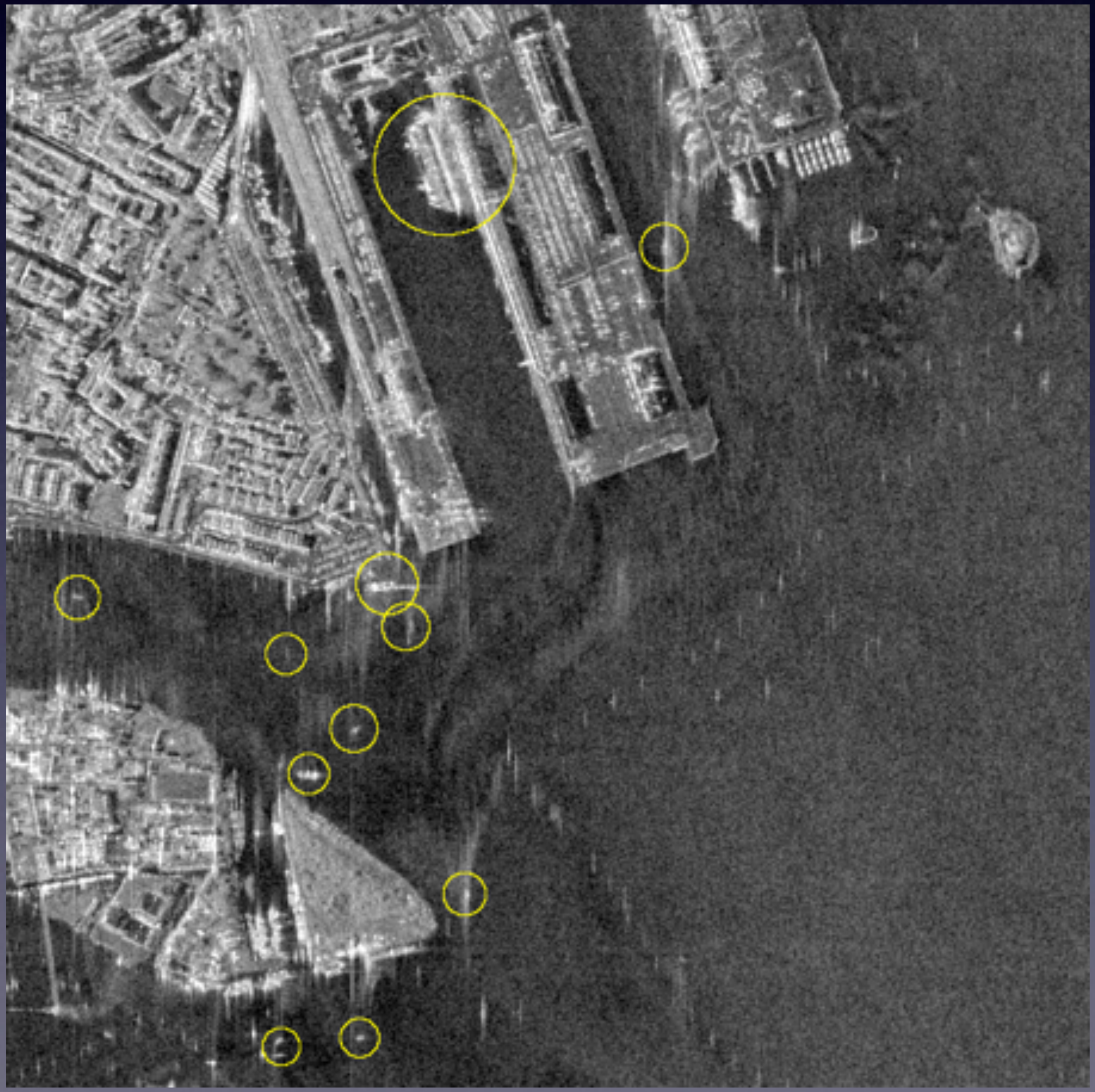
Intensity versus spectral coherence channel

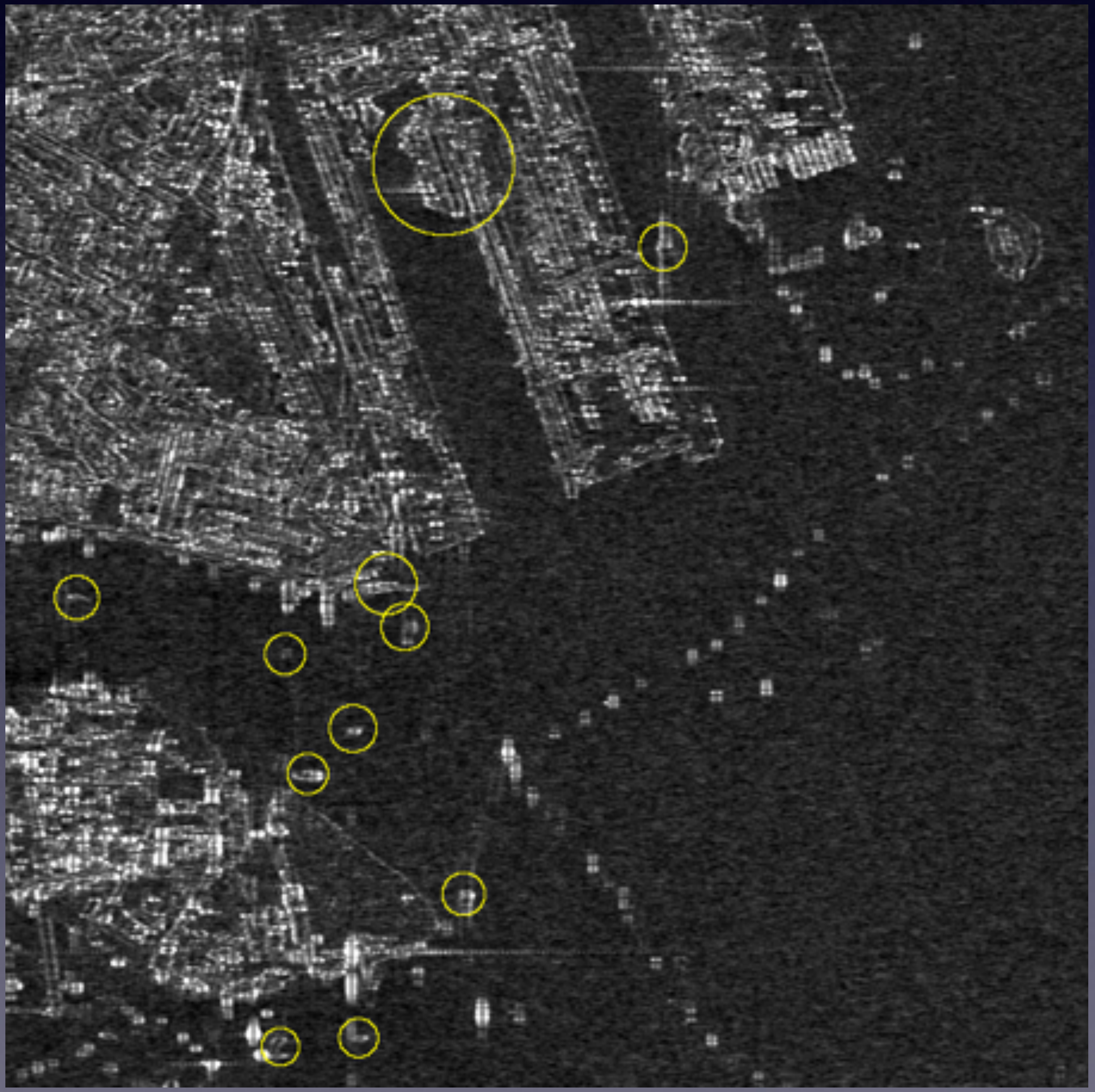
- March 14 acquisition

Intensity versus spectral coherence channel

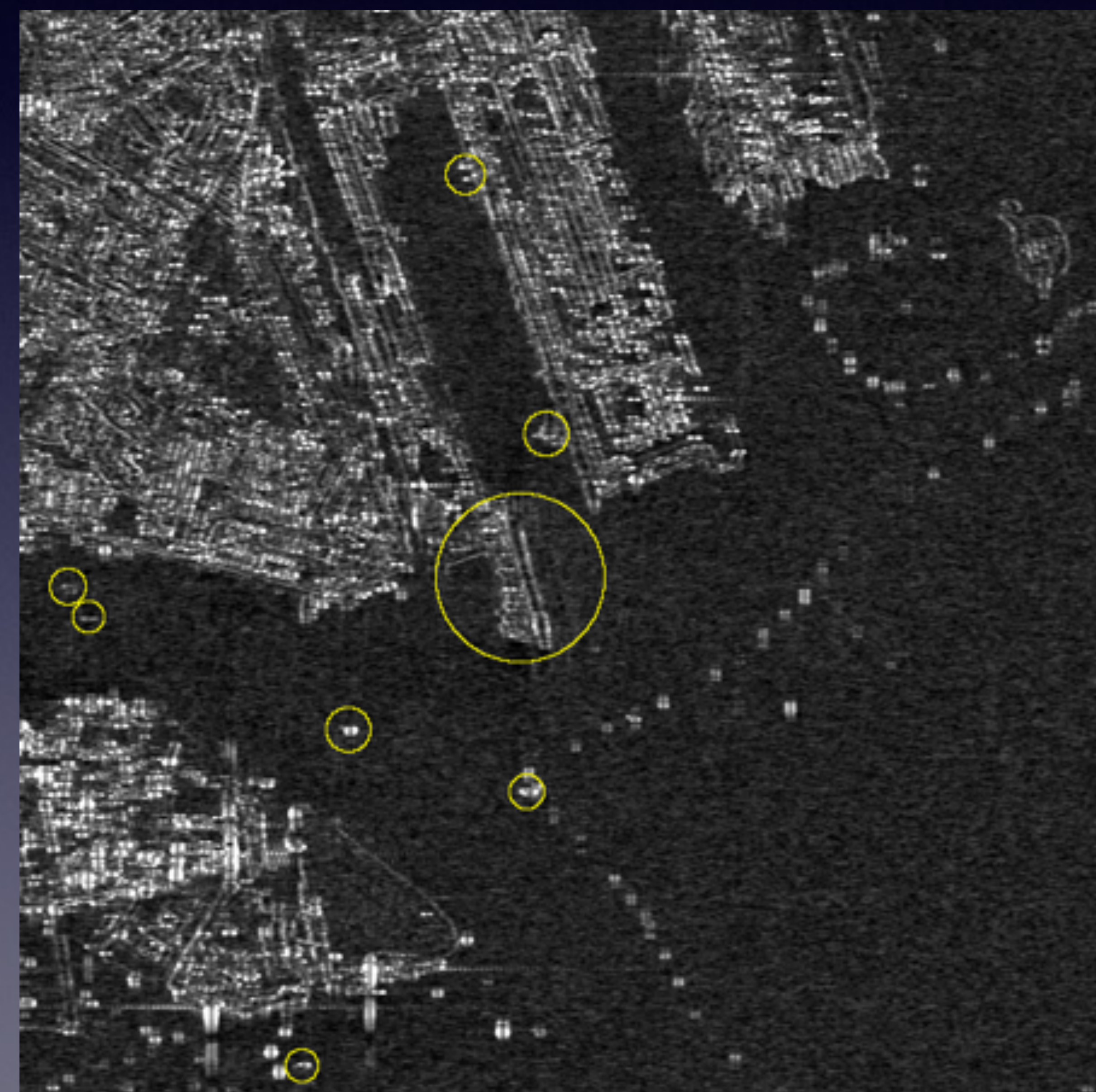
- April 16 acquisition





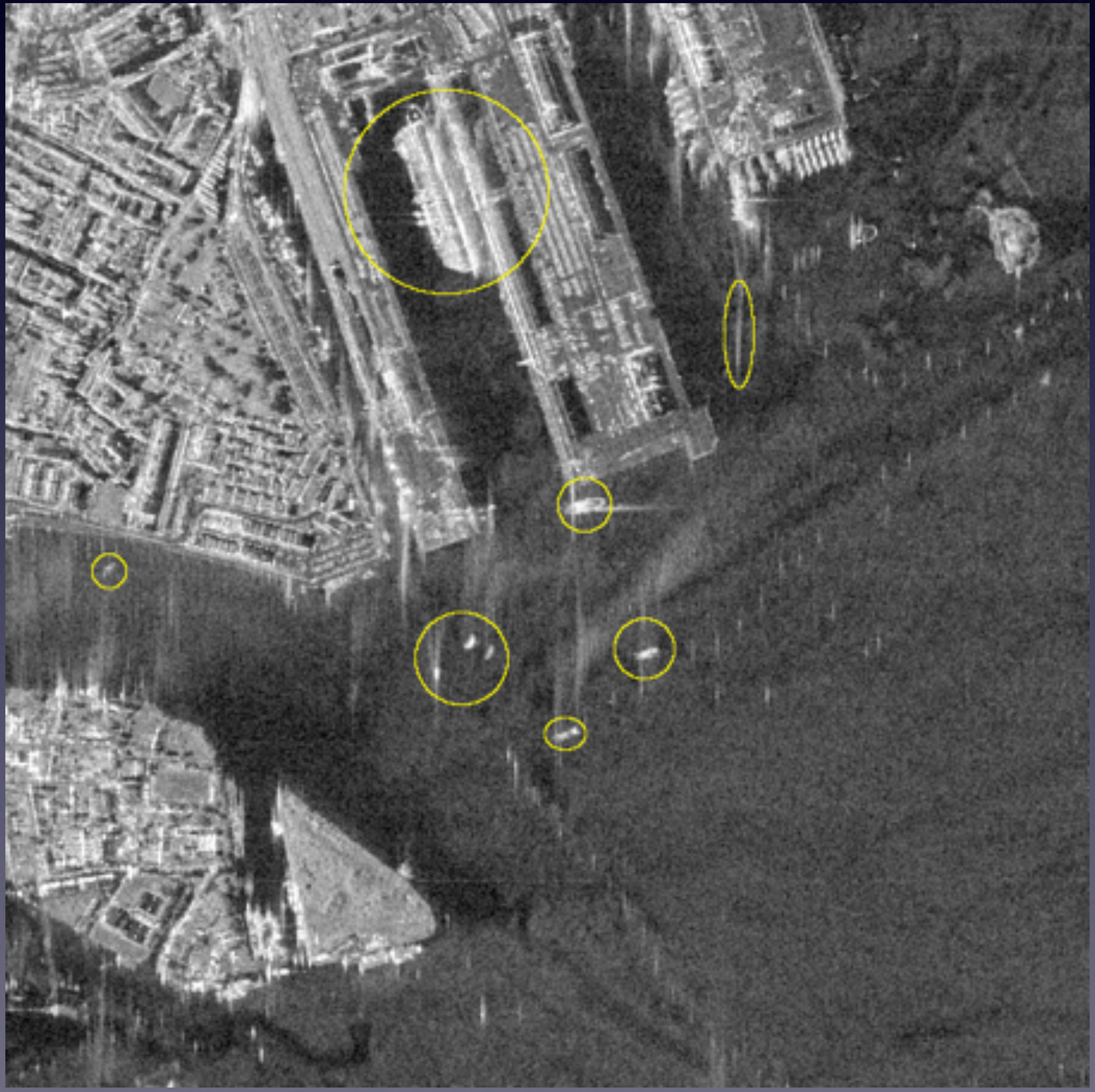
Intensity versus spectral coherence channel

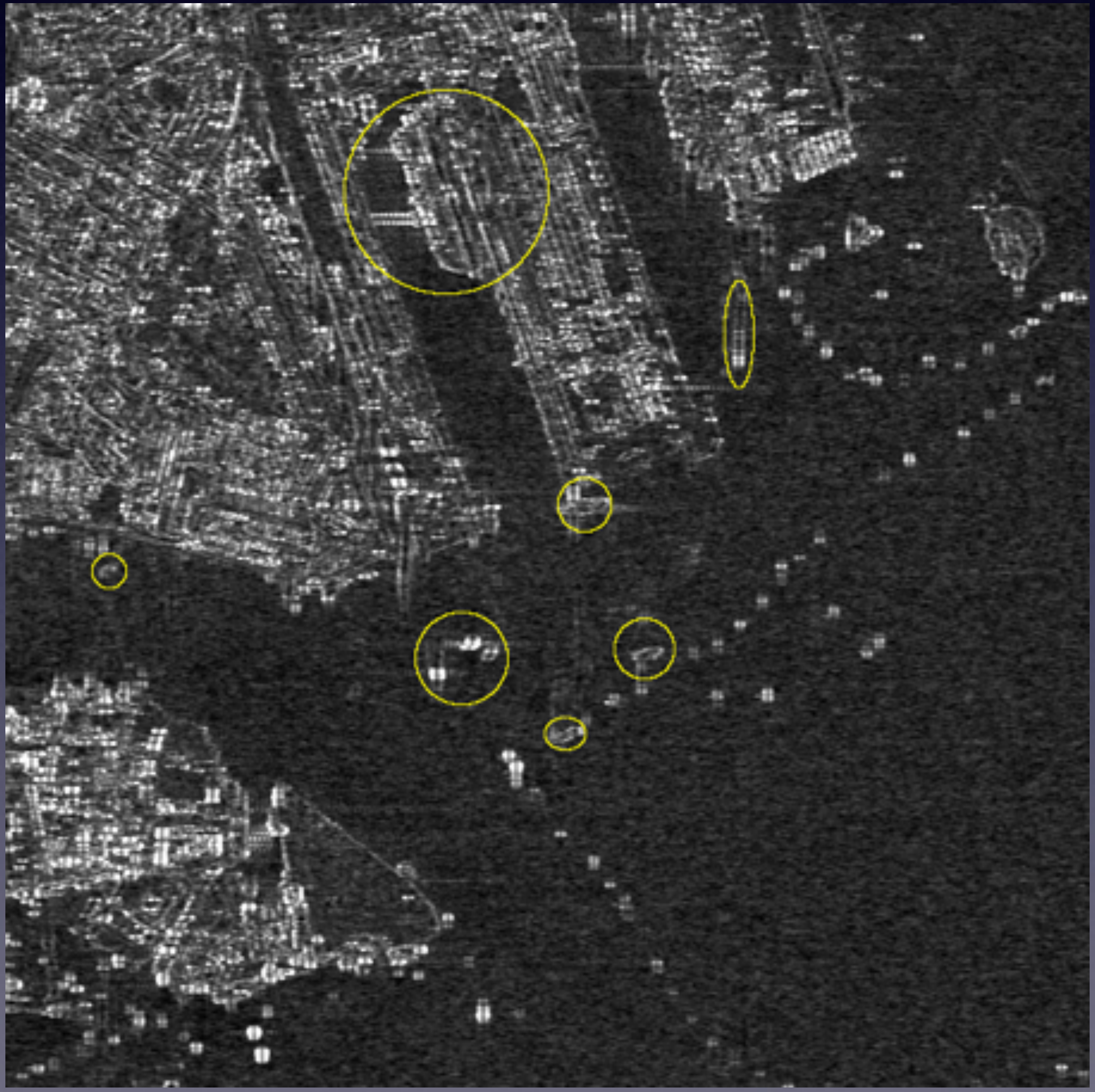
- April 27 acquisition



Intensity versus spectral coherence channel

- May 8 acquisition





Spectral coherence applied to vessel tracking

- Vessels detectability using CFAR algorithm

➪ We developed a basic CFAR algorithm to compare detectability in each channels

➪ Detectability comparison is complicate

✓ Both channels have different resolutions

➪ It is possible to perform the same detection in both channels adapting conveniently parameters

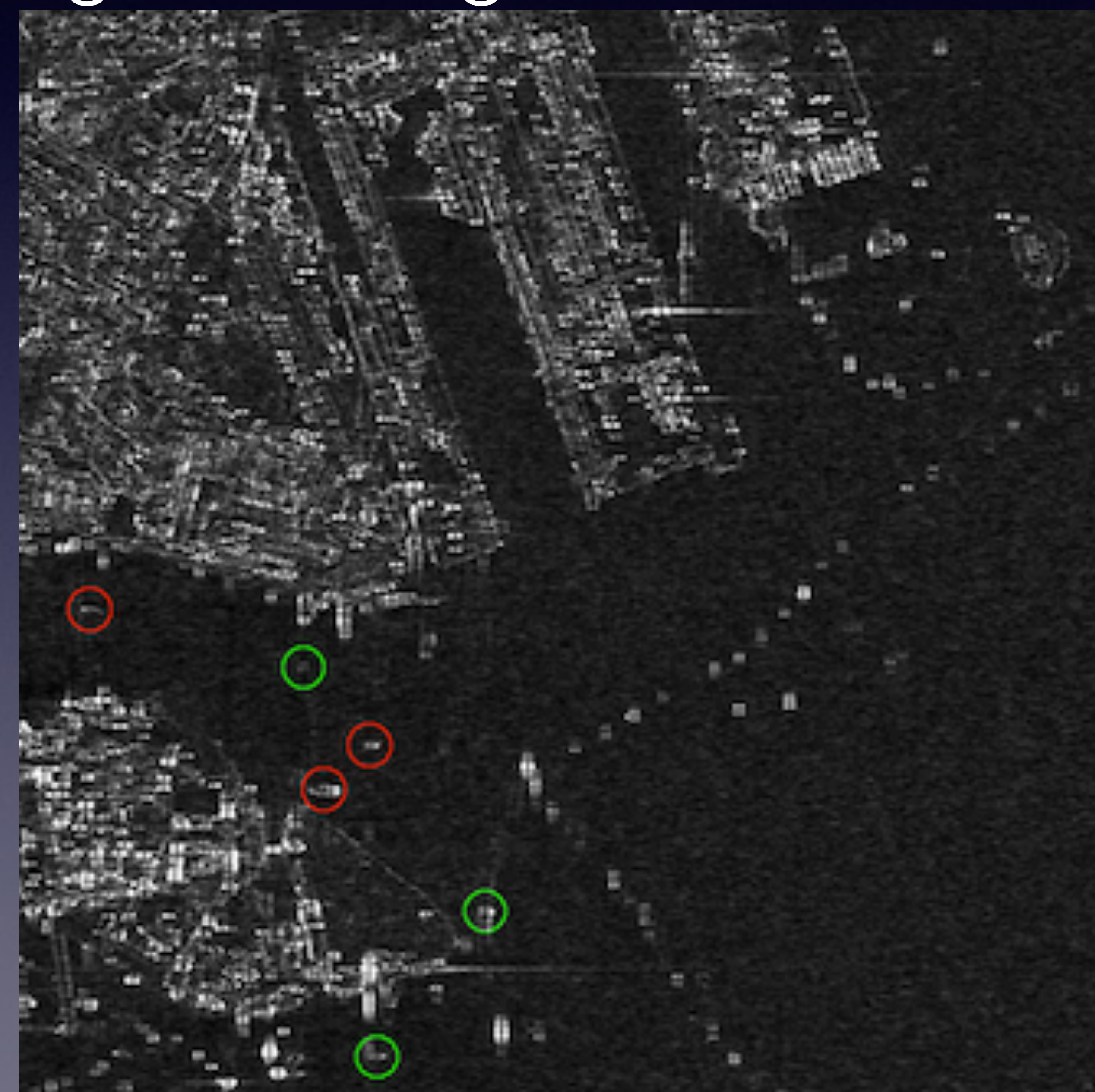
➪ What ever the used parameters, the CFAR detection on spectral coherence gives better results, especially in the detection of faint targets

Spectral coherence applied to vessel tracking

- Vessels detectability using CFAR algorithm

Intensity

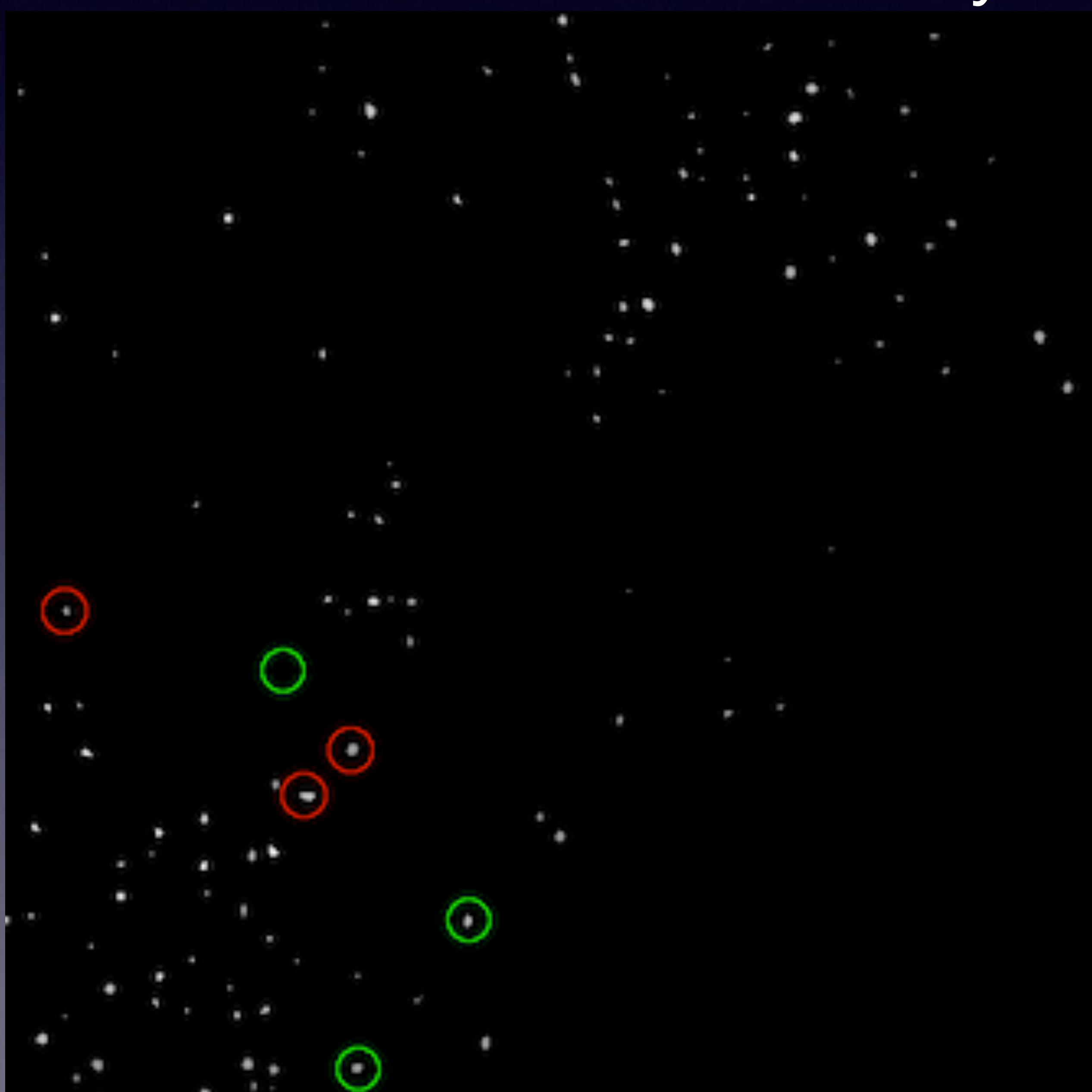
Spectral coherence



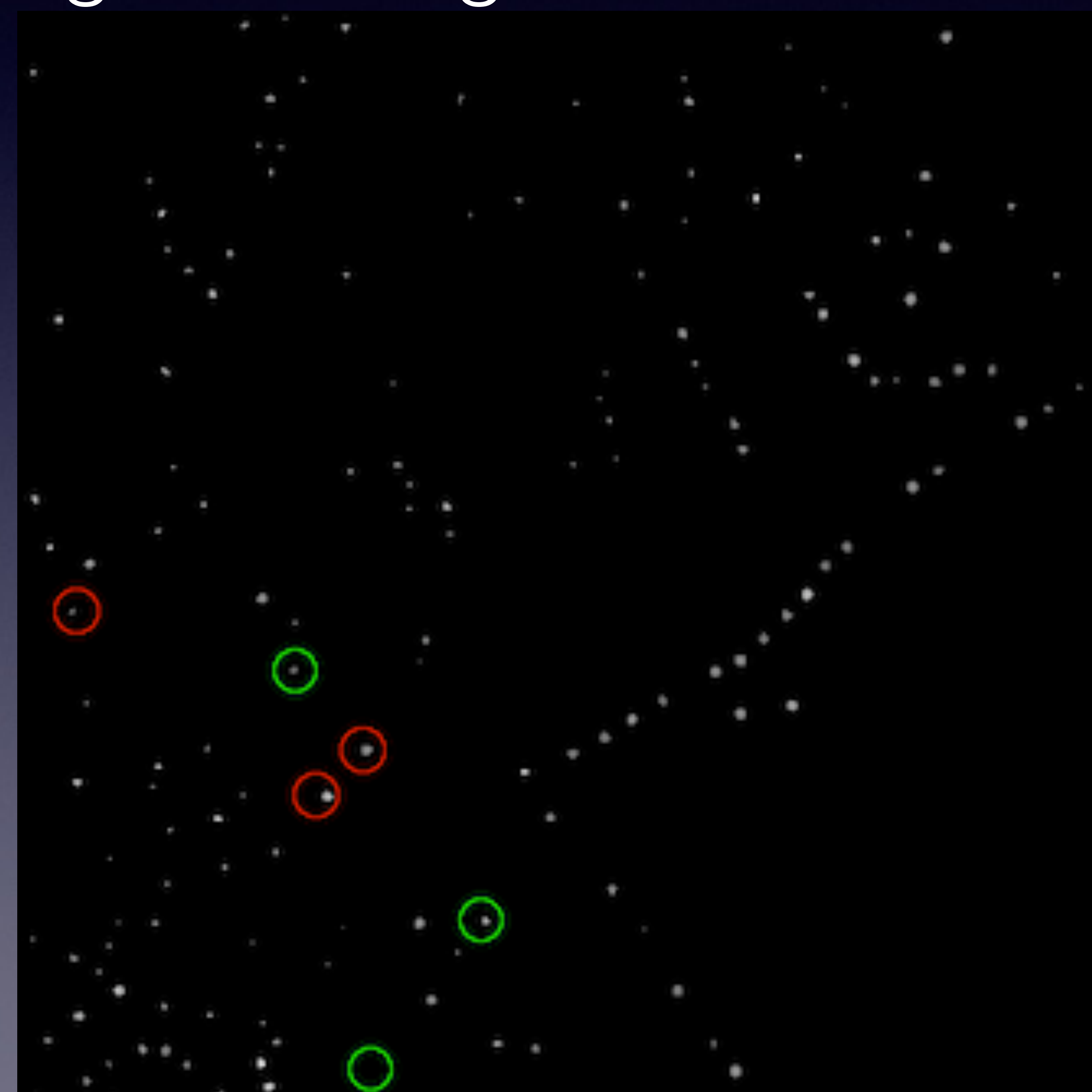
Spectral coherence applied to vessel tracking

- Vessels detectability using CFAR algorithm

CFAR on intensity



CFAR on spectral coherence



Conclusions

- We developed a tool allowing to extract the spectral coherence channel from wide band SAR images
- A simple model shows that, in the presence of a random distribution of surface scatterers, spectral coherence is equal to sub-band overlapping proportion

  ➪ The model appears fully verified on open sea areas

  ✓ Spectral coherence of sea clutter tends to zero

  ➪ Manmade structures departs from this distribution, leading to a preserved spectral coherence

Conclusions

- Spectral coherence seems very well suited for vessel detection in the frame of maritime surveillance

- A first analysis shows that vessels observable in intensity images are easily detected in the spectral coherence image, especially for faint targets.

  ➪ Spectral coherence is a good additional channel for vessel detection

- Spectral coherence may be used as an information channel in addition to intensity channel to still constrain vessel detection