RFI mitigation options for Uniboard²

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Outline

- **The options**
- **Spatial processing :**
    - **the context**
    - **The cyclostationarity concept**
    - **First example : Cyclic detectors**
    - **Second example : Estimation and subtraction**
    - **Third example : cyclic spatial filtering**
- **Conclusions**

RFI mitigation options for Uniboard^2

Application		EC man month (mm) Deliverable : matlab golden model
Starting time		3 mm
Digital receiver		
	Impulse detector	3 mm
	Cyclostationary detector	3 mm
	Kurtosis detector	3 mm
	FFT2D + radon transform	4 mm
Bemformer		
	Pre -beamformer Cyclostationary detector	4mm
	Post-beamformer cyclostationary detector	3mm
	Spatial filtering	???
Correlator		
	Cyclostationary detector	6 mm
Pulsar machine		
	Upgrade of Uniboard design	3 mm

Spatial processing

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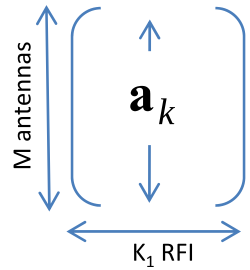
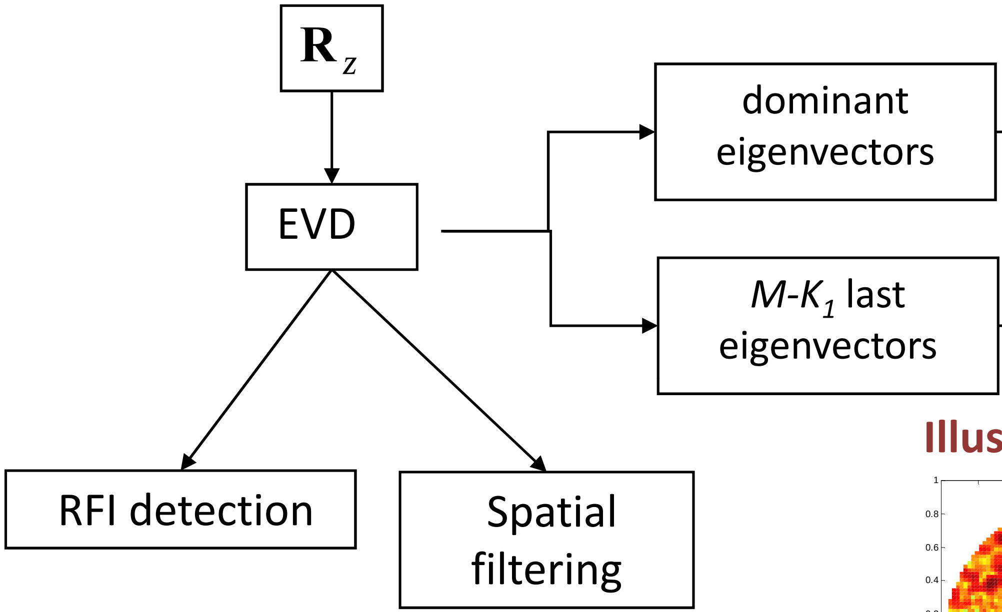
Classic approach

Hypothesis : $\mathbf{R}_z \approx \underbrace{\mathbf{A}_r \mathbf{R}_r \mathbf{A}_r^H}_{\mathbf{R}_{\text{rfi}}} + \underbrace{\sigma_n^2 \mathbf{I}}_{\mathbf{R}_{noise}}$

$\mathbf{A}_r =$



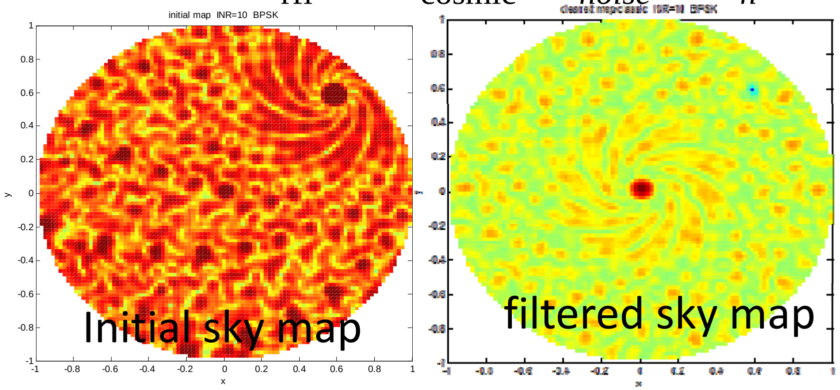


$\mathbf{U}_S \cong \mathbf{A}_r$ *Signal subspace depending* ***on RFI***

$\mathbf{U}_N$ *Noise subspace*

(see papers from A. Leshem, A.J. Boonstra, A.J van der Veen)

Illustration: $P_{\text{rfi}} >> P_{\text{cosmic}}, \mathbf{R}_{noise} = \sigma_n^2 \mathbf{I}$



General case issue

$$\mathbf{R}_z = \underbrace{\mathbf{A}_r \mathbf{R}_r \mathbf{A}_r^H}_{\mathbf{R}_{\text{rfi}}} + \underbrace{\mathbf{A}_s \mathbf{R}_s \mathbf{A}_s^H}_{\mathbf{R}_{\text{cosmic}}} + \underbrace{\mathbf{R}_n}_{\mathbf{R}_{\text{noise}}} \approx \mathbf{R}_{RFI} + \sigma_n^2 \mathbf{I}$$

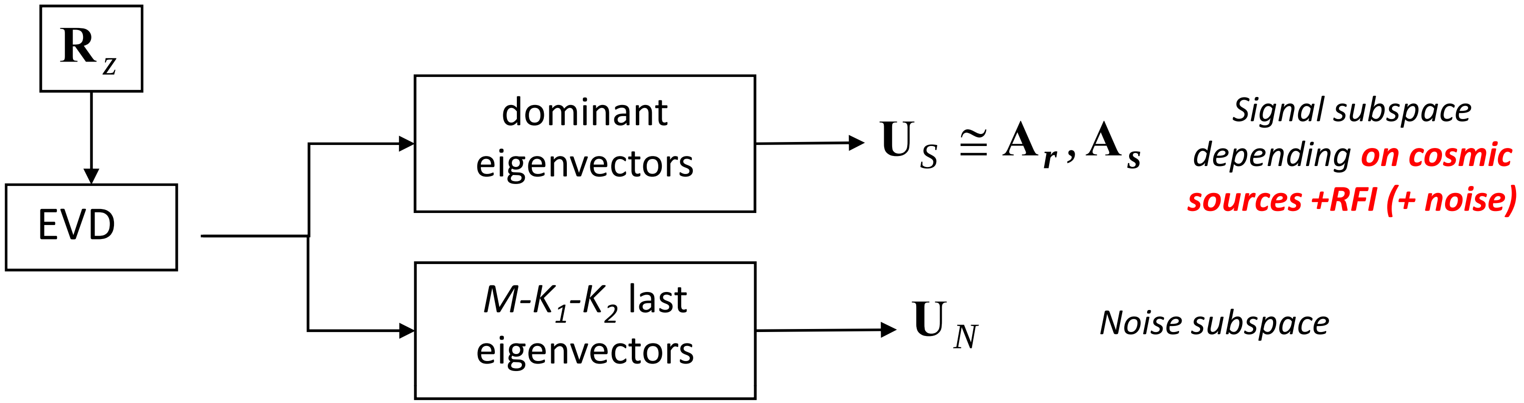
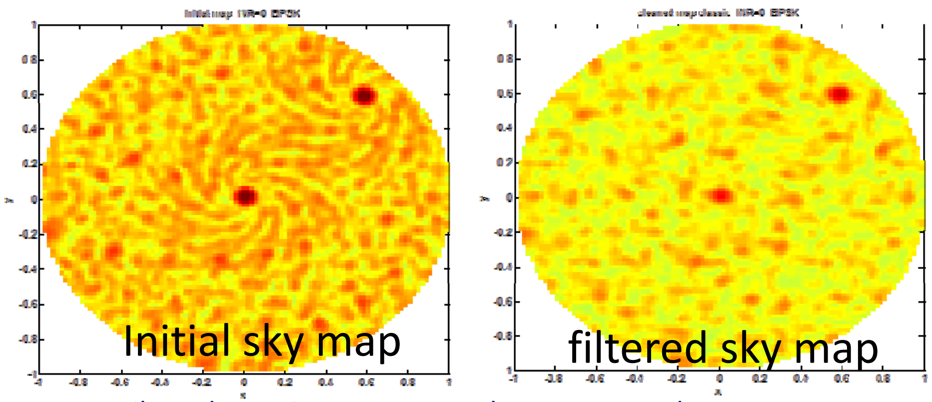


Illustration with :

$$P_{\text{rfi}} \approx P_{\text{cosmic}}$$

$$\mathbf{R}_{noise} = \sigma_n^2 \mathbf{I}$$



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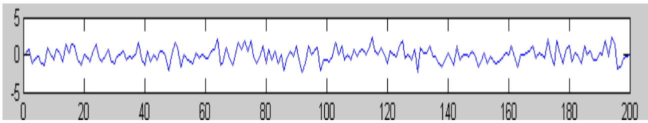
Cyclostationarity concept

Stationary process

≈ statistics time-independent

Example : second order statistics

s(t) or n(t)



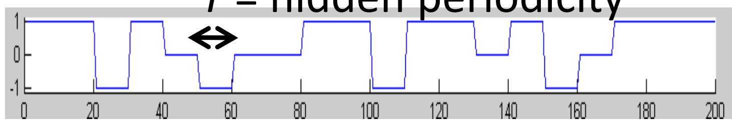
$$R(t,\tau) = R(\tau)$$

Cyclostationary process

≈ statistics are periodic

T = hidden periodicity

r(t)

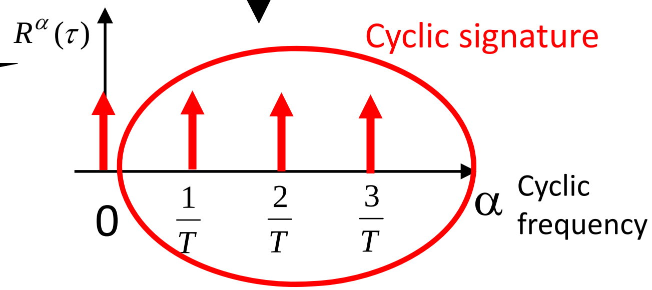


$$R(t+T,\tau) = R(t,\tau)$$

$FT_t(\alpha)$

Cyclic correlation

$$R^{\alpha}(\tau)$$



In practice : $R_z^{\alpha}(\tau) = \left\langle z(t+\tau/2)\,z^*(t-\tau/2)\exp(-j2\pi\alpha t)\right\rangle_{\infty}$

⇨ Gardner and Giannakis

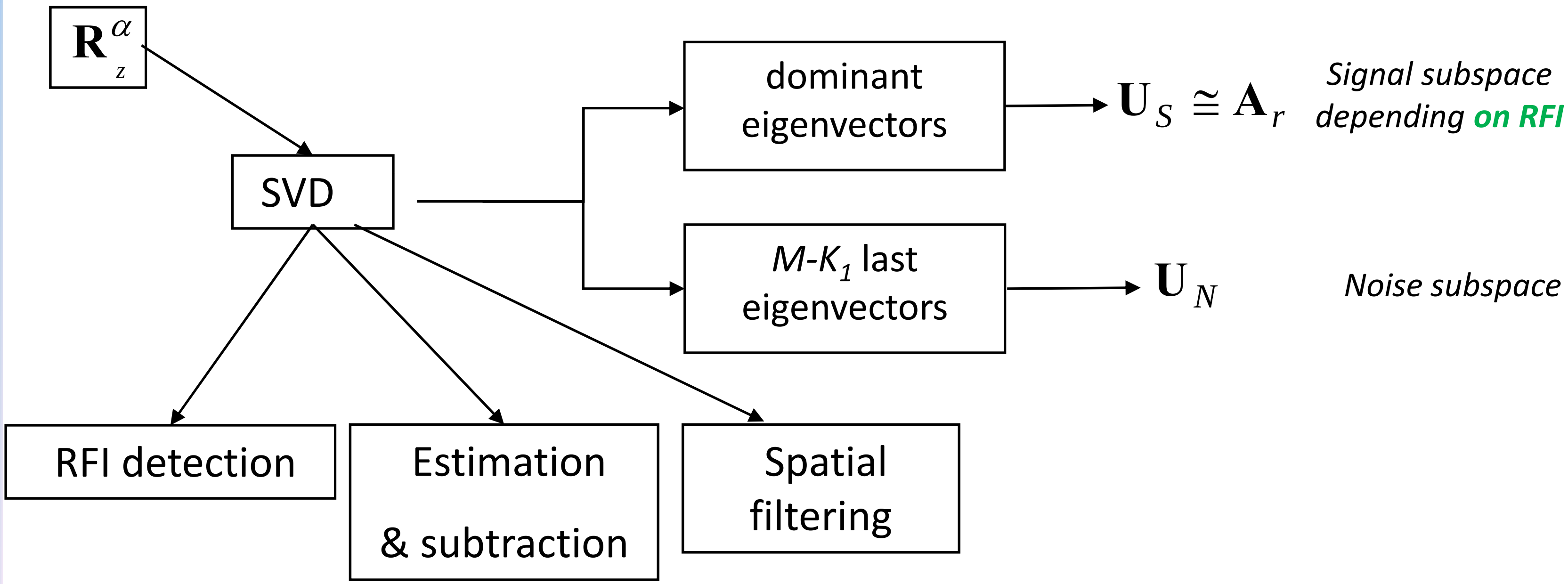
The multidimensional case

$$\mathbf{R}_z^{\alpha} = \left\langle \mathbf{z}(t+\frac{\tau}{2})\mathbf{z}^H(t-\frac{\tau}{2})\exp(-j2\pi\alpha t)\right\rangle_{\infty}$$

Cyclic correlation matrix

$$= \underbrace{\mathbf{A}_r\mathbf{R}_r^{\alpha}(\tau)\mathbf{A}_r^H}_{\mathbf{R}_{RFI}^{\alpha}(\tau)} + \mathbf{A}_s\mathbf{R}_s^{\alpha}(\tau)\mathbf{A}_s^H + \mathbf{R}_n^{\alpha}(\tau)$$

$\mathbf{A}_s\mathbf{R}_s^{\alpha}(\tau)\mathbf{A}_s^H \rightarrow 0$, $\mathbf{R}_n^{\alpha}(\tau) \rightarrow 0$



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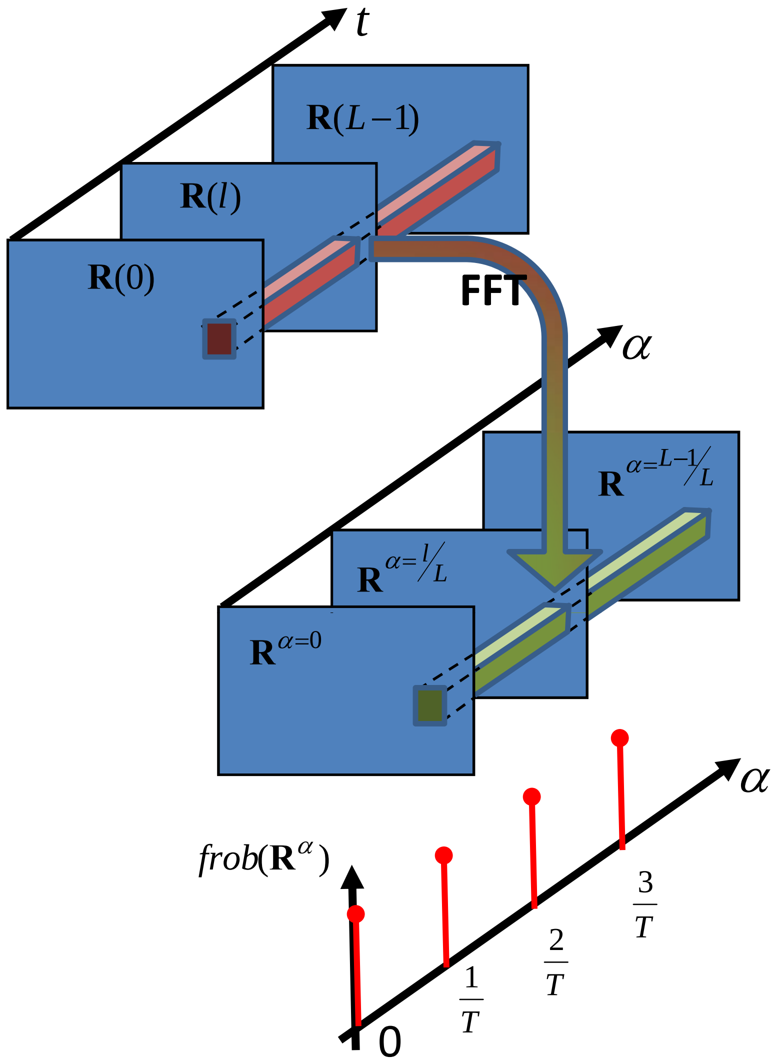
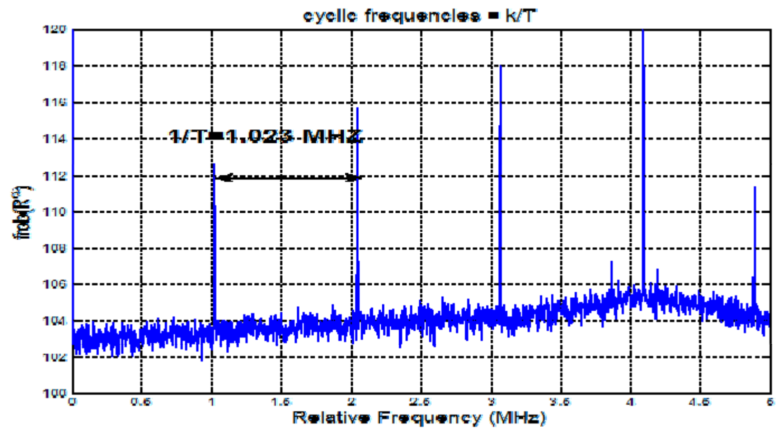
Cyclic detectors



	AM	BPSK	M-PSK	M-QAM
α for R^{α}	none	$1/T_{symbol}$	$1/T_{symbol}$	$1/T_{symbol}$
α for $\overline{R}^{\alpha}$	$2f_0$	$2f_0 + k/T_{sym}$	none	none

Example at Westerbork telescope with GPS data

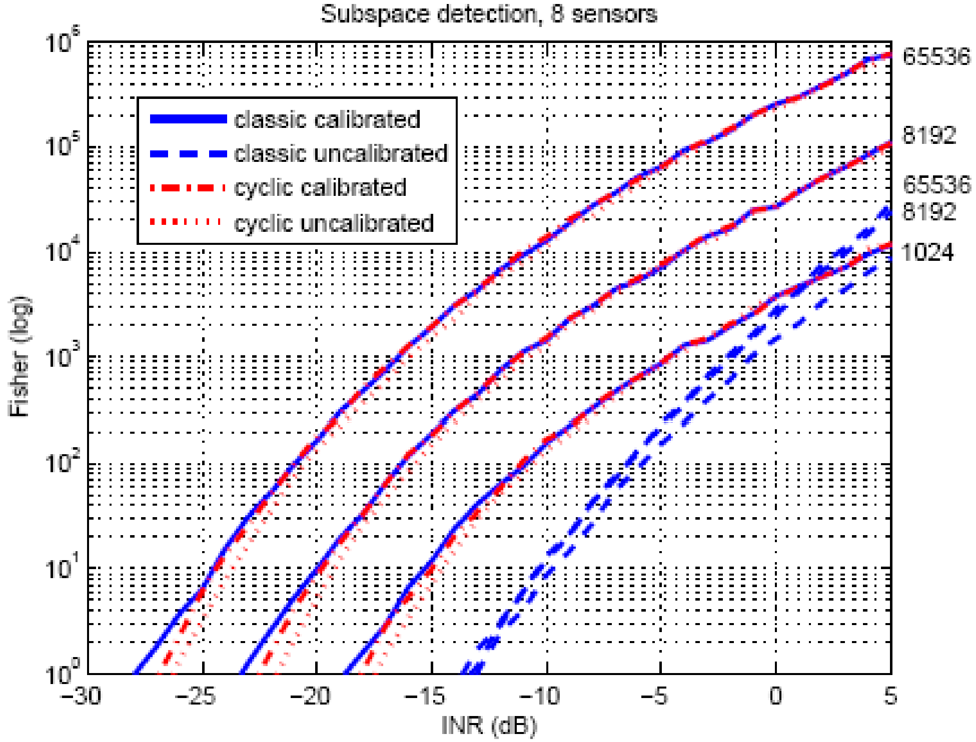


Several implementations:

- Blind detector
- $frob(\mathbf{R}^{\alpha=k/T}) = \sum \lambda_k^2$
- $\max(\lambda_k)$

Cyclic detector performance

AM RFI, no cosmic sources
Power fluctuations between antennas = 20%



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Estimation & subtraction (1)

Consider 1 BPSK RFI : $r(t) = \sum_k c_k h(t - kT - t_0)\ell^{j2\pi f_0 t + j\varphi_0}$

1) $\overline{\mathbf{R}}_z^{\alpha=2f_0} = \mathbf{a}_r \mathbf{a}_r^T \frac{\sigma_r^2}{T} R_h . \ell^{j2\pi\varphi_0}$

2) SVD

3)

$$\mathbf{R}_z = \mathbf{a}_r \mathbf{a}_r^H \frac{\sigma_r^2}{T} R_h + \mathbf{R}_{\text{cosmic}} + \mathbf{R}_{\text{noise}}$$

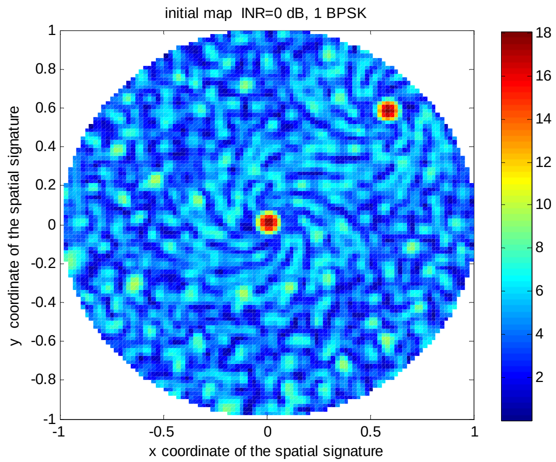
4) $\hat{\mathbf{R}}_{\text{rfi}}$

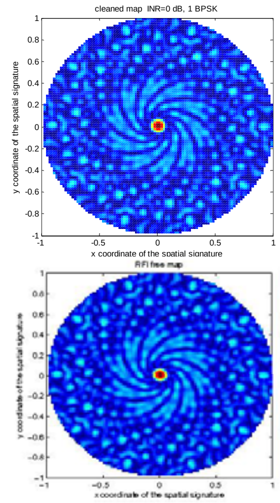
5) $\mathbf{R}_z^{clean} = \mathbf{R}_z - \hat{\mathbf{R}}_{\text{rfi}}$

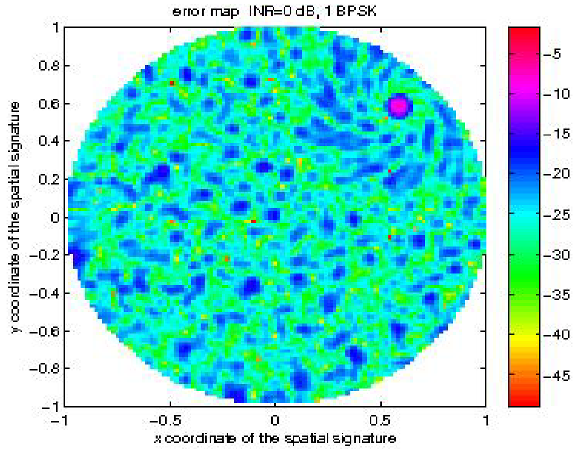
→ OK for AM, BPSK + QAM if h(t) known

Estimation & subtraction (2)

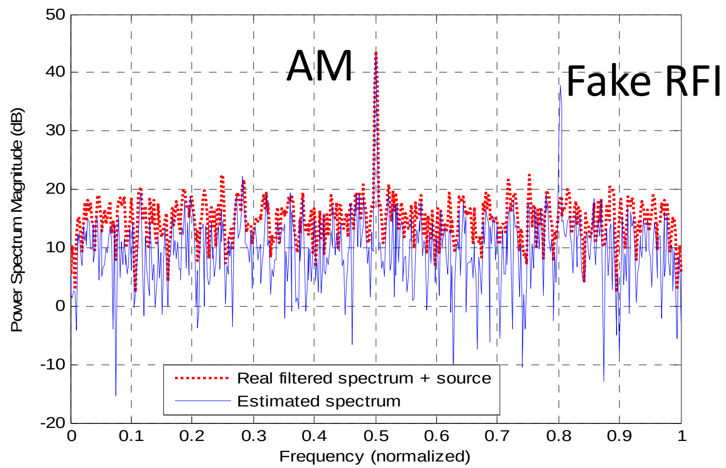
Simulation with a BPSK RFI







Example of an AM RFI in the LOFAR band



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Cyclic Spatial Filtering (1)

Spatial filtering:

1) projector $\mathbf{P} = \mathbf{I} - \mathbf{A}_r(\mathbf{A}_r^H \mathbf{A}_r)^{-1}\mathbf{A}_r^H$

2) cleaning: $\mathbf{R}_{clean} = \mathbf{PRP}$

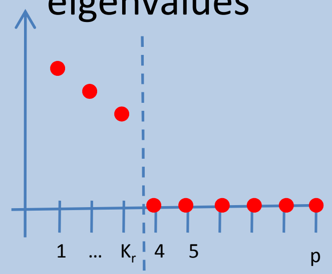
Estimation of $\mathbf{A}_r$:

1) SVD : $\mathbf{R}^{\alpha} = \mathbf{U\Lambda V}^H$

2) Extract the RFI subspace : $\mathbf{U}_r$

3) Since $\mathbf{U}_r = span\{\mathbf{A}_r\}$

⇨ Projector $\mathbf{P} = \mathbf{I} - \mathbf{U}_r(\mathbf{U}_r^H \mathbf{U}_r)^{-1}\mathbf{U}_r^H$



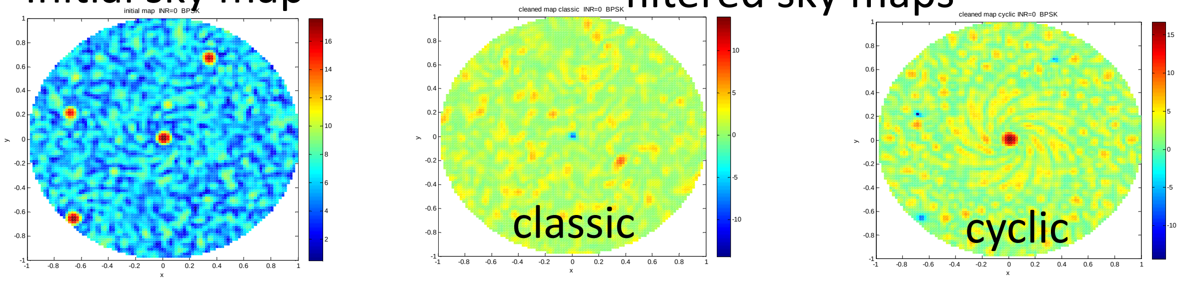
$\mathbf{U} = [\mathbf{U}_r \mid \mathbf{U}_{\text{noise}}]$

eigenvectors

Simulations with 3 BPSK

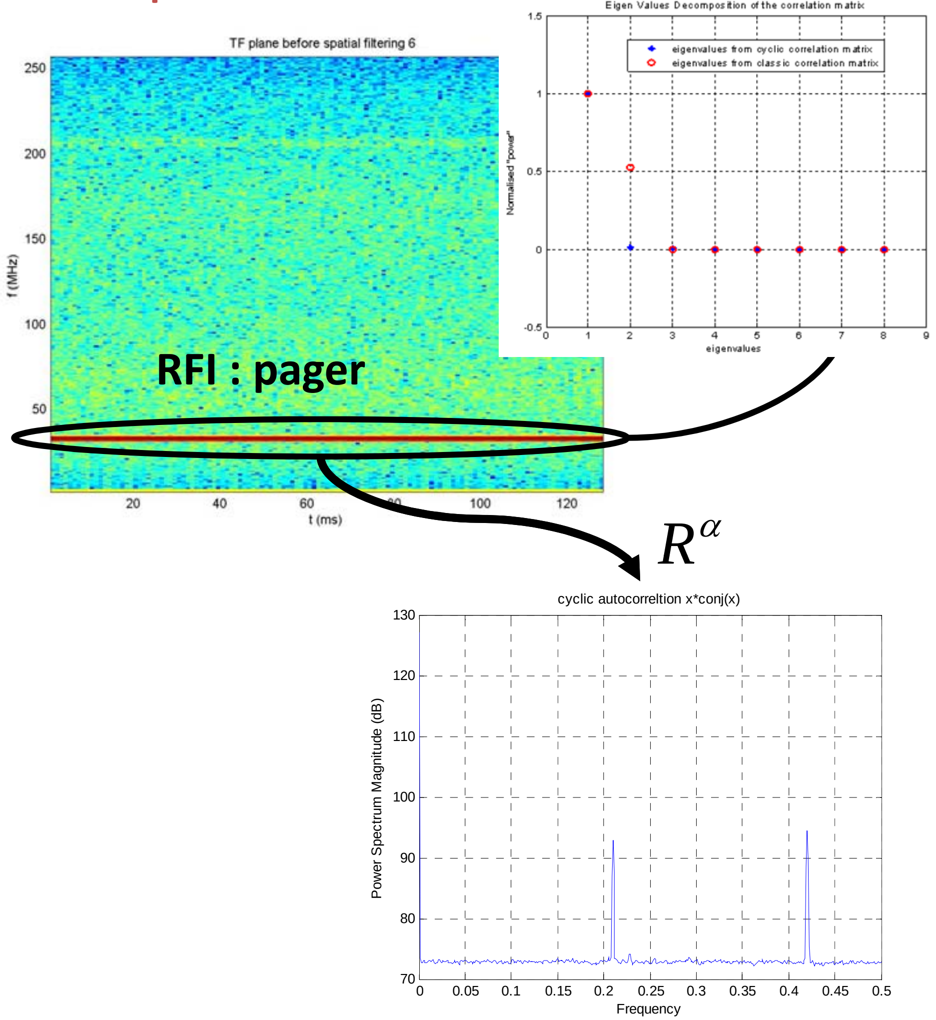
Initial sky map

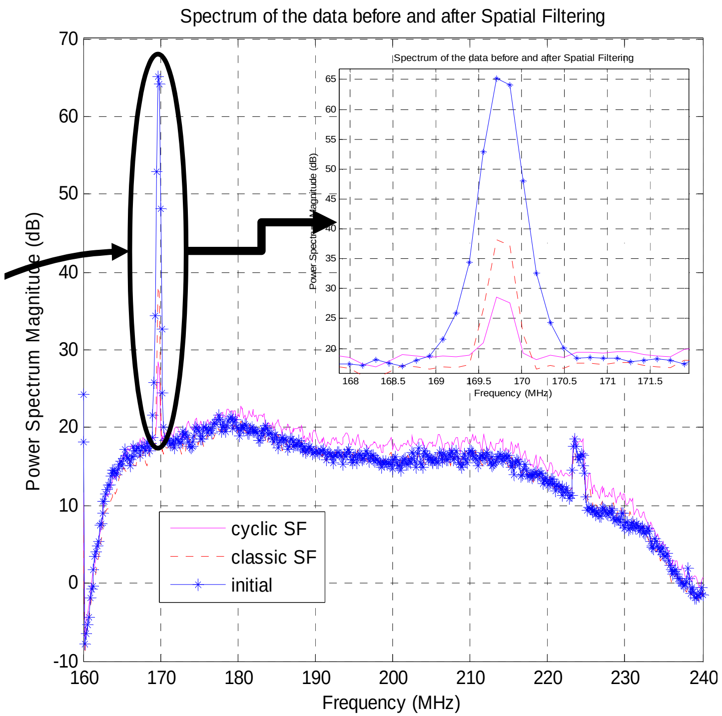
filtered sky maps



Cyclic Spatial Filtering (2)

Example with real data from LOFAR





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In collaboration with Astron,
PhD student will start to work on spatial filtering