SETI and RFI

Separating Terrestrial and Extra-Terrestrial Transmissions

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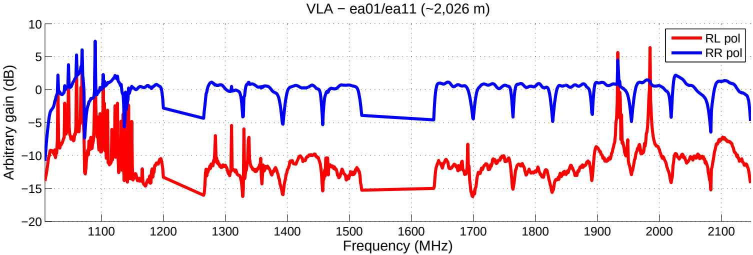
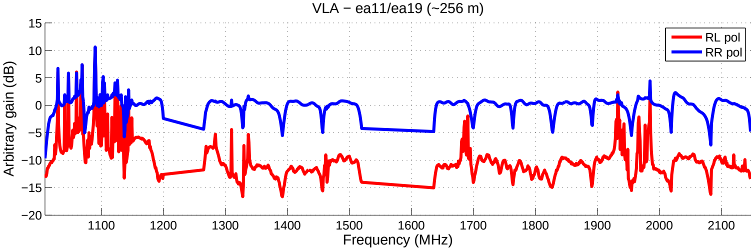
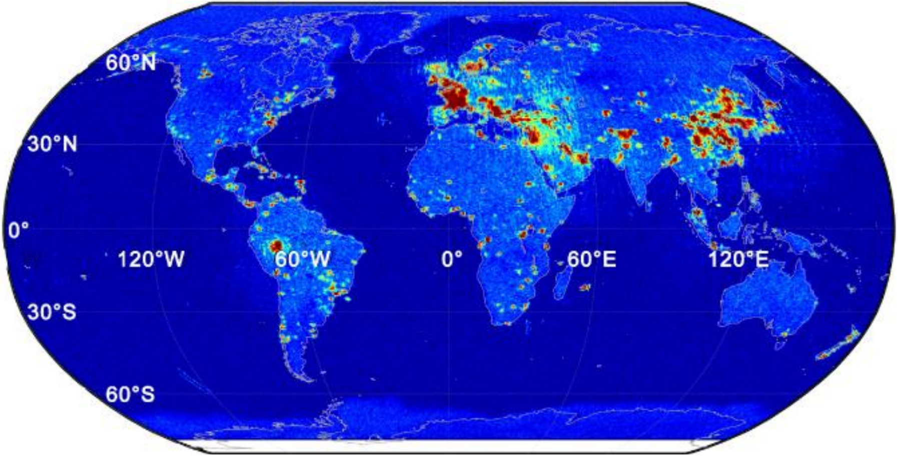
RFI and radio astronomy



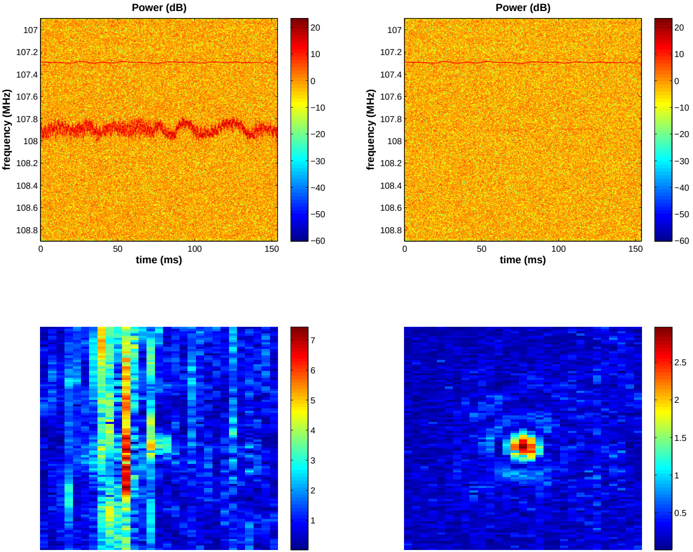


RFI and radio astronomy

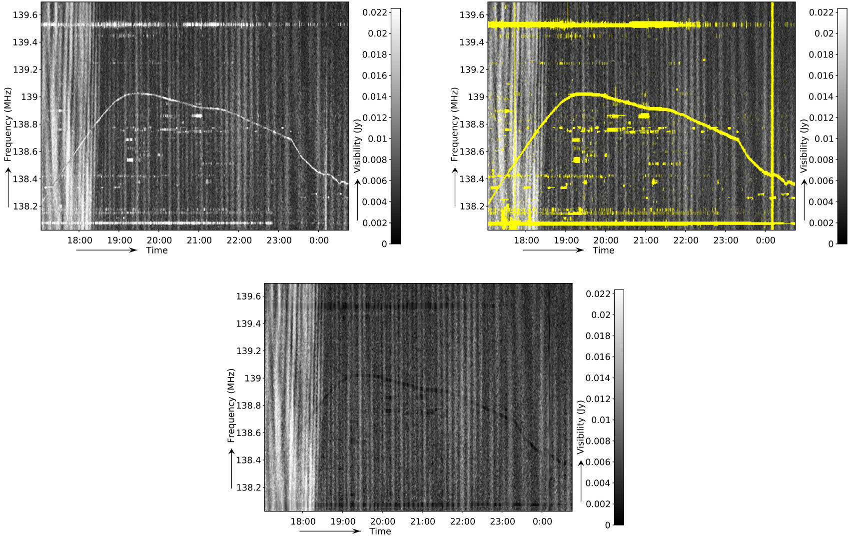
SMOS satellite system (1400-1420 MHz)



RFI mitigation



“Automatic” approach



Generalities on RFI mitigation

Instrumentation for radio astronomy:

- Primary goal is radio astronomy
- Adapted to observe noise-like sources

RFI mitigation:

- Community reached an overall understanding of how RFI affects data
- "Classic" statistical methods (power-based) efficient but rough
- "Sophisticated" methods complicated and model dependent

In Communications:

- Signal detection and mitigation is common business (IEEE 802.22)
- Less sensitive equipment and narrower bandwidth
- Exploitation of a variety of signal feature

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Generalities on SETI and RFI

- Assume proper separation between astro sources and RFI / ET
- Focus on what is not astro
- Strategy:
  - Detect all possible "artificial" transmissions
  - Separate ET from RFI (space and space-time)
- Big data?? *big enough??*
- Sensitive enough to catch the contact?
- SETI at known corrupted frequencies?
- Is Fourier space adapted?

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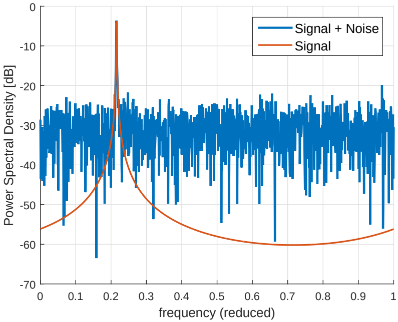
Classic instrumentation

- Produces energy distribution over frequencies
- Natural solution : Energy detector
  - Efficient implementation
  - Model-independent
- Intrinsically limited by SNR
- Additional limits from:
  - Estimation noise
  - Variable RFI environment
  - Noise uncertainties
- Trick : virtually getting rid of system noise



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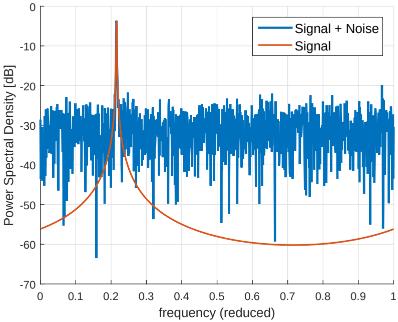

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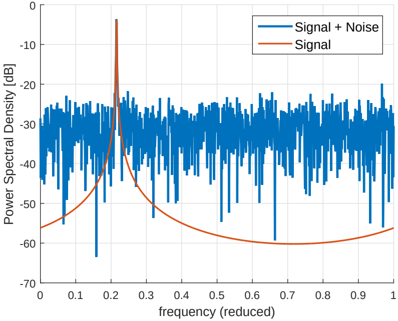

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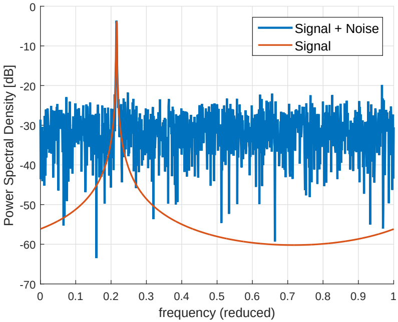

Adaptive processing

$$\mathbf{x}_{\text{obs}}(t) = \mathbf{x}_{\text{astro}}(t) + \mathbf{x}_{\text{artificial}}(t) + \mathbf{x}_{\text{noise}}(t)$$

Find parametrized function f_θ such that:

$$f_\theta\left(\mathbf{x}_{\text{obs}}(t)\right) \approx f_\theta\left(\mathbf{x}_{\text{artificial}}(t)\right)$$

Exploited for:

- Detection : monitor $f_\theta\left(\mathbf{x}_{\text{obs}}(t)\right)$ for all θ
- Mitigation : $\mathbf{x}_{\text{corrected}}(t) = \mathbf{x}_{\text{obs}}(t) - \alpha f_\theta\left(\mathbf{x}_{\text{obs}}(t)\right)$ for $\theta = \hat{\theta}$

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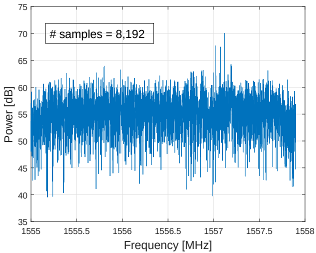
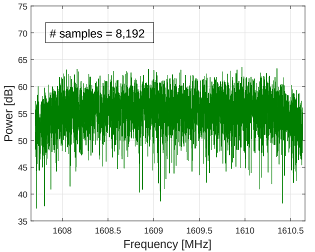
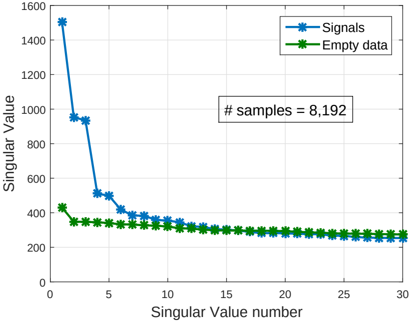
Time-covariance

Karhunen-Loeve Transform “explains” the auto correlation

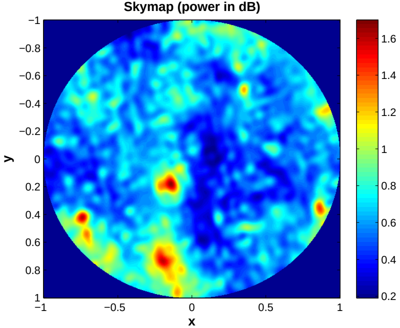




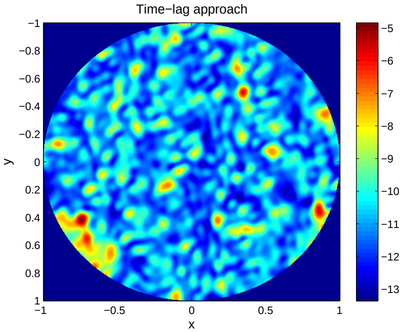


“Colored” process extraction

'Standard' data:



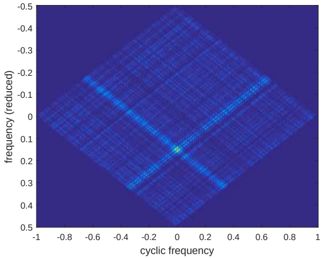
'Time-lagged' data:

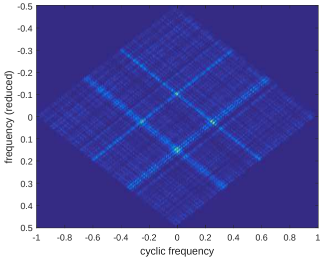


Feature extraction / exploitation

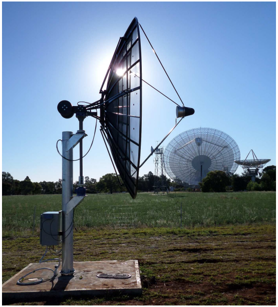
Exploitable features include:

- Interference-to-Noise Ratio
- Higher order statistics
- Polarization
- Non-/cyclo-stationarity
- Non-circularity
- Signal bandwidth
- Sparsity
- Dispersion
- Near / Far field
- Spatial location
- ...??





Exploiting the spatial location



$$\mathbb{E}\left\{\mathbf{x}(t)x_{\text{ref}}^{*}(t)\right\} = \gamma_{\text{ref}}\ \mathbf{a_r}$$

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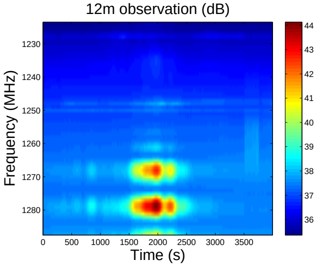
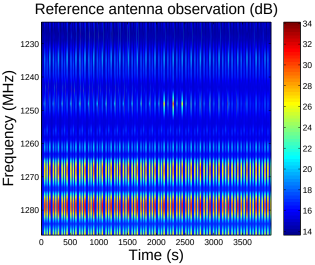
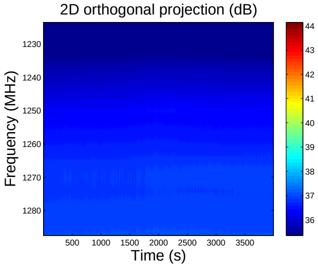






Time-domain covariance-based detection

Auto-Correlation Matrix:

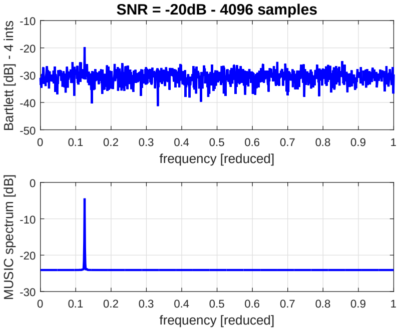
$$\hat{\mathbf{R}}_{xx^*_{i,j}} = \frac{1}{M}\sum_{k=1}^{M} x(k+i)x^*(k+i-j])$$

$\rightarrow$ separate into "signal" and "noise" subspace
$\rightarrow$ KLT : deduct signal model from eigen values and vectors

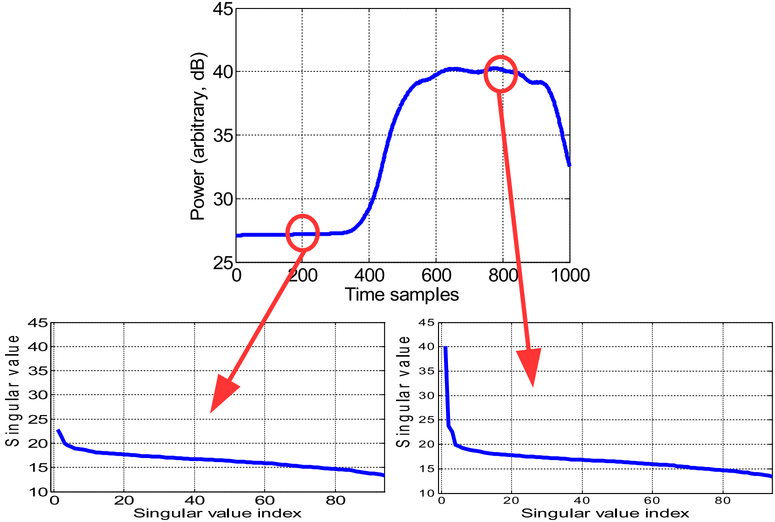
MUSIC:

- MUltiple SIgnal Classification
- "High-resolution" technique
- Find poles in noise subspace

$$S_{\text{MUSIC}}(f) = \frac{1}{\mathbf{e}_f^H \mathbf{U}_{\text{noise}} \mathbf{U}_{\text{noise}}^H \mathbf{e}_f}$$



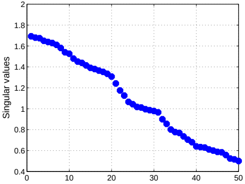
Spatial-domain covariance-based detection



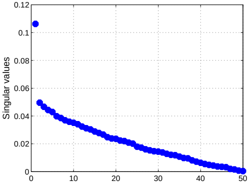
Spatial information

- Interferometers / phased array telescopes provide spatial information
- Calibrated arrays allow DoA estimation
- ET signals spatially stationary and impinge through primary lobe
- RFI likely non-stationary and impinge through side lobes
- "Non-astronomical" features exploited to isolate a source

Classic covariance matrix:



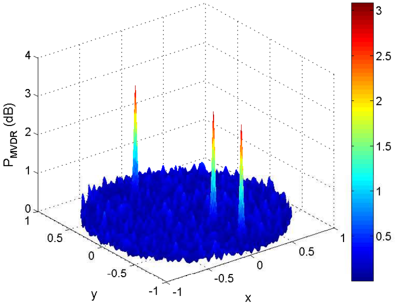
Cyclic covariance matrix:



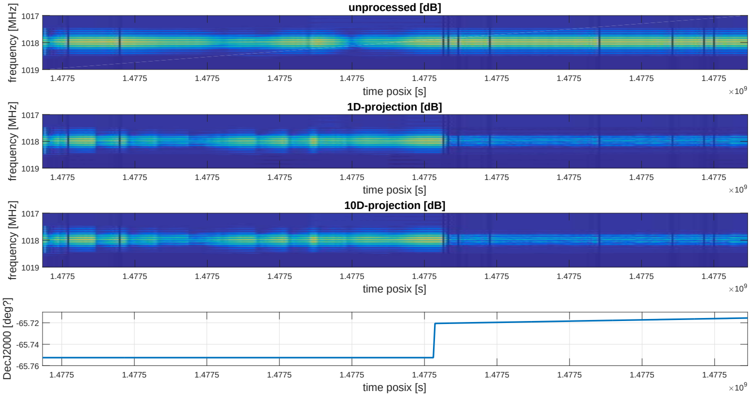
50 elements - INR $= -5$ dB - 10^5 samples - 60% gain uncalibration

DoA estimation

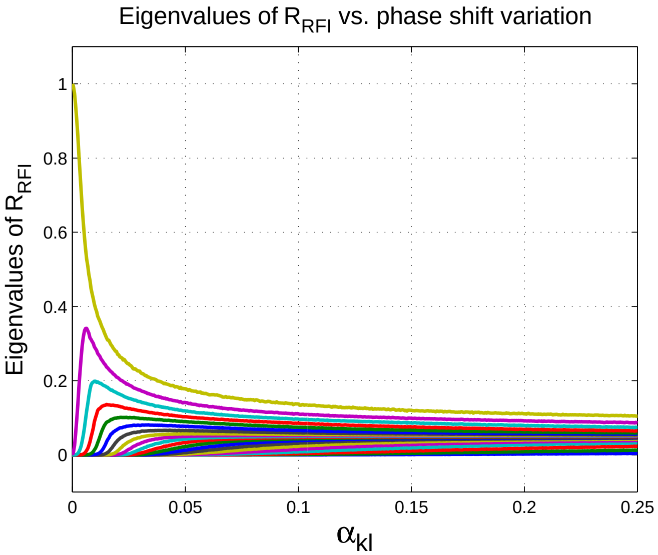
- Requires array calibration (primary beam)
- Enables primary / side lobes distinction
- "High-resolution" techniques based on optimization
- Resolution given by instrument
- Angular Resolution Limit $\neq$ Beam width



Spatial covariance as a motion sensor



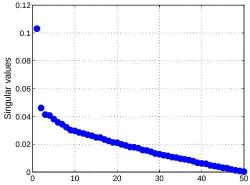
RFI subspace dimensionality



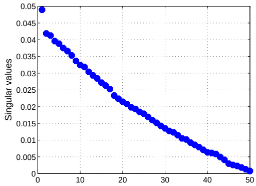
Subspace smearing

- Subspace smearing due to model misspecification (spatial non-stationarity)
- Limits deep-nulling
- Always observed with RFI
- Possible robust motion RFI detector
- Stationary signal likely to be ET

Stationary RFI:



Moving RFI:



Conclusions

- Sensitivity of astronomy instrumentation is necessary for SETI
  explore SNR space
- Taking *big data* requires *big thoughts*
  standard astronomical data products limit sensitivity to non-astronomical sources
- Lot to learn from telecom / spectrum sharing communities
  encourage to people do differently
- Need for data sharing and standardization
  build a strong community, foster collaborations and ideas
- **Monthly SETI Collaborative Meeting**:
  June 6 - 8AM CEST *(get in touch with me)*