POLINSAR 2013

The 6th International Workshop on Science and Applications of SAR Polarimetry and Polarimetric Interferometry

Ship detection using polarimetric RadarSat-2 data and multi-dimensional coherent Time-Frequency analysis

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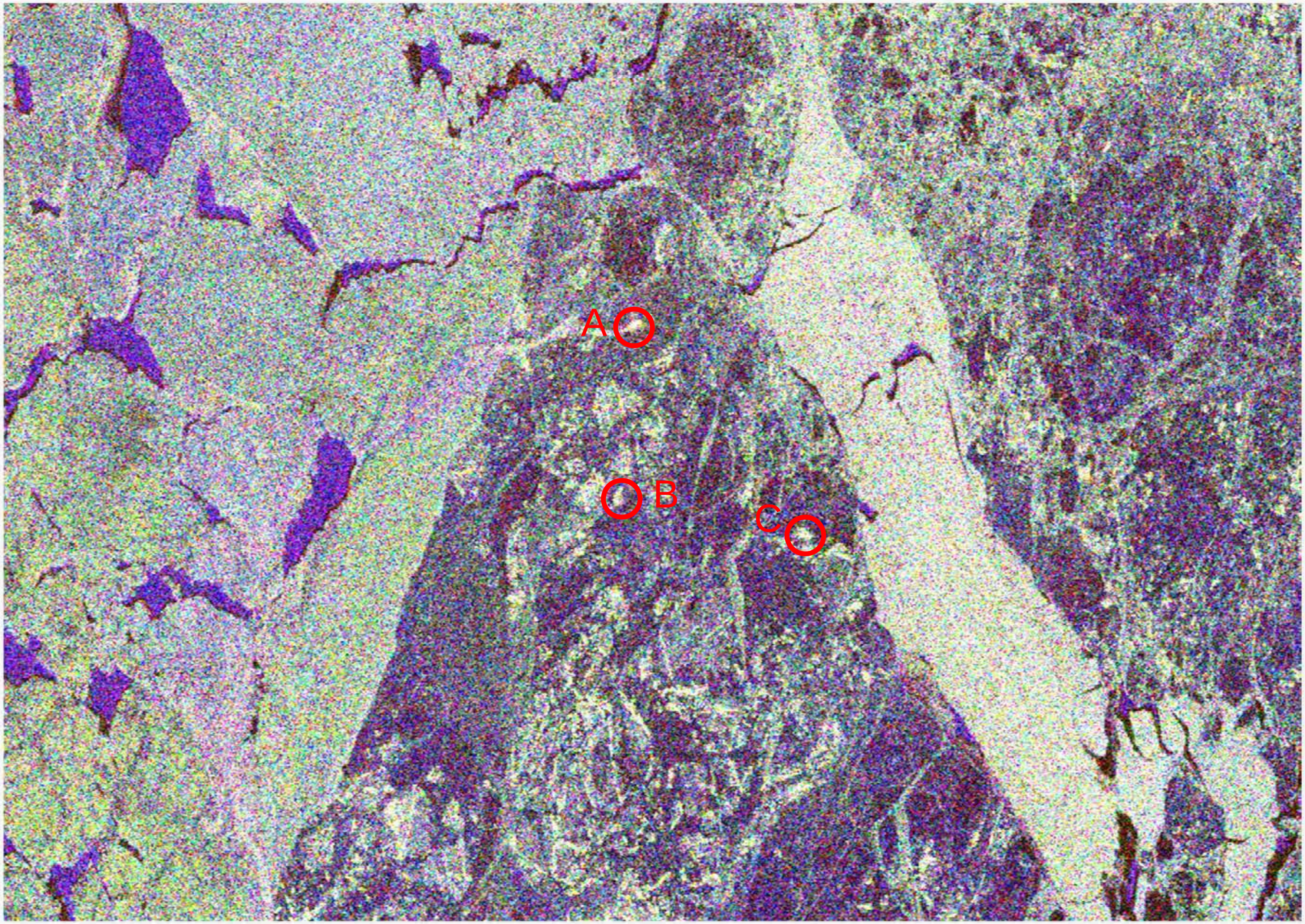
Outline

- Principle of TF analysis
  - TF decomposition
  - TF SAR signal model
  - Polarimetric coherence TF indicator
- Application to ship detection
  - Ship in open sea
  - Ship in sea ice
- Conclusion

Where is the ship?



Time-Frequency decomposition

Local spectral estimation

$\mathbf{l} = [l_{az}, l_{rg}]$ $\boldsymbol{\omega} = [\omega_{az}, \omega_{rg}]$

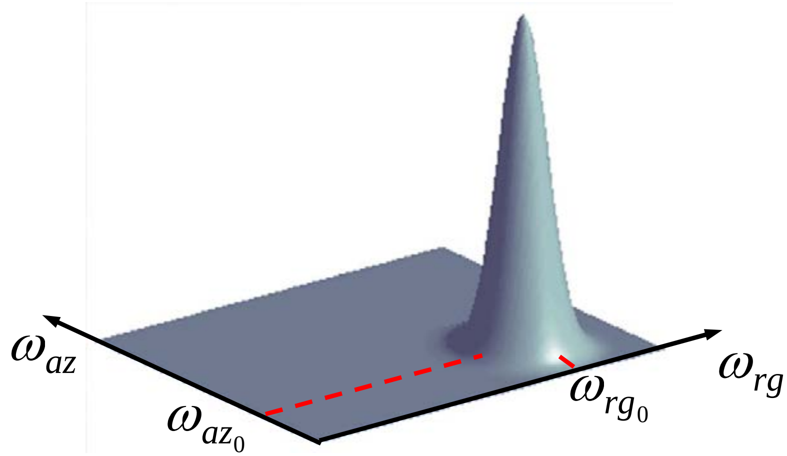
SAR image **Spectrum**

$$d(\mathbf{l}) \longrightarrow D(\boldsymbol{\omega})$$

$$d(\mathbf{l}, \boldsymbol{\omega_0}) \longleftarrow D(\boldsymbol{\omega}, \boldsymbol{\omega_0}) = D(\boldsymbol{\omega})G(\boldsymbol{\omega} - \boldsymbol{\omega_0})$$

T-F SAR image **Local spectrum**

$G(\boldsymbol{\omega} - \boldsymbol{\omega_0})$



Azimuth

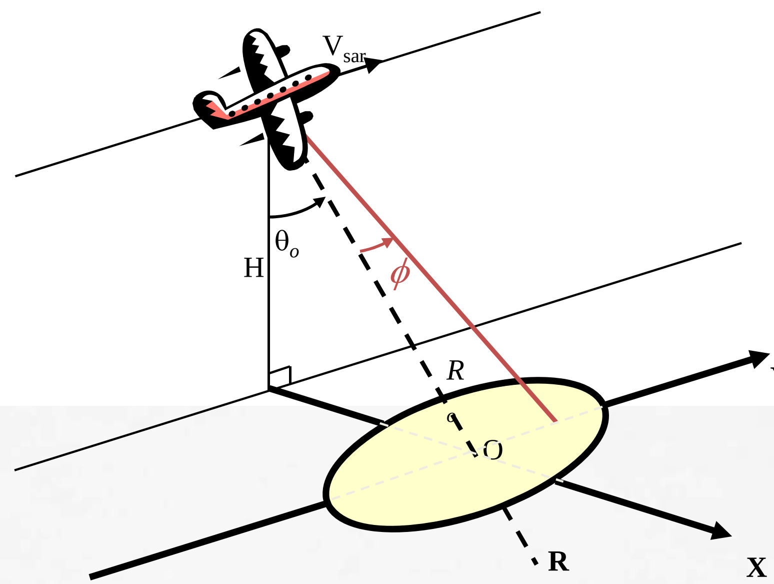
$$\omega_{az_0} = 2\omega_c \frac{V_{SAR}}{c} \sin\phi_0$$

Angular behavior

Range

$$\omega_{rg_0} \in \left[\omega_c \pm \frac{B_\omega}{2}\right]$$

Frequency sensitivity



TF varying SAR signal model

esa

Varying T-F signal model

$$\mathbf{s}(\omega) = \mathbf{t}(\omega) + \mathbf{c}(\omega)$$

$\mathbf{s}(\omega)$: varying composite signal

$\mathbf{t}(\omega)$: quasi-deterministic, slowly varying component ⇨ highly coherent

$\mathbf{c}(\omega)$: random component, potentially non-stationary ⇨ incoherent scattering

coherence T-F behaviors

Ocean	Natural island	Iceberg	Icebreaker	Cargo
				

low ← coherence → high

(Ref: L. Ferro-Famil & E. Pottier, "*Urban area remote sensing from L-band PolSAR data using Time-Frequency techniques*", in Proc. Urban Remote Sens. Joint Event, Apri. 2007, Paris)

Full-Pol TF coherence analysis

Full-pol response sampled at *R* spectral positions:

$$\mathbf{k}_{TF-Pol} = \begin{bmatrix} \mathbf{k}_1 \\ \vdots \\ \mathbf{k}_R \end{bmatrix} \quad \text{where} \quad \mathbf{k}_i = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{hh}(\boldsymbol{\omega}_i) + S_{vv}(\boldsymbol{\omega}_i) \\ S_{hh}(\boldsymbol{\omega}_i) - S_{vv}(\boldsymbol{\omega}_i) \\ 2S_{hv}(\boldsymbol{\omega}_i) \end{bmatrix}$$

$$\Rightarrow \mathbf{T}_{TF-Pol} = \left\langle \mathbf{k}_{TF-Pol}\, \mathbf{k}^{\dagger}_{TF-Pol} \right\rangle = \begin{bmatrix} \mathbf{T}_{11} & \cdots & \mathbf{T}_{1R} \\ \vdots & \ddots & \vdots \\ \mathbf{T}^{\dagger}_{1R} & \cdots & \mathbf{T}_{RR} \end{bmatrix} (3R \times 3R)$$

T-F coherence behavior characterization

TF-Pol coherence matix off-diagonal terms: $\mathbf{T}_{ij} \quad i \neq j$

Coherent pixel detection

Hypothesis testing

H_0 : **Uncorrelated PolSAR responses over R spectral positions**

$$\mathbf{T}_{TF-Pol} \sim \mathcal{W}_c(n, \mathbf{\Sigma}_{TF-Pol}) \qquad \mathbf{\Sigma}_{TF-Pol} = \begin{bmatrix} \mathbf{\Sigma}_{11} & \dots & \mathbf{\Sigma}_{1R} \\ \vdots & \ddots & \vdots \\ \mathbf{\Sigma}_{1R}^{\dagger} & \dots & \mathbf{\Sigma}_{RR} \end{bmatrix}$$

$$H_0 : \mathbf{\Sigma}_{ij} = \mathbf{0} \quad \forall i \neq j \qquad \mathbf{\Sigma}_{TF-Pol}|_{H_0} = \begin{bmatrix} \mathbf{\Sigma}_{11} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{0} & \ddots & & \vdots \\ \vdots & & \ddots & \mathbf{0} \\ \mathbf{0} & \dots & \mathbf{0} & \mathbf{\Sigma}_{RR} \end{bmatrix}$$

Maximum Likelihood test

$$\Theta = \frac{\max L(\mathbf{\Sigma}_{TF-Pol}|_{H_0})}{\max L(\mathbf{\Sigma}_{TF-Pol})} = \frac{|\mathbf{T}_{TF-Pol}|^n}{\prod_{i=1}^{R} |\mathbf{T}_{ii}|^n}$$

- Decide H_0 if $\Theta > c_\beta$
- Threshold c_β : $P_{fa} = \Pr(\Theta < c_\beta | H_0) = \beta$

Coherent pixel detection

Another representation: polarimetric whitening process

$$\Theta = \frac{|\mathbf{T}_{TF-Pol}|^n}{\prod_{i=1}^{R} |\mathbf{T}_{ii}|^n} = |\tilde{\mathbf{T}}_{TF-Pol}|^n$$

$$\tilde{\mathbf{T}}_{TF-Pol} = \mathbf{P}\,\mathbf{T}_{TF-Pol}\,\mathbf{P}^\dagger$$

$$\tilde{\mathbf{T}}_{TF-Pol} = \begin{bmatrix} \mathbf{I} & \mathbf{\Pi}_{12} & \cdots & \mathbf{\Pi}_{1R} \\ \mathbf{\Pi}_{12}^\dagger & \ddots & & \vdots \\ \vdots & & \ddots & \\ \mathbf{\Pi}_{1R}^\dagger & \cdots & & \mathbf{I} \end{bmatrix}$$

Coherence information

$$\mathbf{\Pi}_{ij} = \mathbf{T}_{ii}^{-\frac{1}{2}}\mathbf{T}_{ij}\mathbf{T}_{jj}^{-\frac{1}{2}}$$

TF-Pol coherence

$$\rho_{TF-Pol} = 1 - |\tilde{\mathbf{T}}_{TF-Pol}|^{\frac{1}{3R}}$$

$$0 \leq \rho_{TF-Pol} \leq 1$$

Applied data sets

- **Radarsat-2 SAR data in fine quad-pol mode**

- **Two groups**:

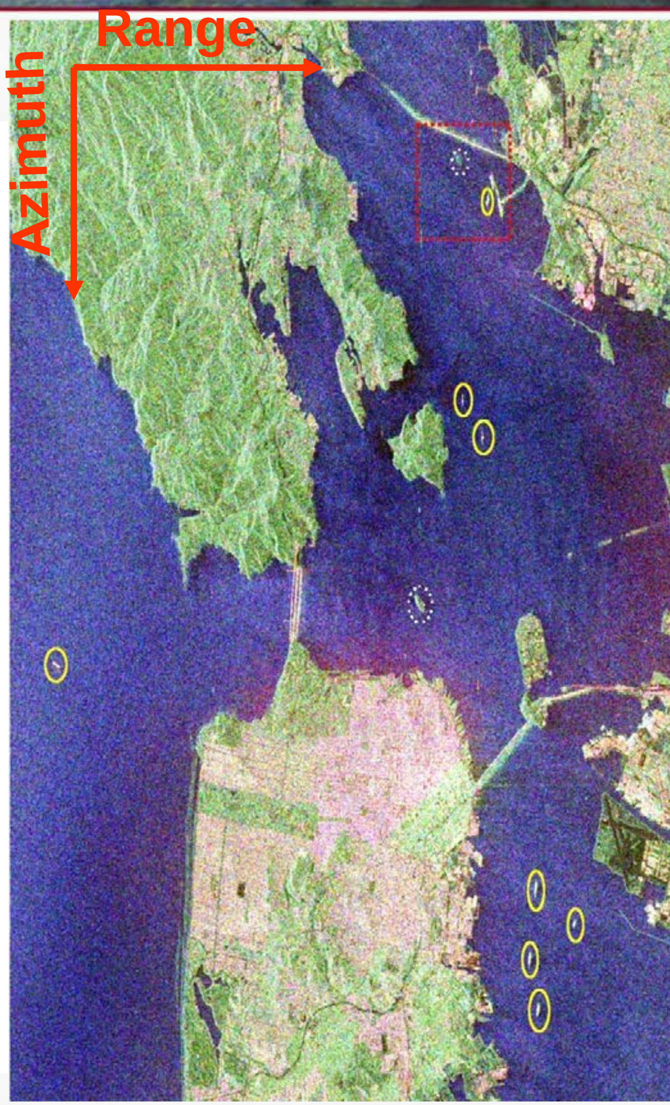
  1) Ship in open sea

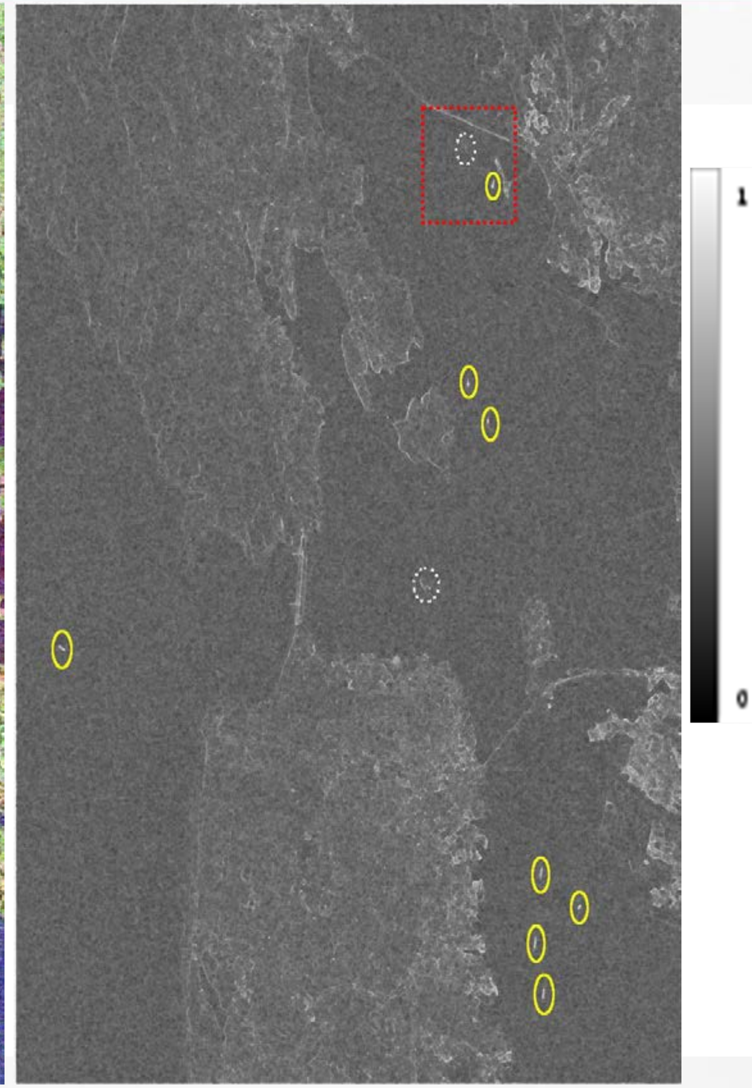
     (harbor, islands & artefact)

  2) Ship in sea ice

     (ice cracks, ridges, ice-infested water etc.)

Ships in the open sea of San Francisco area





Optical image

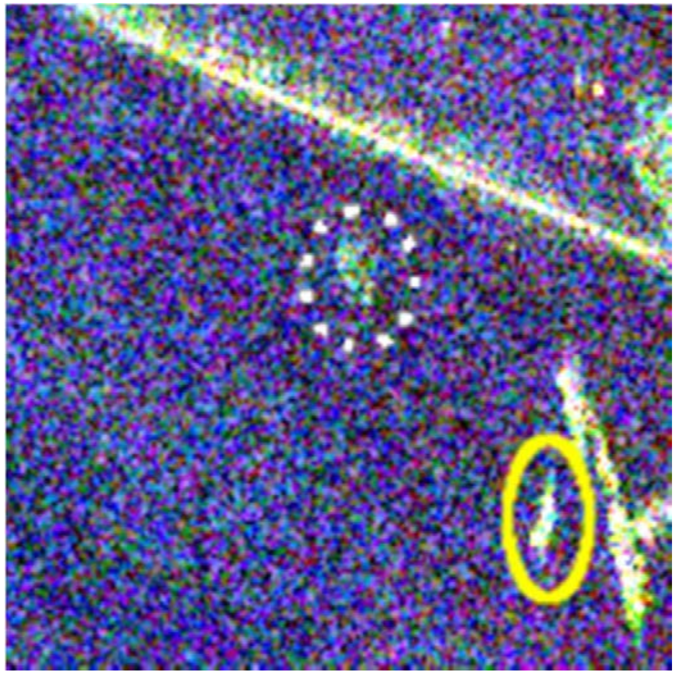
⇨ Spectral locations:4

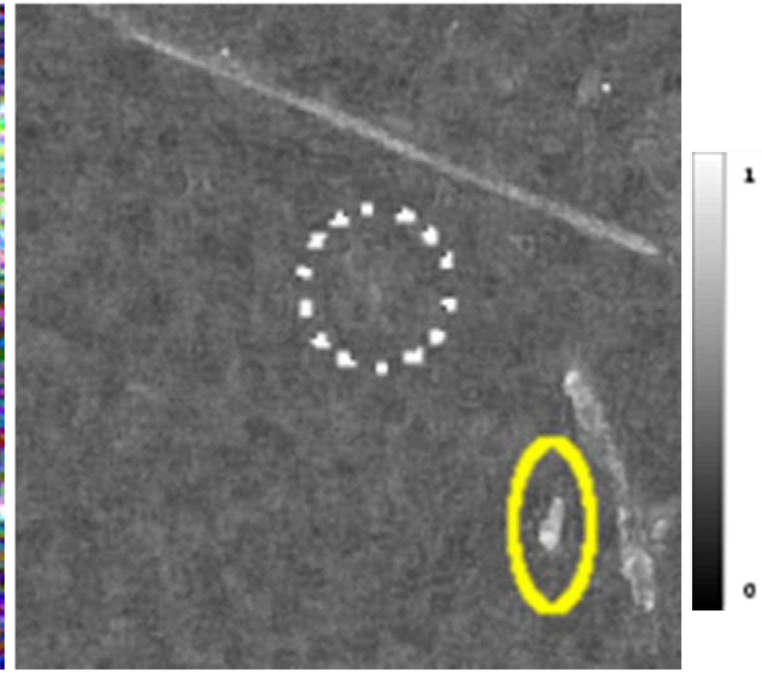
Pauli image

⇨ Direction: 2 in Azimuth, 2 in Range

TF-Pol coherence

ship vs. island

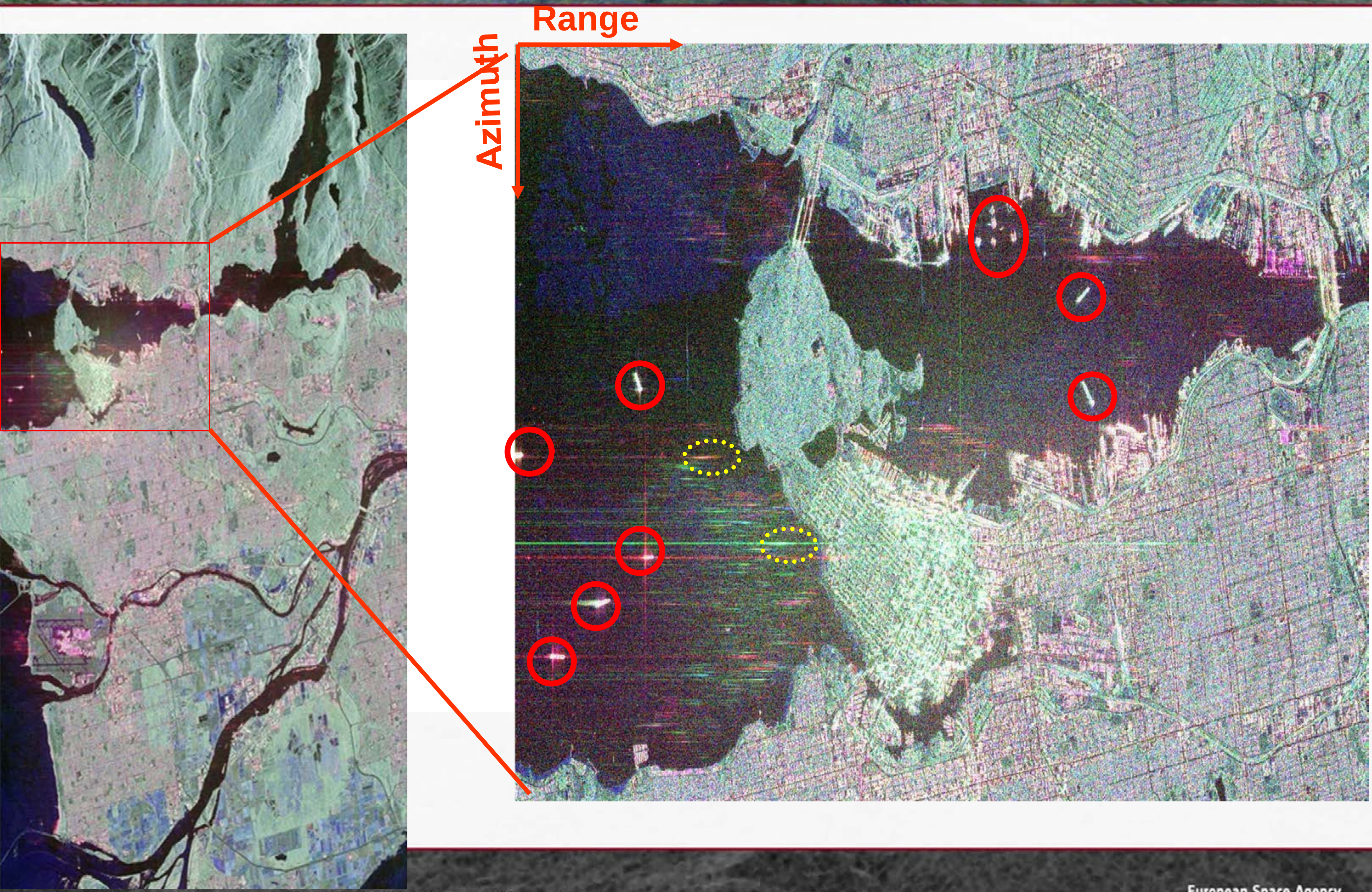




Optical image **Pauli image** **TF-Pol coherence**

Discriminating ships from small natural island

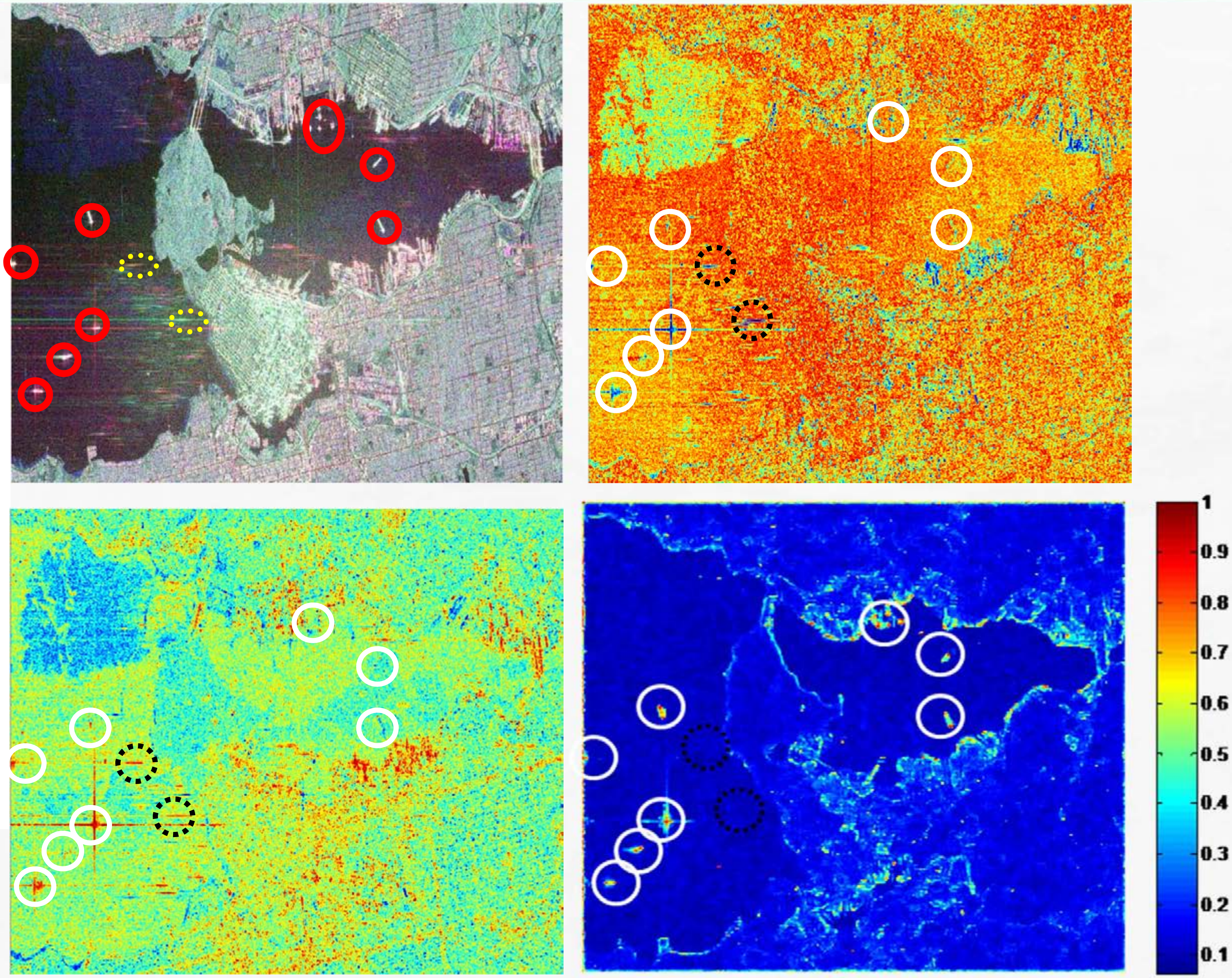
Ships in the open sea of Vancouver area



ship vs. ‘ghosts’

Pauli image

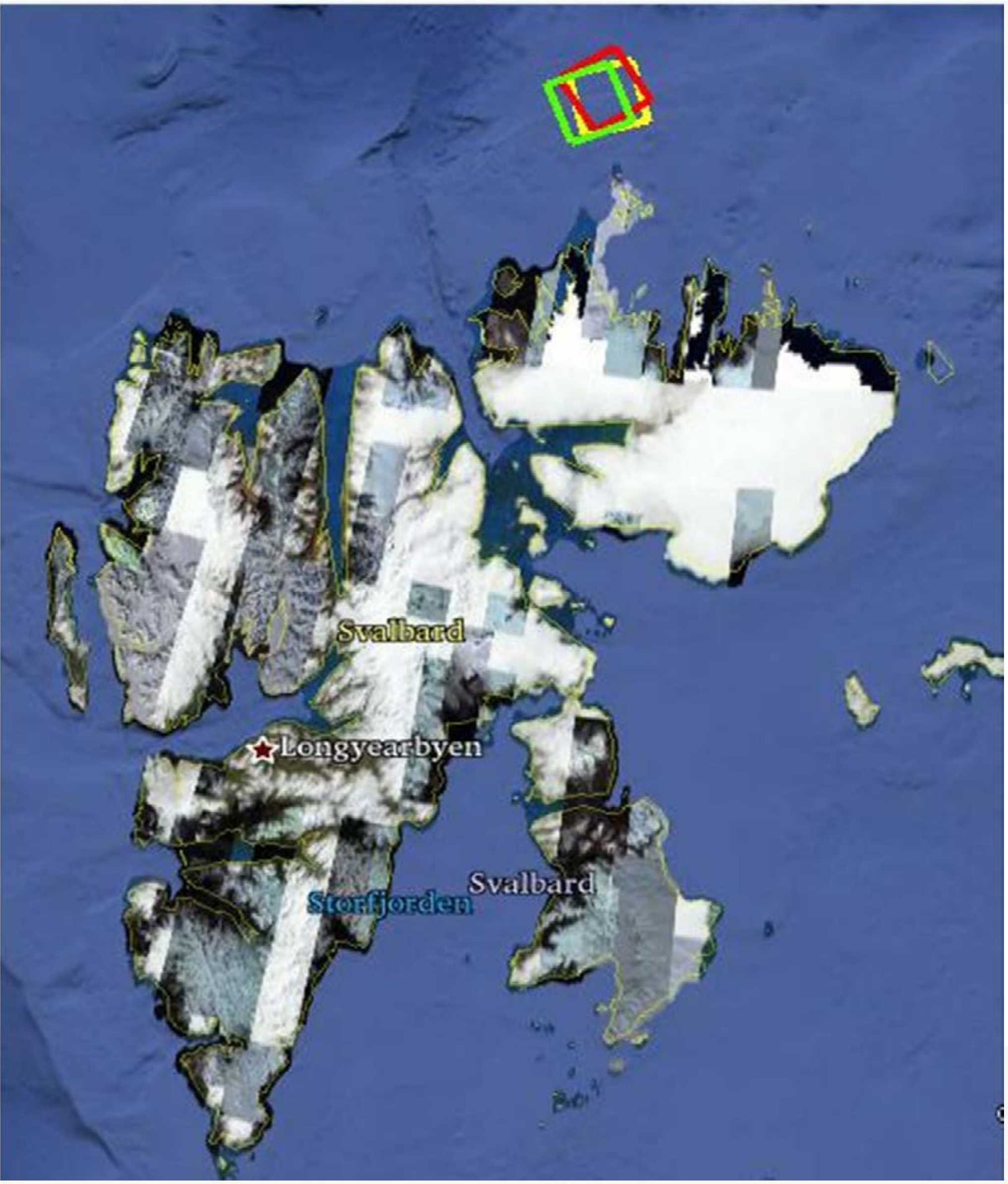
H



α

ρ_{TF-Pol}

Ships in sea ice



- ➢ **test site:**

  near Savalbard archipelago

  Norway

- ➢ **test time:**

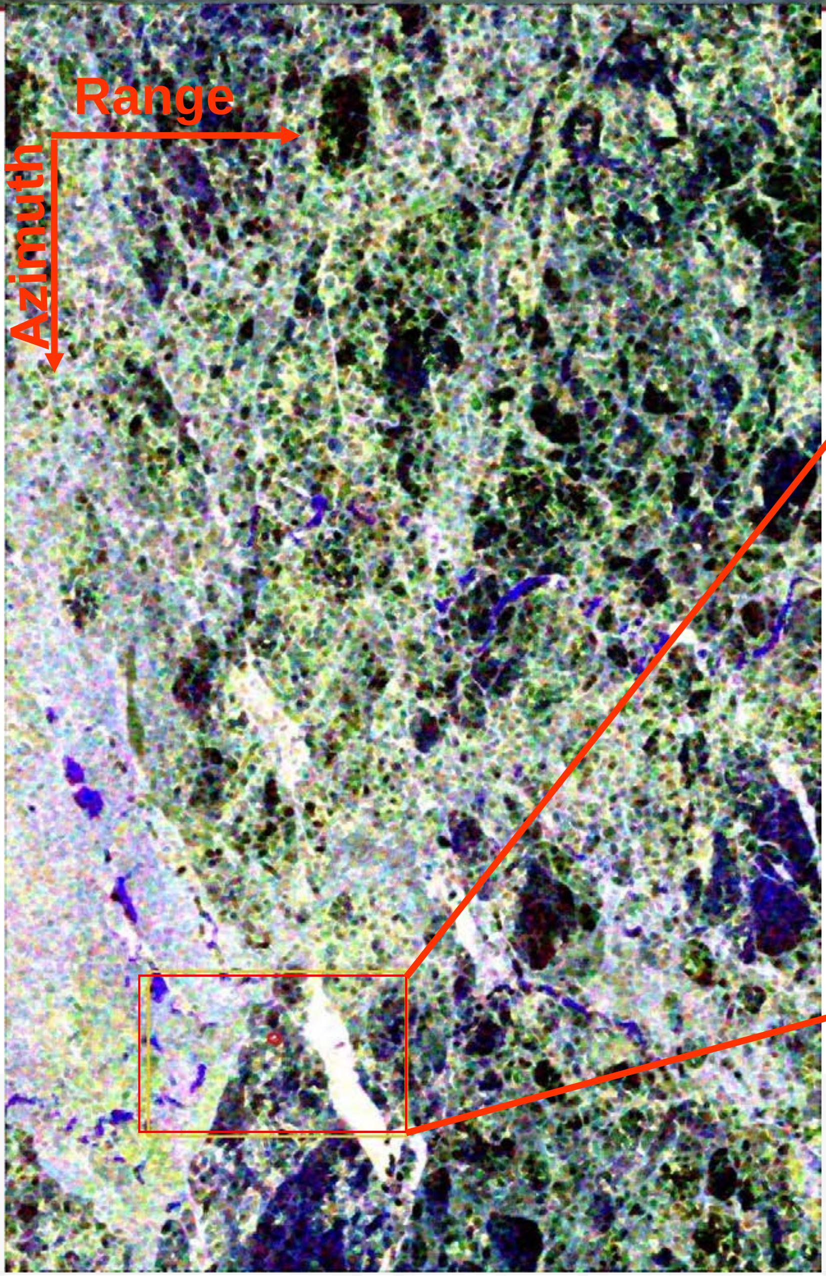
- 11 April 2011 (Red)
- 12 April 2011 (Yellow)
- 13 April 2011 (Green)

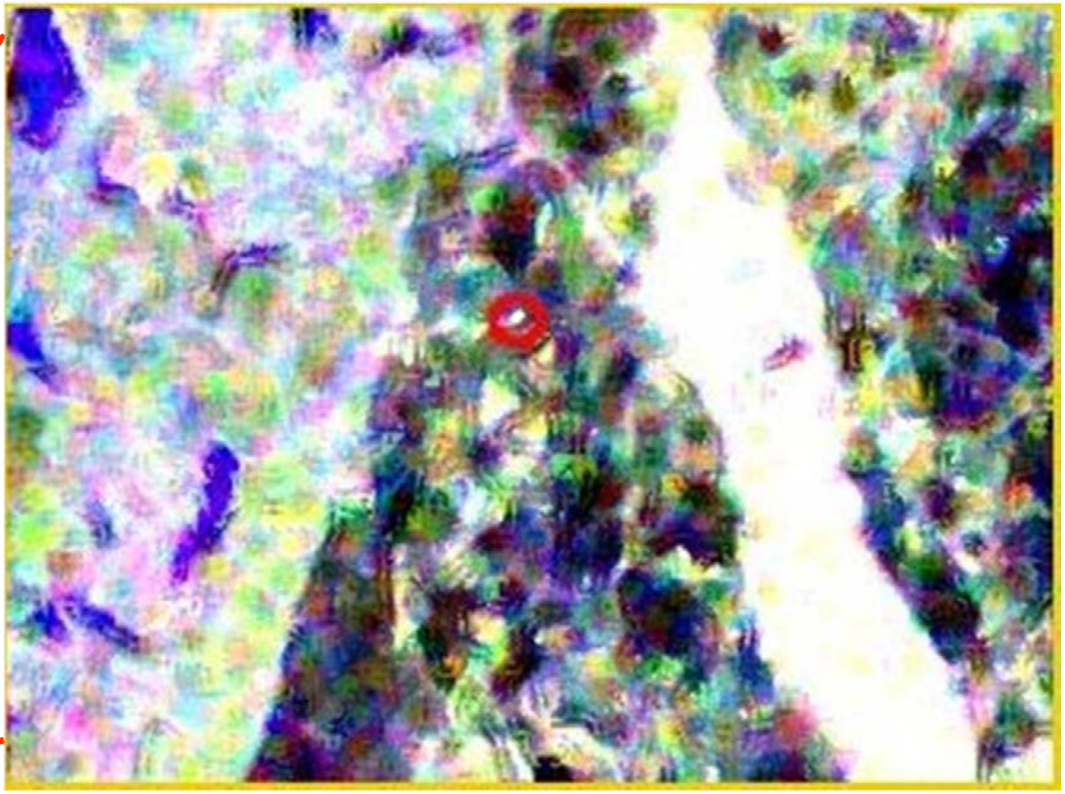
Verified ship in the sea ice

Norwegian coast guard icebreaker and offshore patrol vessel

- **Name:** **K/V Svalbard**
- **Length:** **103.7 m**
- **Breadth:** **19.1 m**

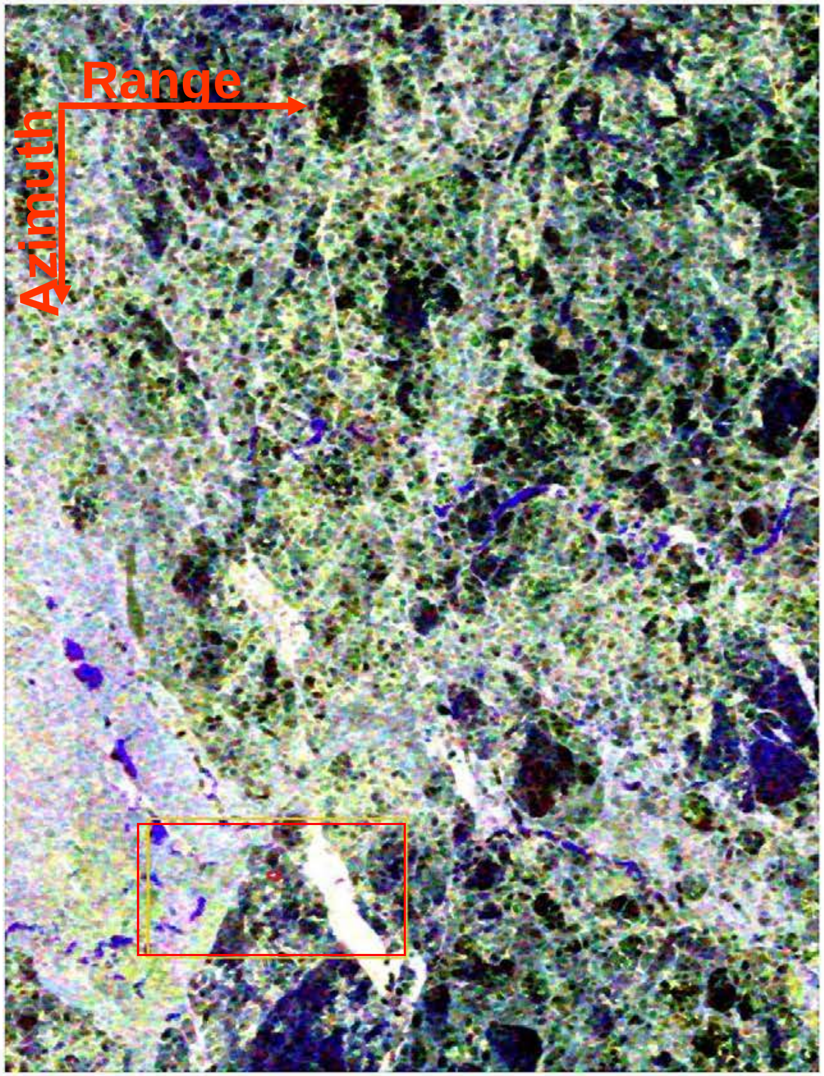
11 April 2011

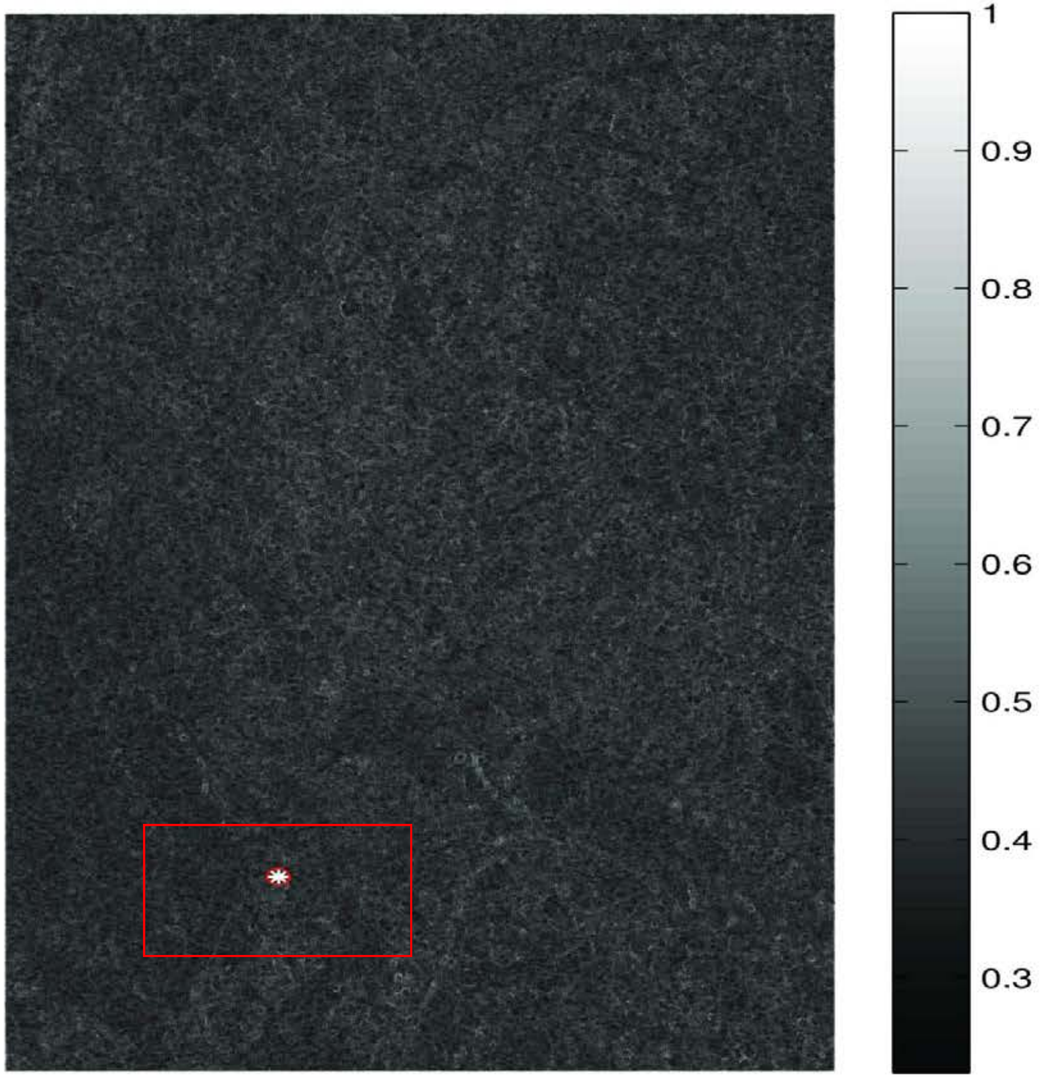




Pauli basis

11 April 2011 Ship vs. Ice





Pauli

⇨ Spectral locations:4

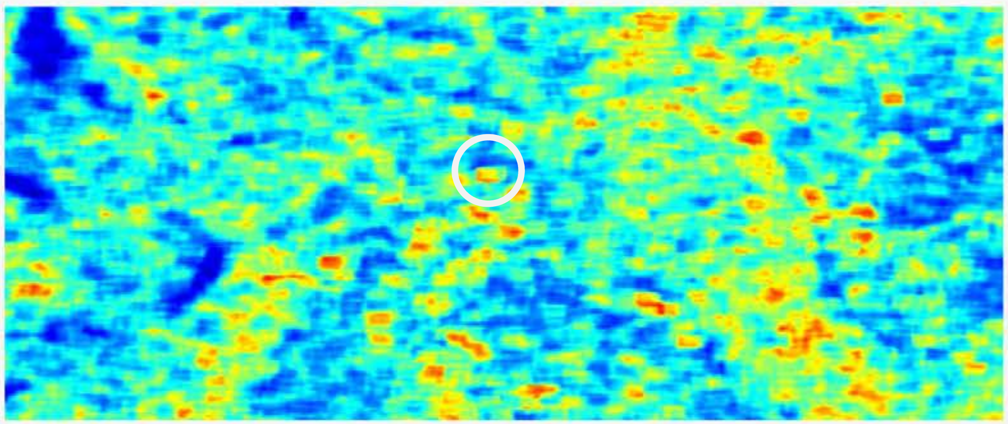
TF coherent (threshold =0.79)

⇨ Direction: 2 in Azimuth, 2 in Range

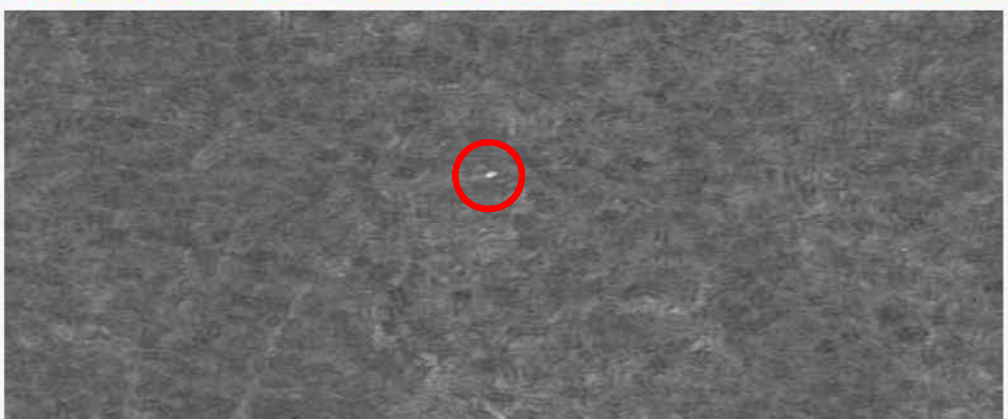
11 April 2011 Ship vs. Ice

Pauli image

H



ρ_{TF-Pol}



⇨ Spectral locations:

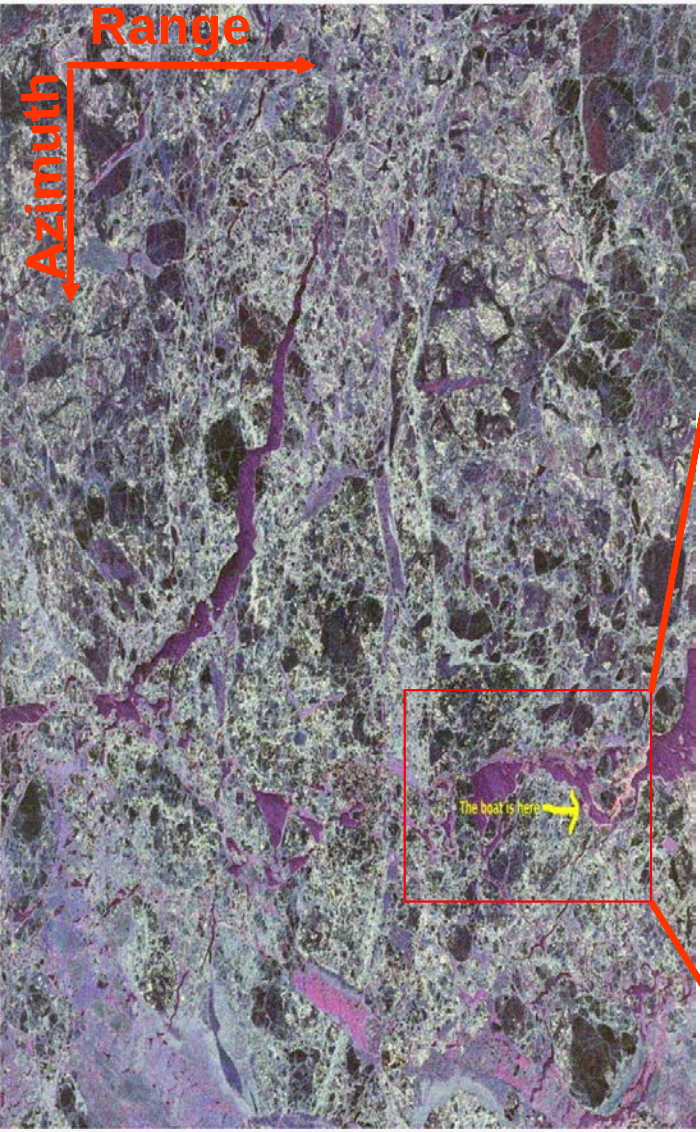
4

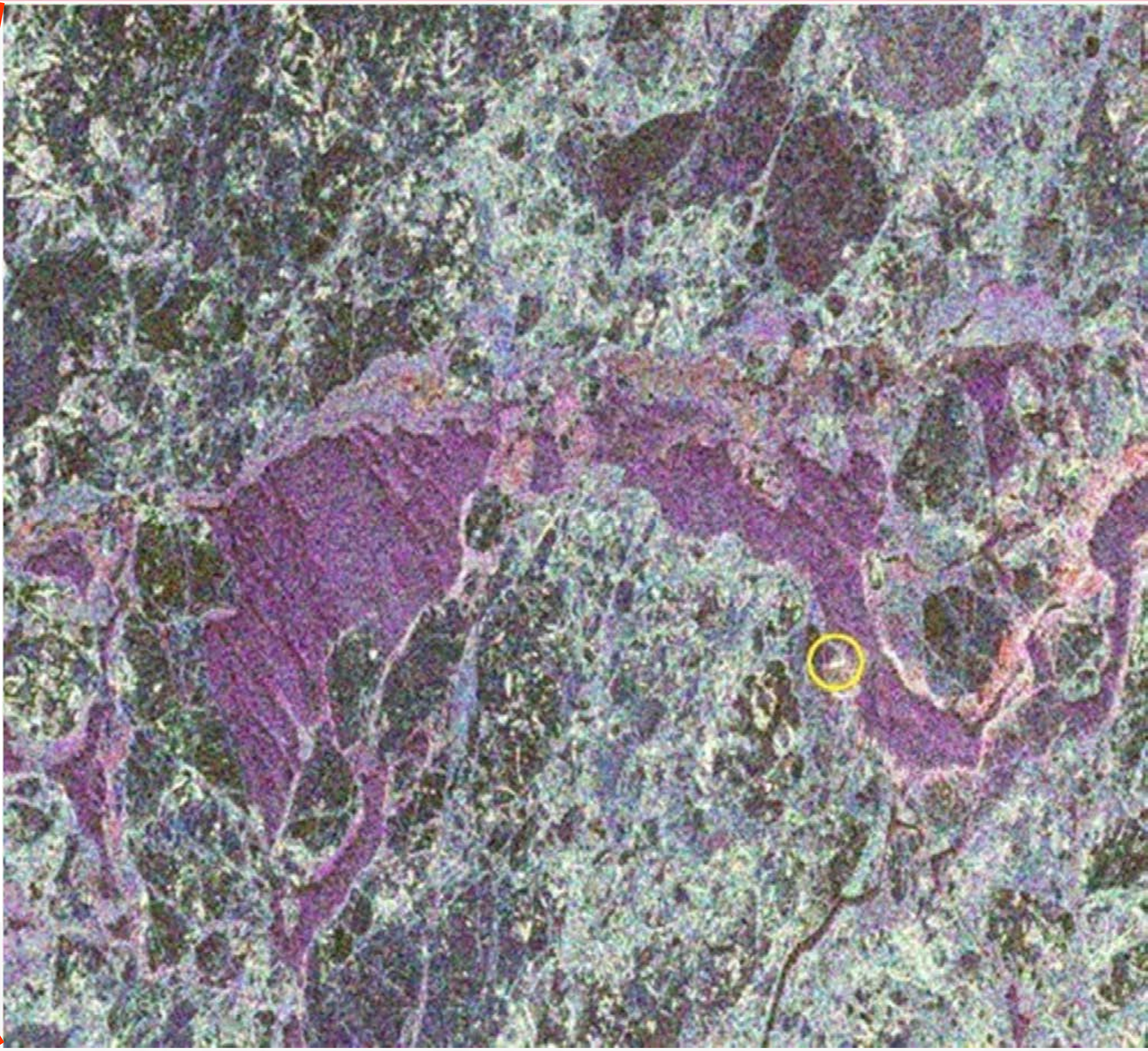
⇨ Direction:

2 in Azimuth,

2 in Range

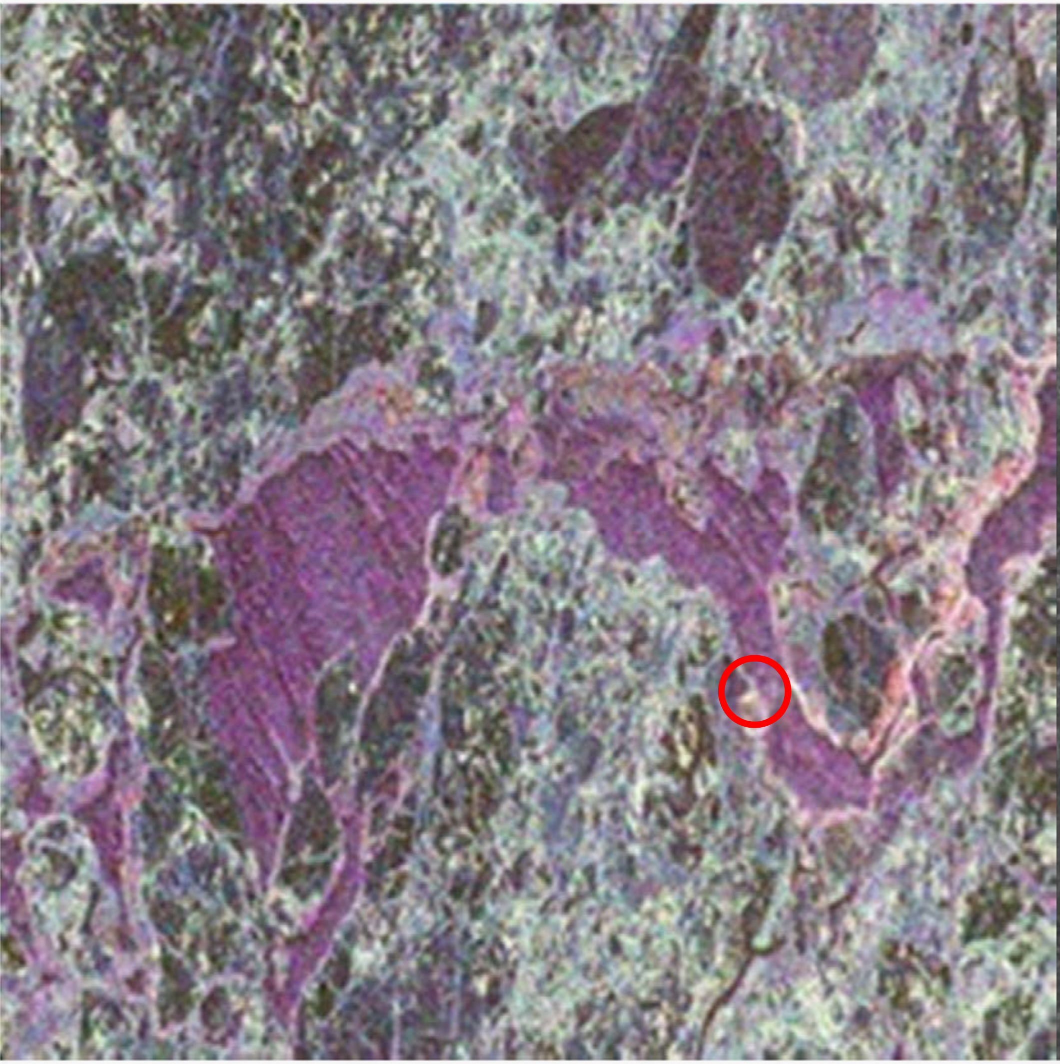
12 April 2011

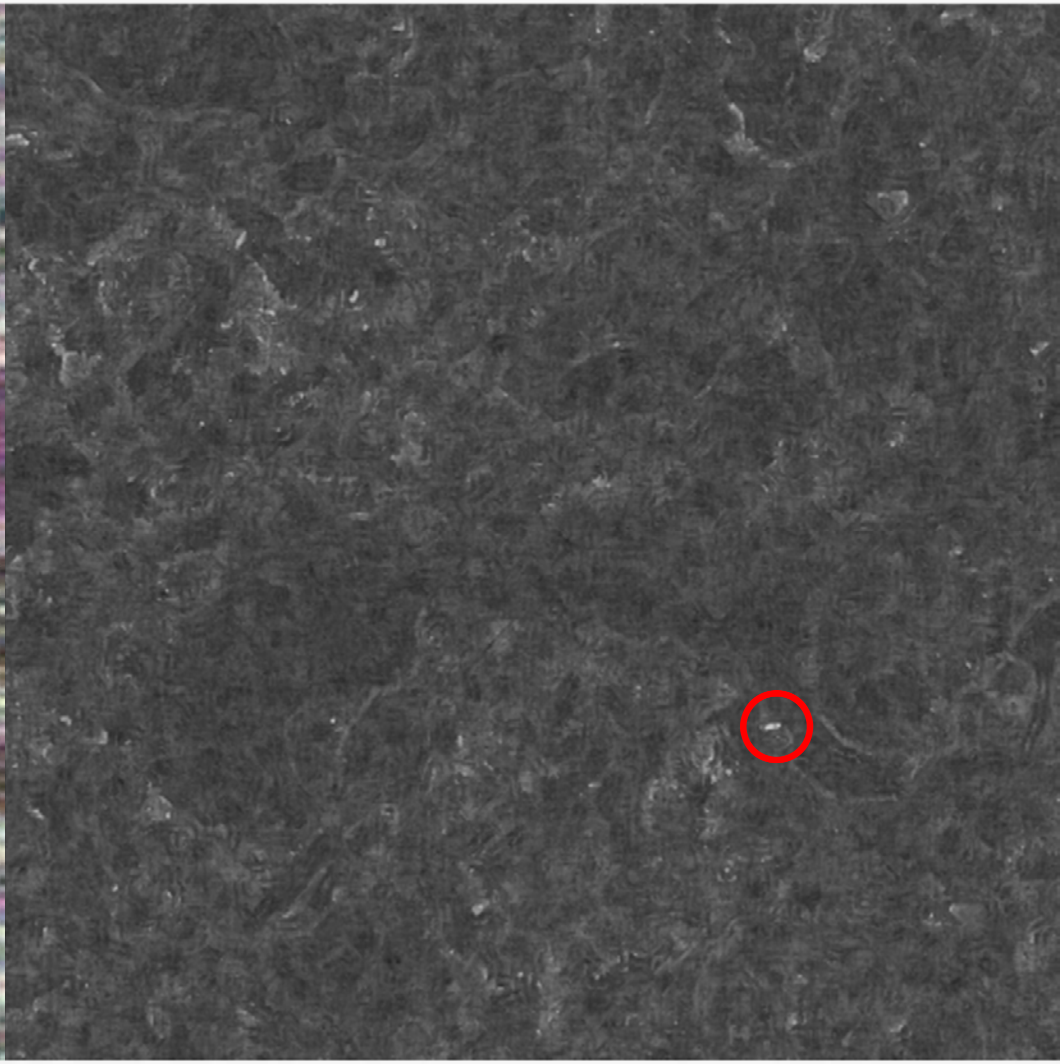




Pauli basis

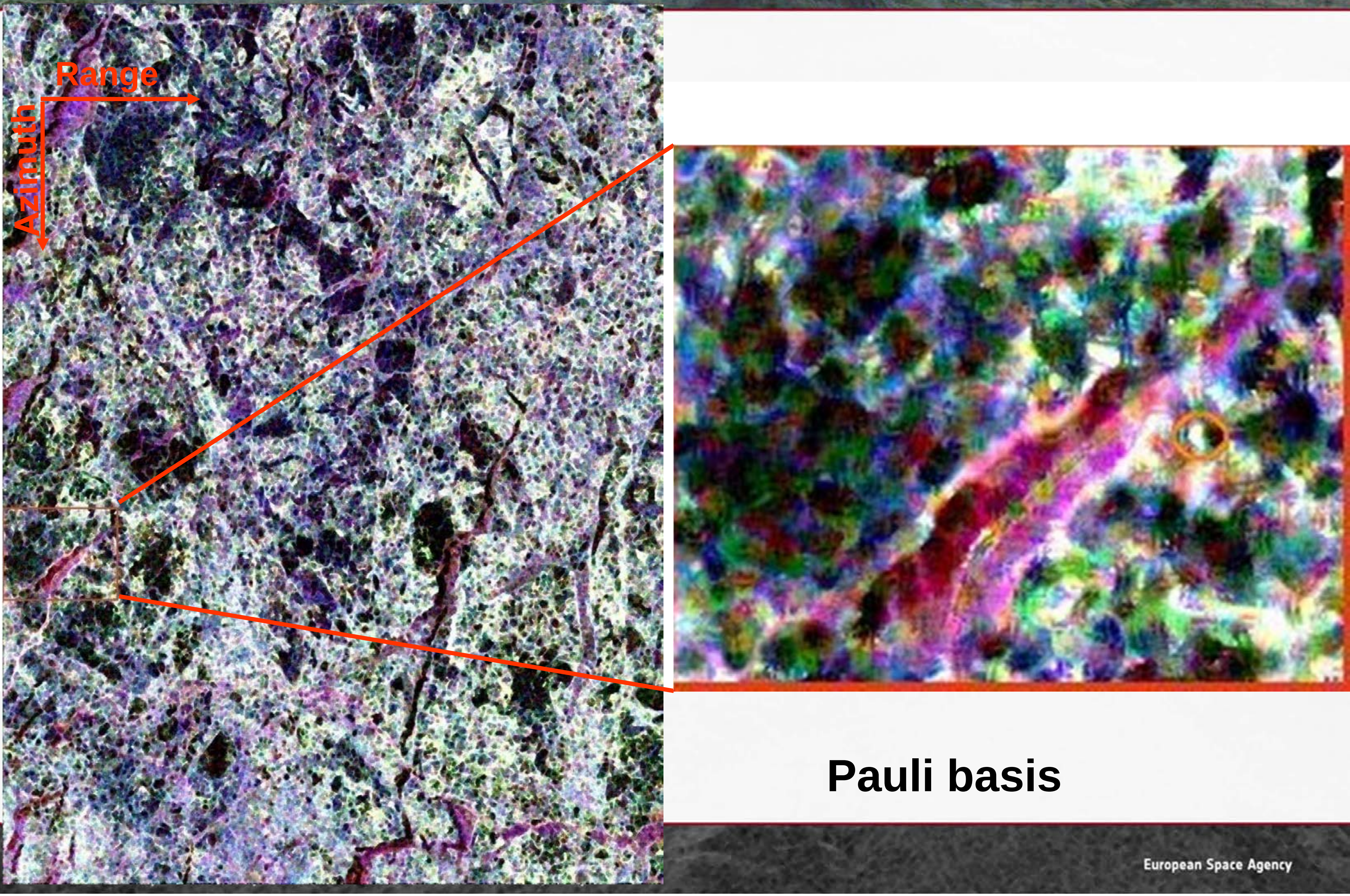
12 April 2011 Ship vs. Ice





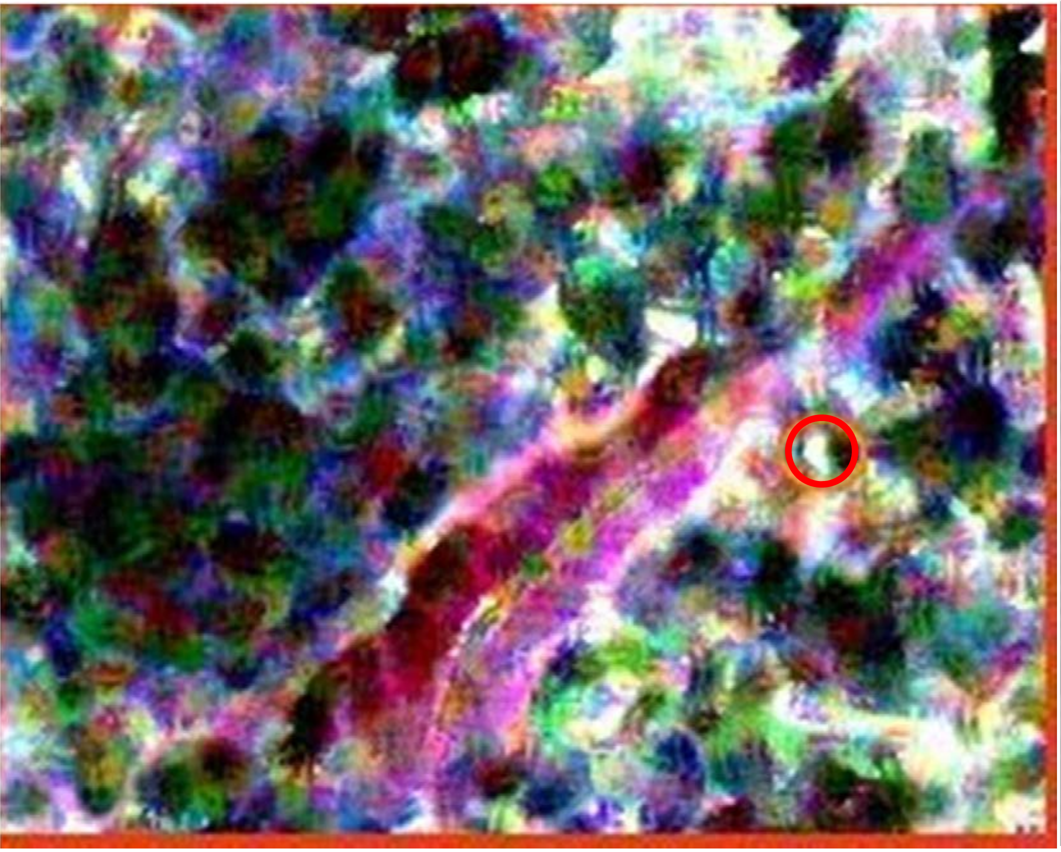
⇨ Spectral locations:4 ⇨ Direction: 2 in Azimuth, 2 in Range

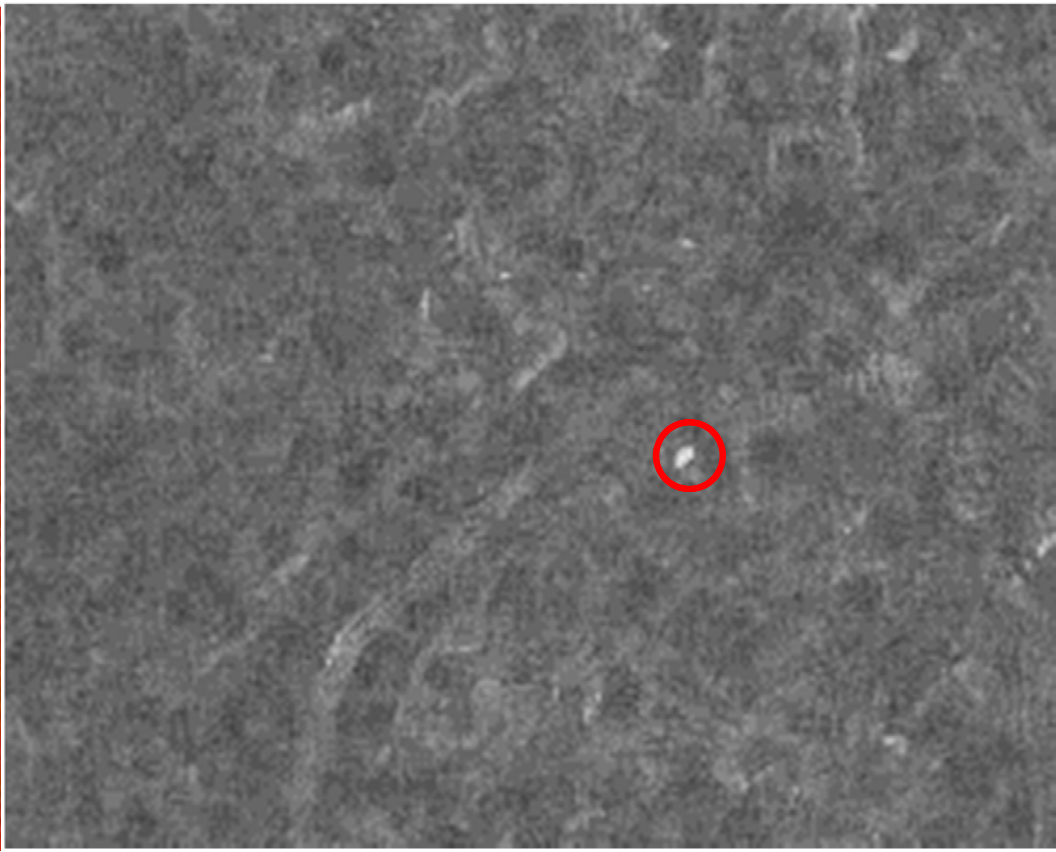
13 April 2011



Pauli basis

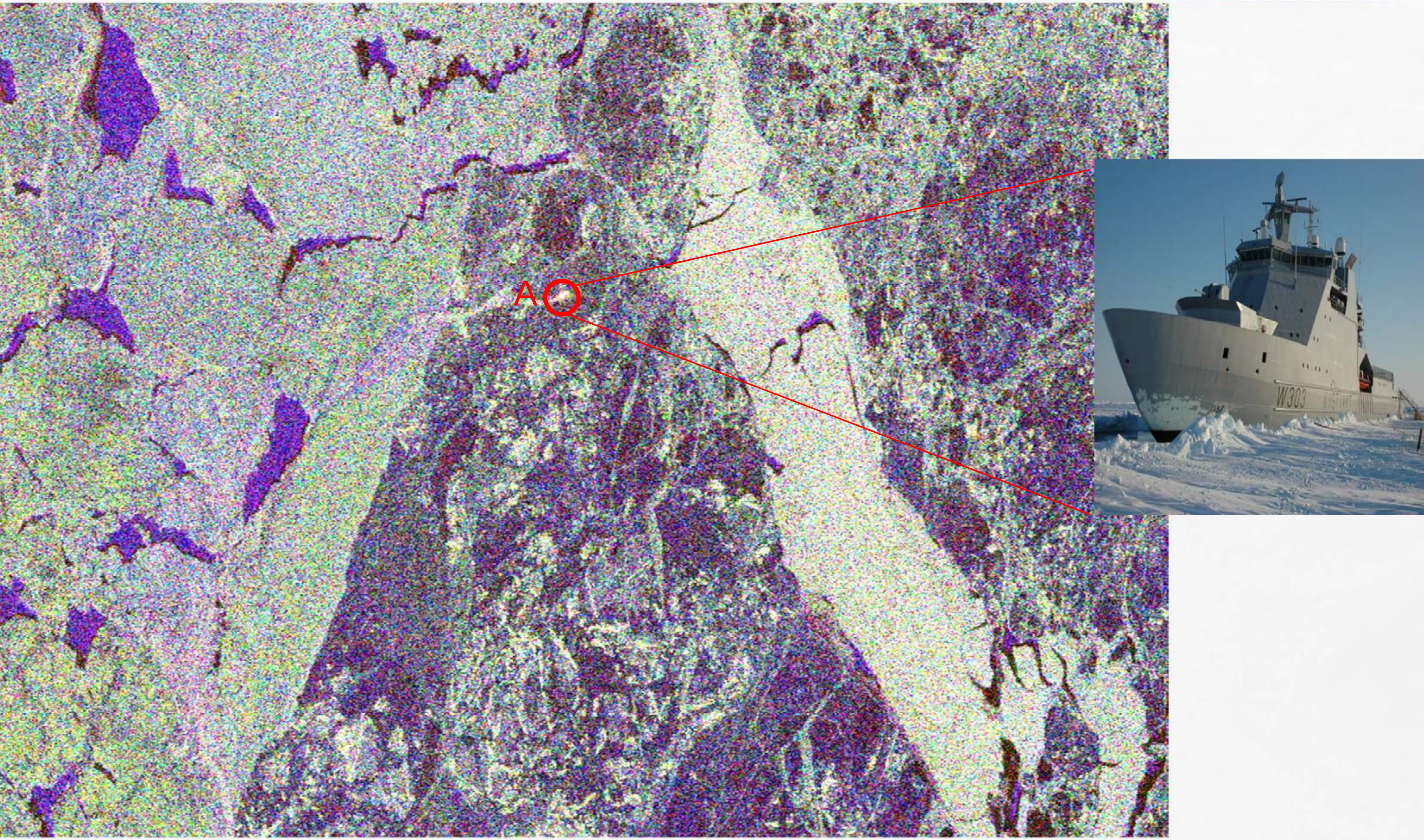
13 April 2011 Ship vs. Ice



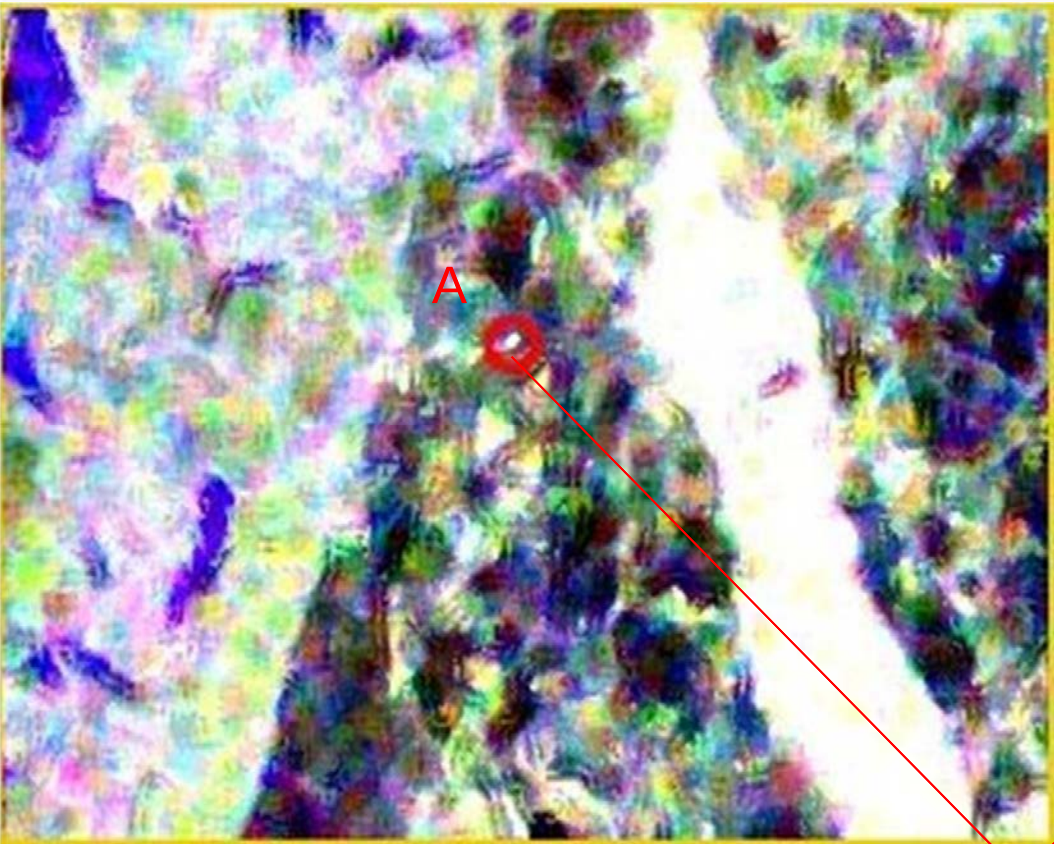


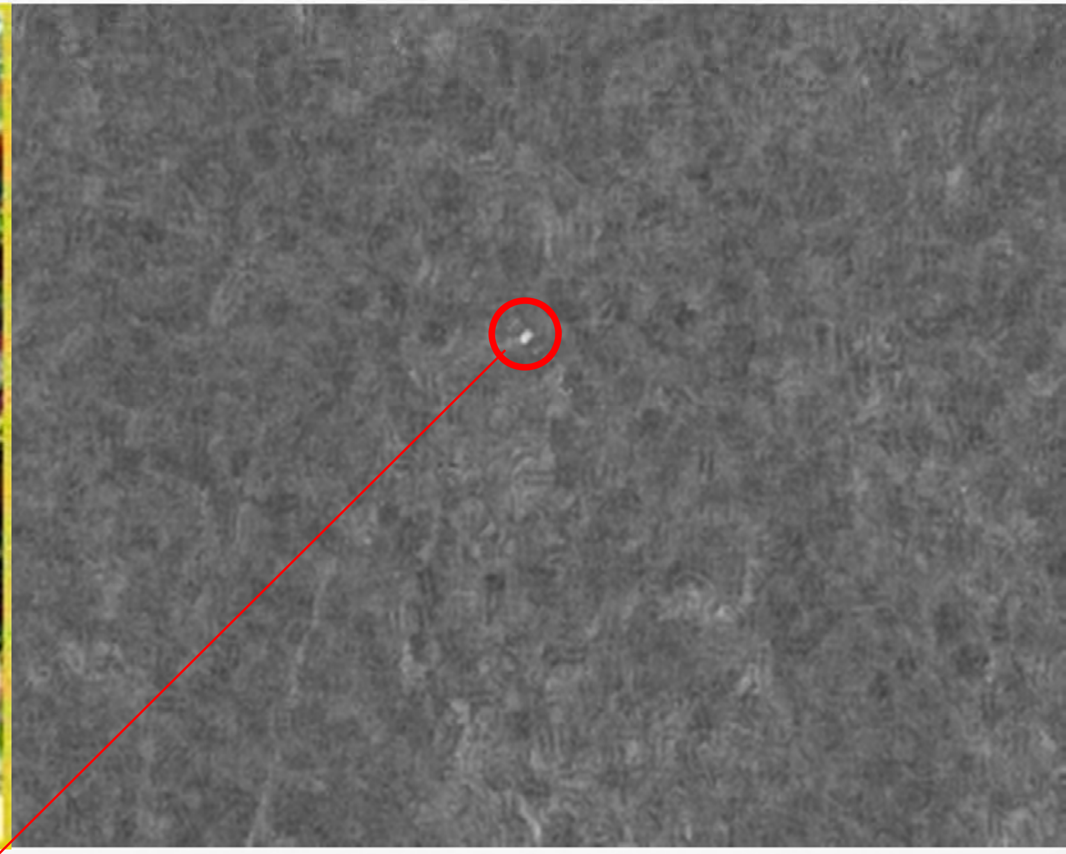
⇨ Spectral locations:4 ⇨ Direction: 2 in Azimuth, 2 in Range

Where is the ship?



11 April 2011 Ship vs. Ice





Conclusion

- **T-F coherence analysis**
  - ⇨ A multi-data set, polarimetrically adaptive, detector
  - ⇨ Coherent behavior : (3R $\times$ 3R) TF normalized coherence matrix
  - ⇨ a novel detector: TF-Pol coherence indicator ρ_{TF-Pol}
- **Application to ship detection**
  - ⇨ Ship vs. Small Natural island
  - ⇨ Ship vs. Artefact ('Ghosts')
  - ⇨ Ship vs. Sea ice
- **Enhance contrast efficiently beween ships and background**
  - ⇨ When full-res polarisation does not perform well (high entropy)
  - ⇨ In very difficult environements (low Signal to Clutter Ratio)
- **Ongoing and future work**
  - ⇨ using dual polarization data for ship detection
  - ⇨ Improved statistical T-F descriptors