Radio Interference in Large Bandwidth Observations
MPIfR, Bonn

9/4/2013

RFI Effects on Phased Array Feeds for Radio Astronomy

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Outline

1. Motivation
2. Square Kilometre Array and its Receivers
3. SKA and RFI vs. Effelsberg and RFI
4. RFI Mitigation with Phased Array Feeds
5. The Spoilsport: RFI (and our efforts to fight it)
6. Conclusions

Motivation

1. Hunger of Bandwidth:
   - More bandwidth = Higher sensitivity

$$\text{Sensitivity} \propto \sqrt{\text{Bandwidth}}$$

2. New Technologies, New Observatories:
   - The Square Kilometer Array

Credit: bbc.co.uk

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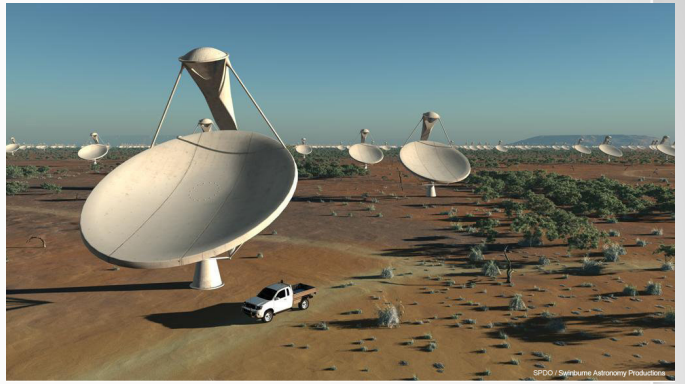
The Square Kilometre Array (SKA)

- The most powerful radio telescope ever built

Low Frequency Array

Mid Frequency Array



High Frequency Array

- Total Collecting Area: 1.000.000 square metres = 1km²
- Frequency Range of Operation: 10MHz – 10GHz
- Location: Split between South Africa and Western Australia
- Phase 1 (10%): 2016-2020, Phase 2: 2020-2024

SKA-technology Receivers

Ultra Broad Band Receivers

Large Bandwidths

BW ~ 3 – 12 GHz

Single Pixel

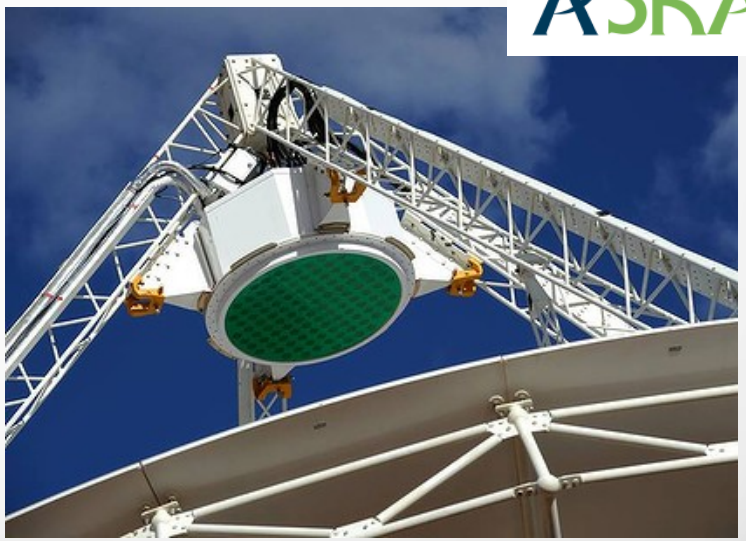
Ultra Broad Band Receiver on MeerKAT. Credit: antennamagus

Phased Array Feeds (PAFs)

Medium Bandwidths

BW ~ 300 MHz

Multiple Pixels



Checkerboard PAF on ASKAP. Credit: Justin McManus

SKA-technology at Effelsberg

Ultra Broad Band Receiver

MPIfR built its own

600MHz – 3000MHz

Already Operating

Ultra Broad Band Receiver for Effeslberg.
Credit: C. Kasemman (MPIfR HF-lab)

Phased Array Feed

Front-End from ASKAP

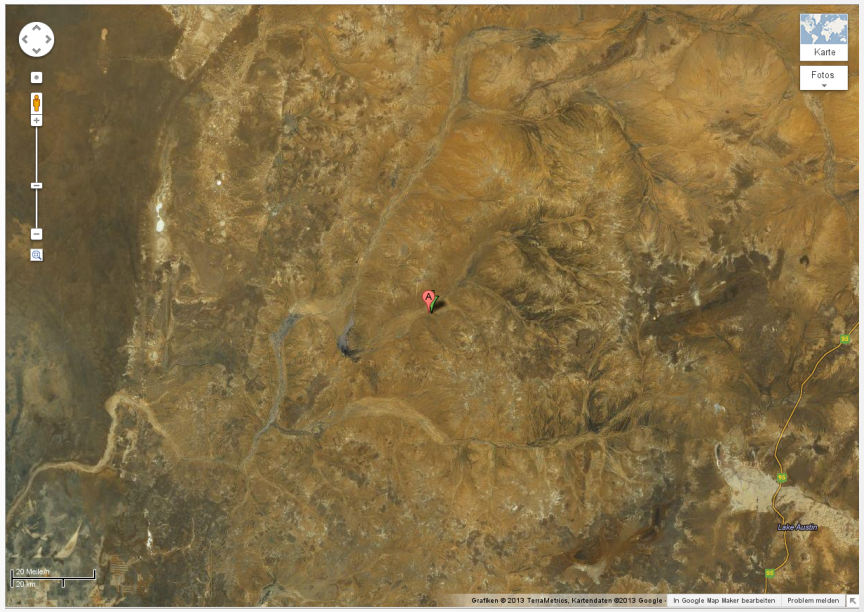
700MHz – 1800MHz

Coming soon

Checkerboard PAF MkII. Credit: Justin McManus

SKA vs. RFI: Playing Hide-and-Seek

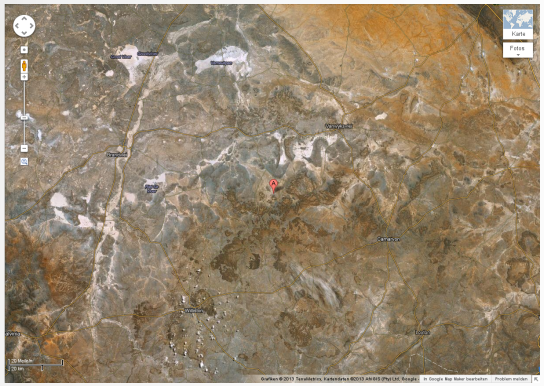
~ 300 km

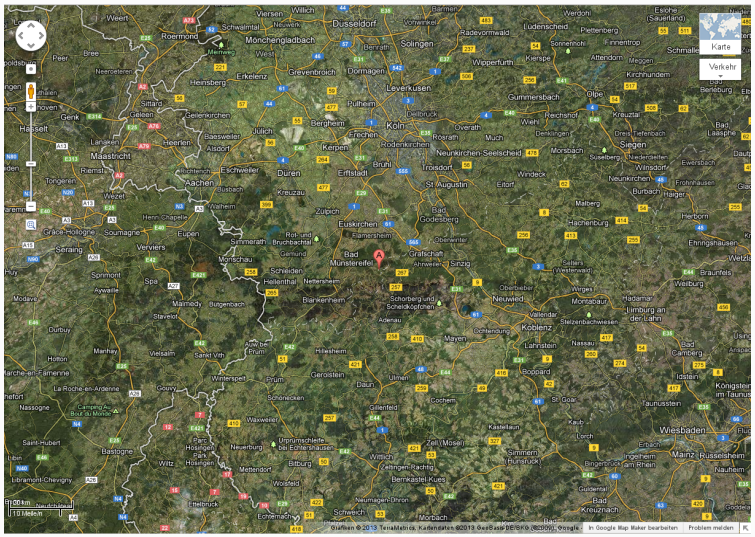


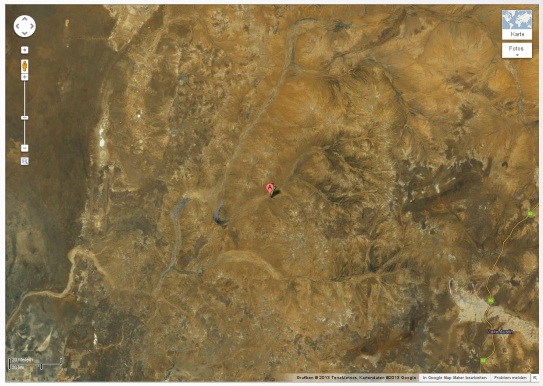
~ 300 km

RFI Environment at Effelsberg

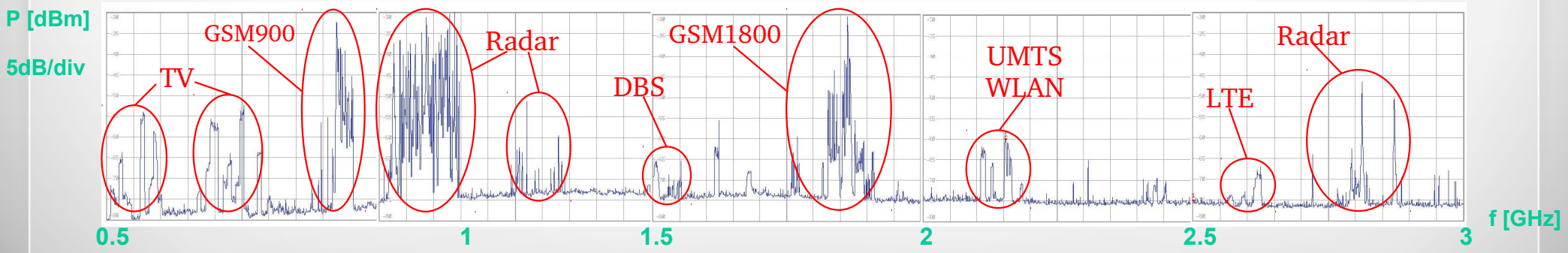
- Effelsberg Site is far from a desert...







Effelsberg RFI spectrum



Credit: R. Keller, K. Grypstra

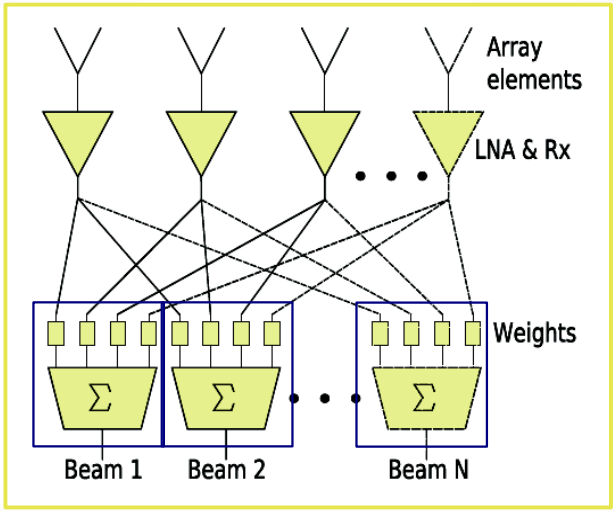
RFI Mitigation Techniques

(See Fridman and Baan 2001)

1. Excision by Thresholding
2. Excision by Filtering (Analogue, Digital)
3. Excision by Statistics
4. Adaptive cancellation with reference antenna
5. Multi-Beam Information
6. Spatial Nulling using Multi-element Phased Arrays
   - Interferometers
   - Single-Dish (!)

How a Phased Array Feed Works?

Credit: R. Millenaar



Credit: D. Hayman

Credit Original Picture: G.Jonas

- Combination of signals from several antenna elements = 1 beam
- **Many beams simultaneously. Control of direction and shape.**
- Figure-of-Merit as a function of the weights:

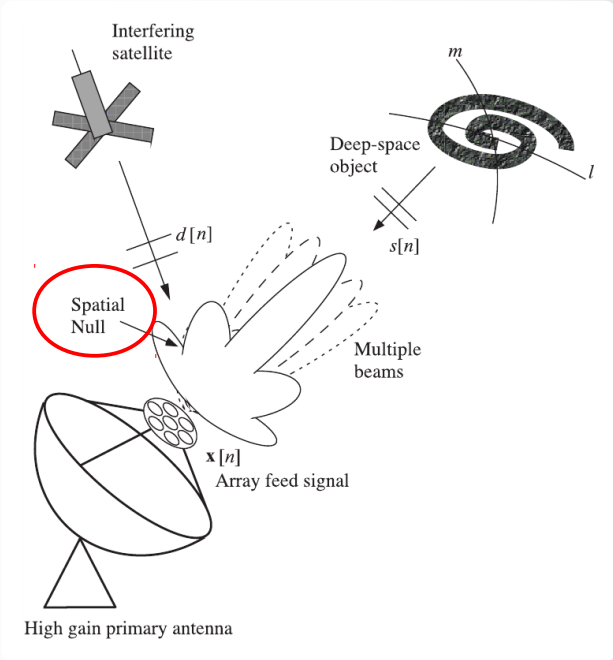
  Beam_Shape(**w**), Gain(**w**), Signal-To-Noise-Ratio(**w**), …
- Control of **w** → Optimize Figure-of-Merit

Spatial Nulling: Theory and Simulations

- van Ardenne et al. 2000, Hansen et al. 2005
- New Figure-of-Merit:

  Signal-To-Interference+Noise (SINR)

$$S = \frac{G}{T_{sys} + T_{interferer}} \rightarrow \frac{\mathbf{w}^H \mathbf{R}_{ss} \mathbf{w}}{\mathbf{w}^H \mathbf{R}_{nn+ii} \mathbf{w}}$$

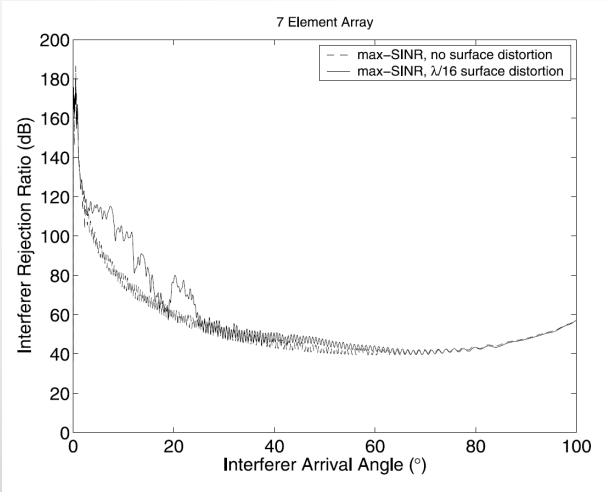


RFI rejection with controlled spatial nulls.
Credit: Landon et al. 2010

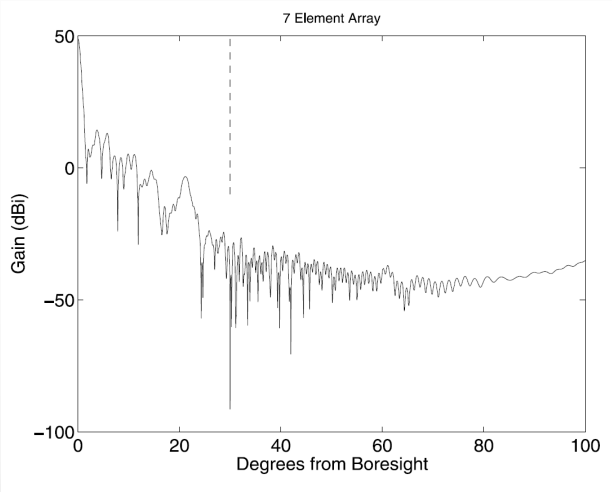
- Simulated 2 cases:
  - One static interferer with +10dB INR
  - Static Interferer + Moving Interferer

Spatial Nulling: Theory and Simulations

- Min. 40dB Interference Rejection !
- Moving RFI case: “Pattern rumble”, Loss in sensitivity
- Theoretical Solution: Hybrid Beamforming
  - Sub-optimal MAX SINR



Hansen et al. 2005



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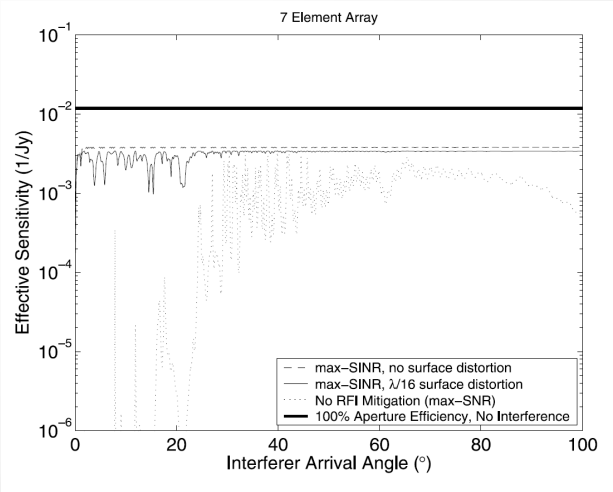
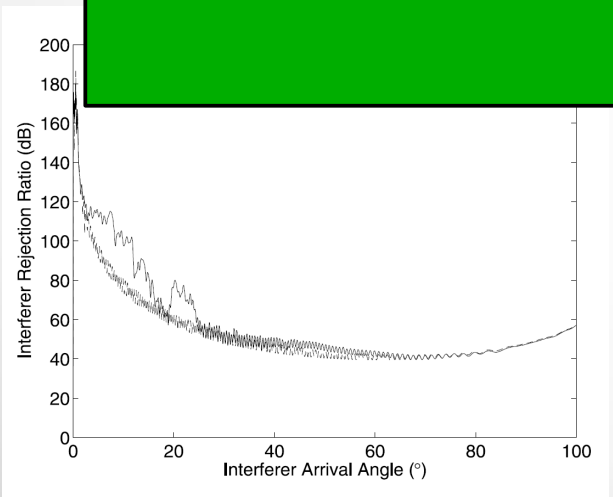


Hansen et al. 2005

Spatial Nulling: Theory and Simulations

- Min. 40dB Interference Rejection !
- Moving RFI case: “Pattern rumble”, Loss in sensitivity
- T

- Theoretically feasible
- Promising



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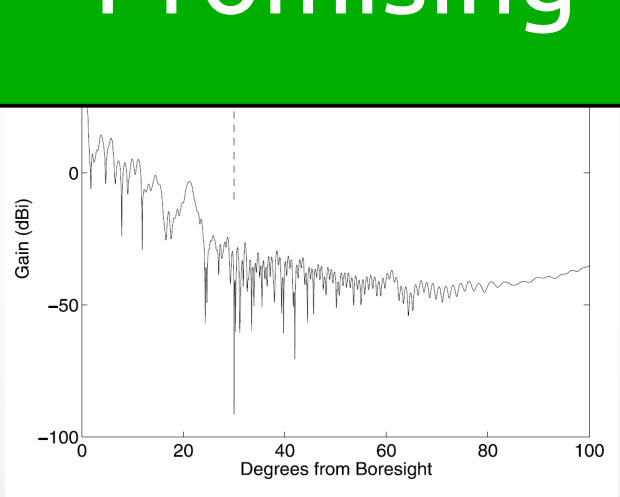

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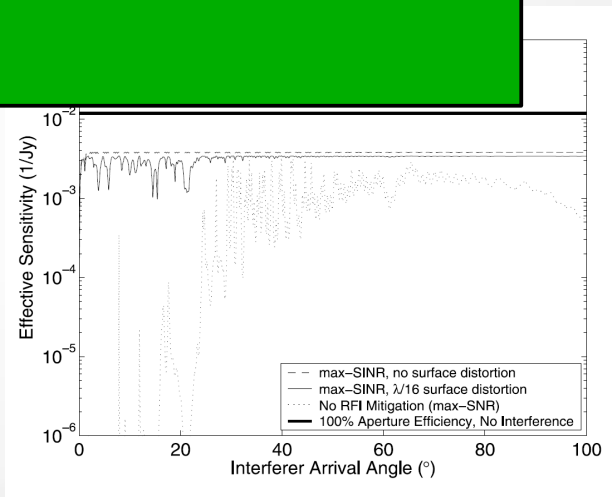
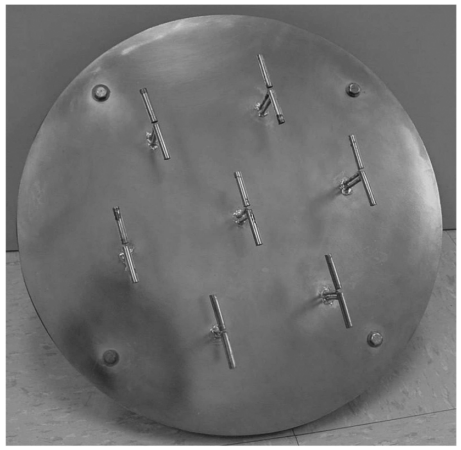


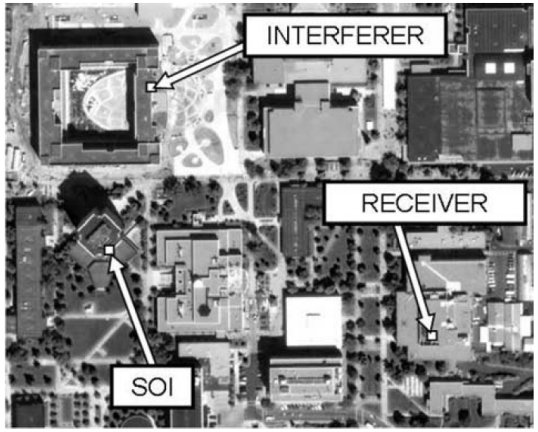
Hansen et al. 2005

Spatial Nulling: Experimental Verification

- Nagel et al. 2007



Jeff and Warnick. 2008



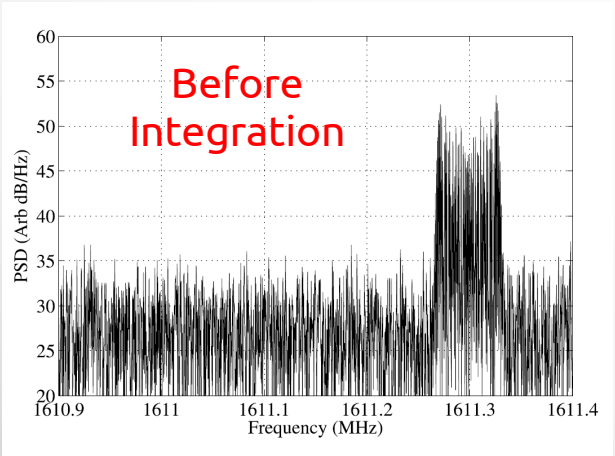
Nagel et al. 2007

- SOI = -110dBm

  (under noise floor)

- RFI = FM signal

  0dBm



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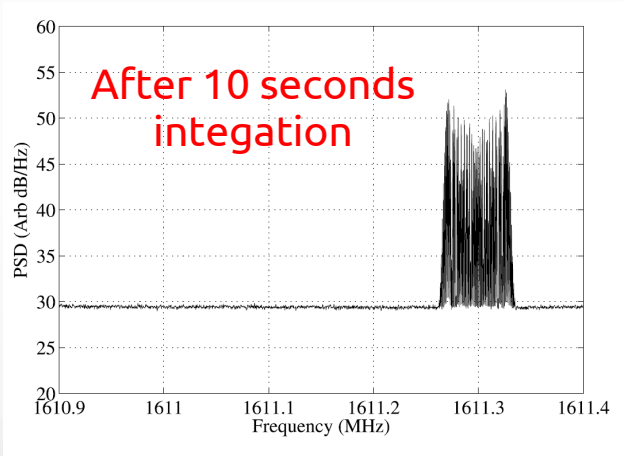

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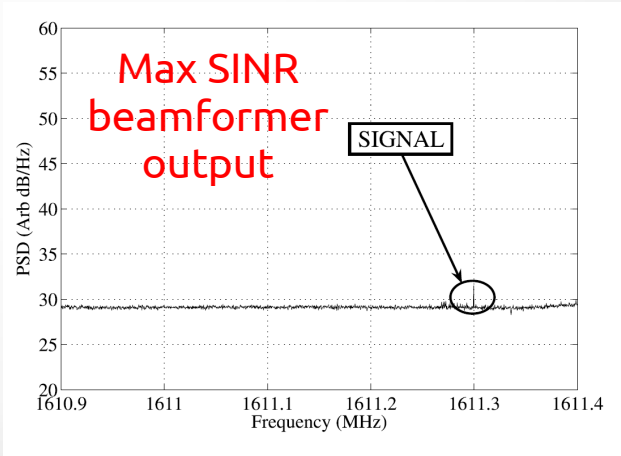

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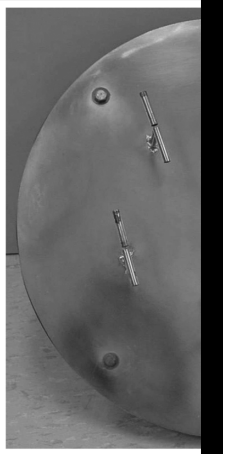


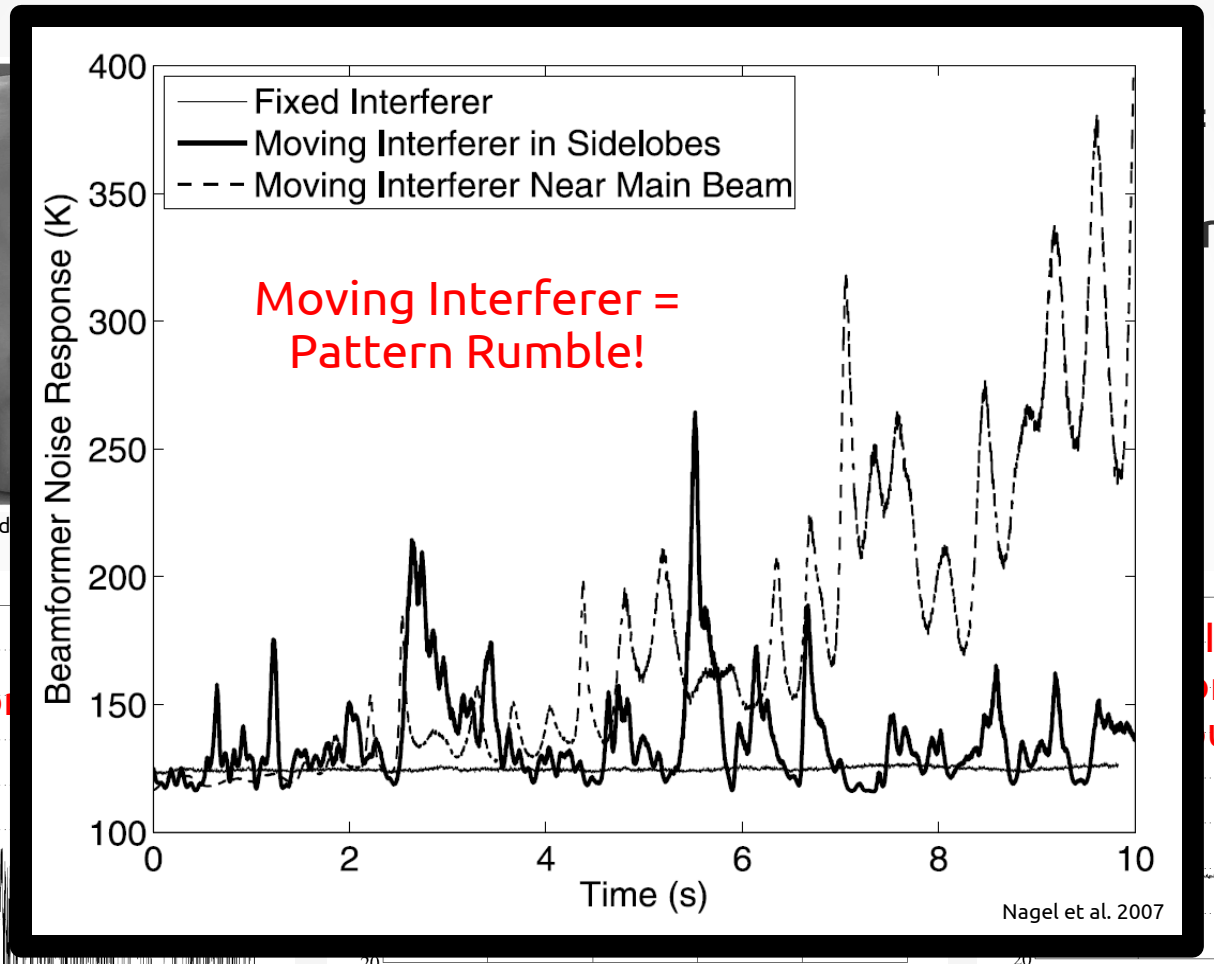
Jeff and

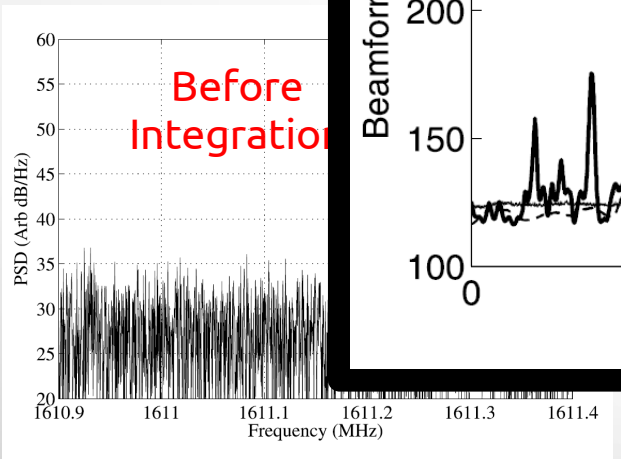
-110dBm

r noise floor)

FM signal

0dBm





Nagel et al. 2007

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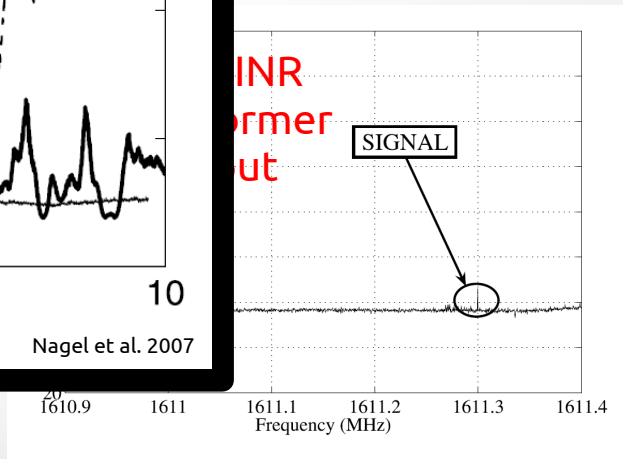

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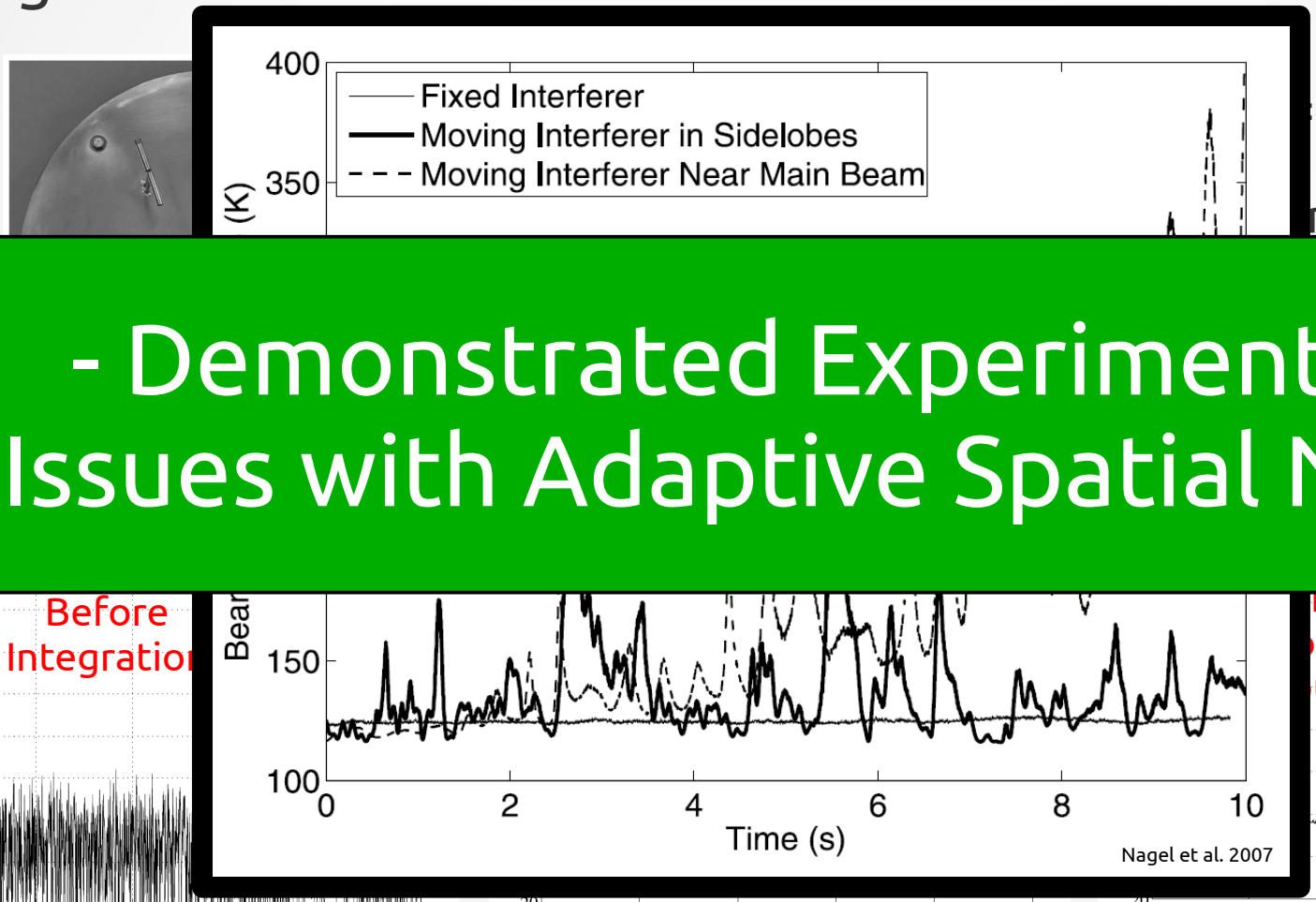


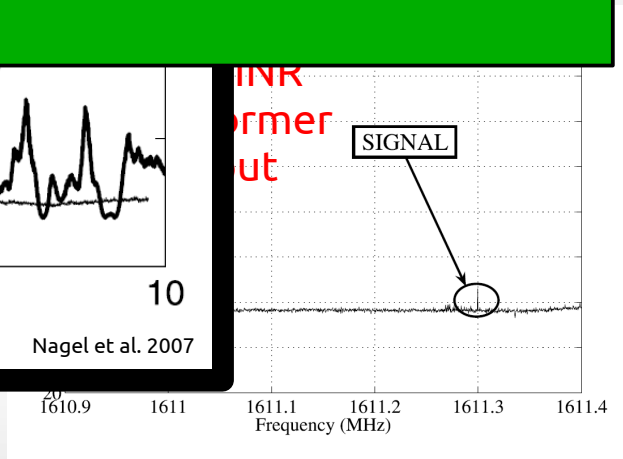
-110dBm

noise floor)

- Demonstrated Experimentally
- Issues with Adaptive Spatial Nulling

Nagel et al. 2007

Nagel et al. 2007

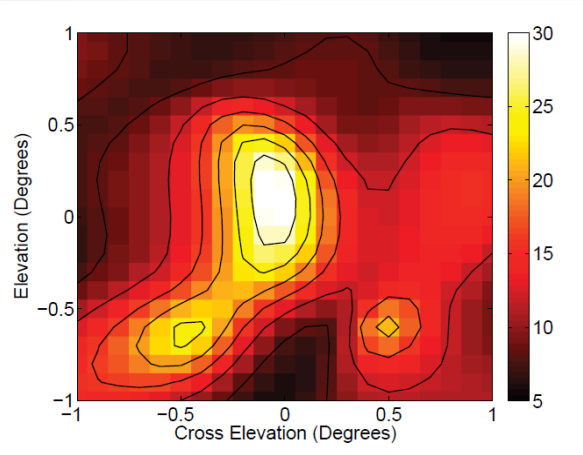


Nagel et al. 2007

Spatial Nulling: Improvements

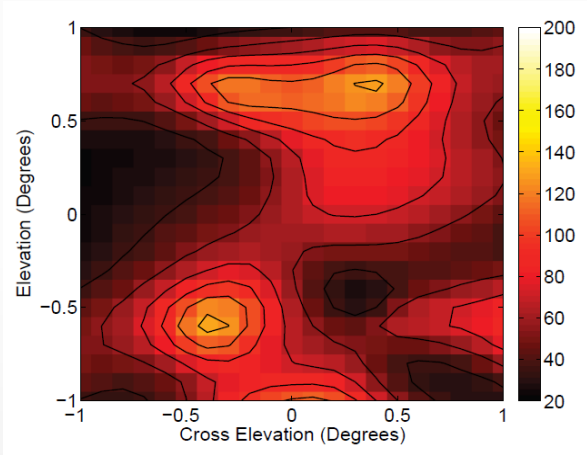
- Improvements complicated, but achieved
  - Jeffs and Warnick 2008, combination of algorithms …
- Tests on Green Bank 20m + PAF, Cygnus X at 1600 MHz

No RFI



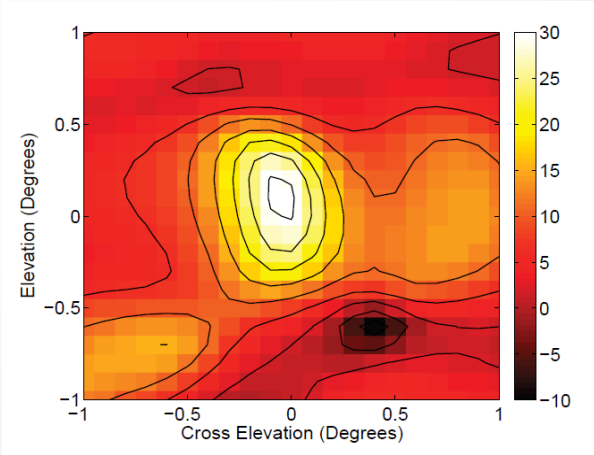
Warnick et al. 2009

FM interferer



Warnick et al. 2009

Adaptive Spatial Filtering

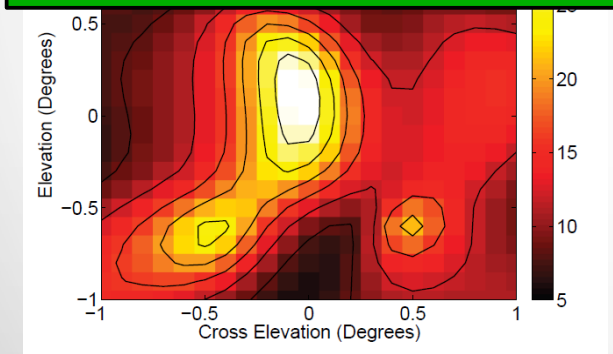


Warnick et al. 2009

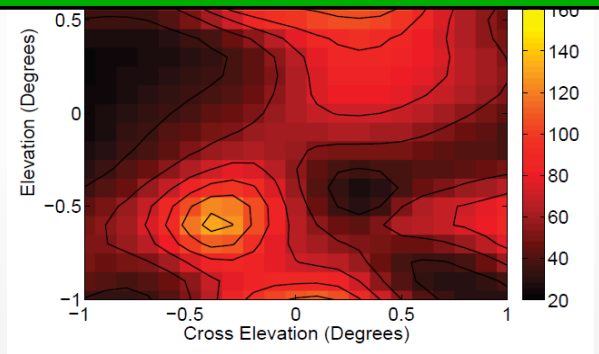
Spatial Nulling: Improvements

- Improvements complicated, but achieved
  - Jeffs and Warnick 2008, combination of algorithms …

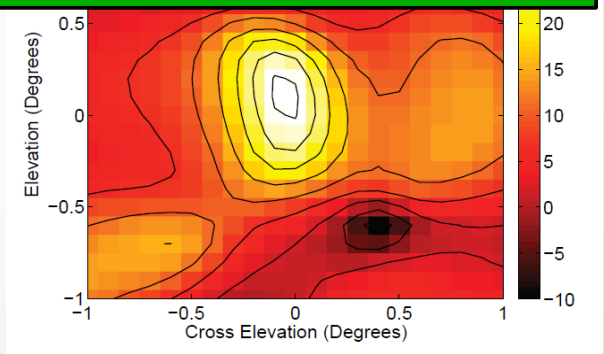
- Adaptive Spatial Nulling Improved
- Static Spatial Nulling Working



Warnick et al. 2009



Warnick et al. 2009



Warnick et al. 2009

Spatial Nulling with PAFs

- Theoretically feasible
- Very promising
- Experimentally verified
- Static nulling “easy”, Adaptive nulling complicated
- Adaptive nulling improved over the last years
- 2013 – Enough maturity of theory and hardware to be applied to real observations

The Spoilsport: RFI

- All the methods and **techniques work in the theory**
- The **practice is more complicated**
  - Calibrate (Set-up) the beamformer weights requires measurements with no RFI (almost never possible)
  - Rejecting RFI without affecting SOI is difficult
  - Astronomical signals very faint,
    Large Amplification required
  - **Large Amplification + Strong RFI**

    = SATURATION of Receiver!

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    = SATURATION of Receiver!

Signal Distortion
Information Loss

The Spoilsport: RFI

- **We have to avoid LNA saturation at all cost**
- Some solutions:
  - More dynamic range in LNAs
  - Filtering pre-LNA
  - Analogue Beamforming pre-LNA
  - Physically shielding the antenna
  - Survey/Control RFI environment

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  - Physically shielding the antenna
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No HW Modifications

Fastest Results

Wide Utility

Enough for our initial objective

RFI Effects on PAFs

- Our initial objective:

  Test a PAF in Effelsberg at 700-1000MHz

- First question:

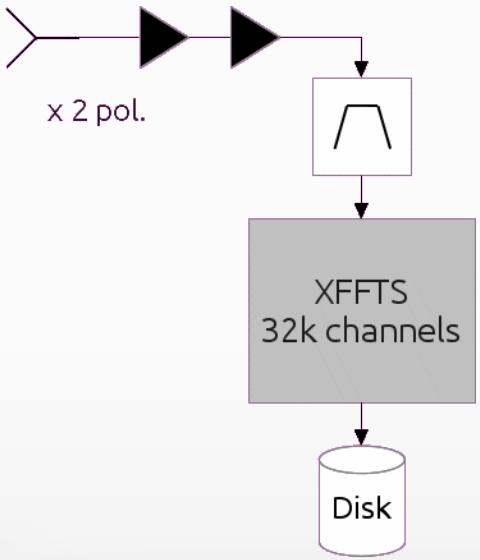
  Will the PAF saturate due to RFI?

  1) SURVEY the RFI

  2) Evaluate PAF response to our RFI

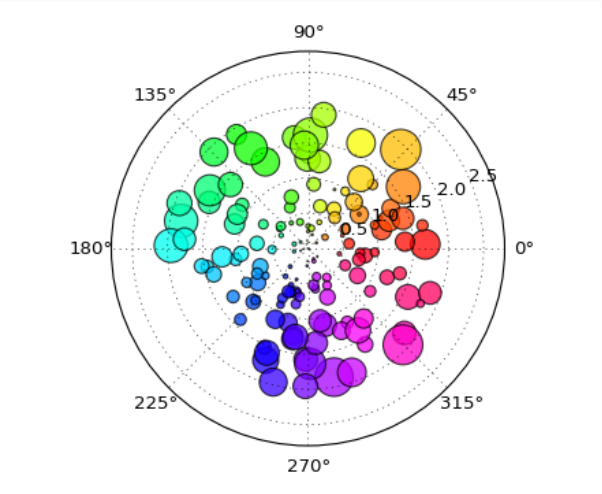
The Effelsberg All-Sky RFI Survey

- RFI survey at 500-1000 MHz (maybe more)
- Mimic the future PAF system
- System already set-up in the 100-m



The Effelsberg All-Sky RFI Survey

- Create a map of the RFI on Effelsberg Sky



Picture credit: matplotlib gallery

- Complement existing RFI information at L-band
- Find “clean” patches of sky where PAF LNA saturation is avoided
  - In position and time
- Test the PAF system within this “clean” regions of the sky

Conclusions

1. New technologies → Larger Bandwidths → More RFI
2. RFI mitigation increasingly important. Even mandatory.
3. PAFs present very promising new methods of RFI rejection
4. Challenging to operate PAFs in strong RFI environments
5. Combining RFI mitigation methods is usually the best solution
6. Saturation of receivers by RFI is a major problem
7. Surveying and Control RFI may be a ‘simple’ way to fight it
8. Along these lines: Effelsberg All-Sky RFI Survey, Future PAF

Thank you!

Contact Info: ptorres (at) mpifr-bonn.mpg.de

Special thanks to:

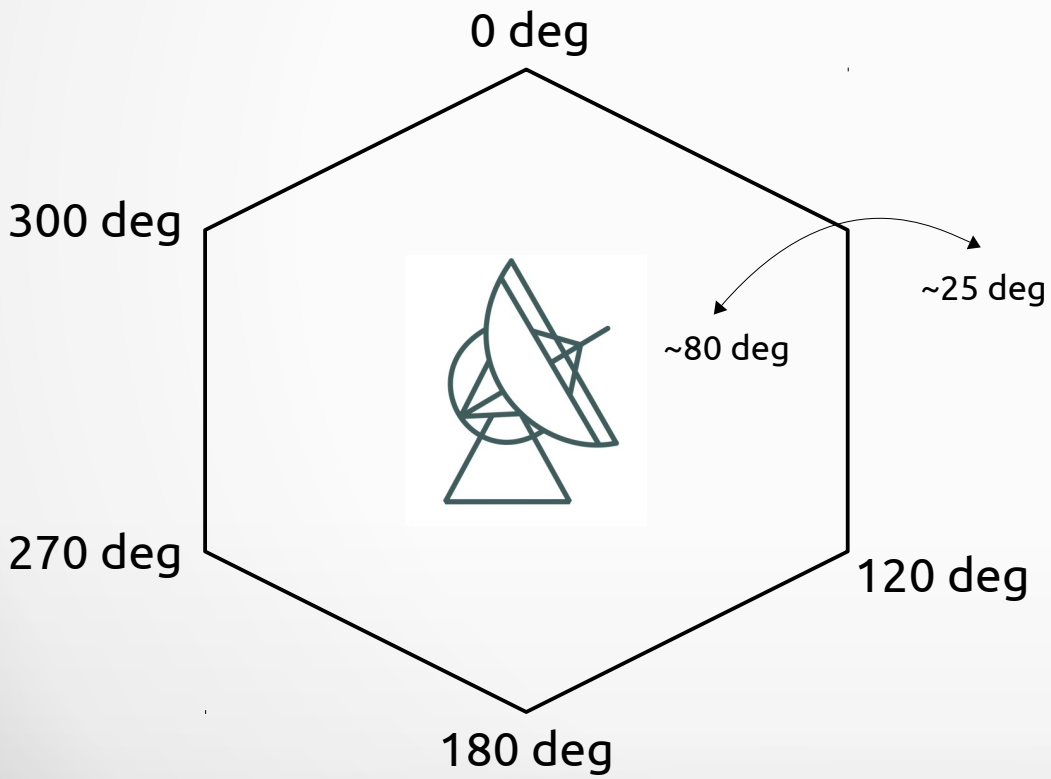
- Effelsberg Telescope Team
- ASTRON institute
- Advisors and Collaborators
- International Max-Planck-Research School of the Universities of Bonn and Cologne (IMPRS)

Appendix

Backup Slides

Some Preliminary Results

- RFI with the 30cm receiver in Effelsberg on 4th March 2013
- Initial Tests to Set-Up a more accurate RFI Survey



6 Azimuths positions

Elevation 80 to 25 deg

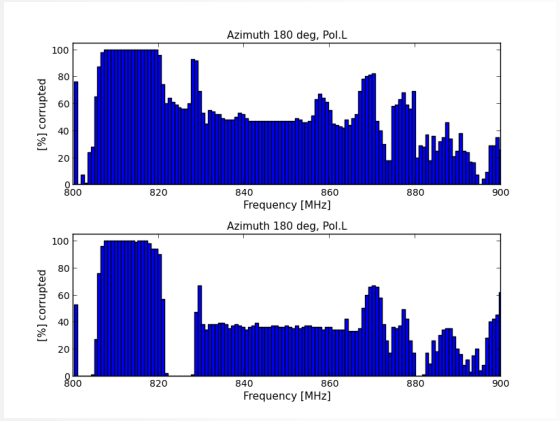
800-1000 MHz

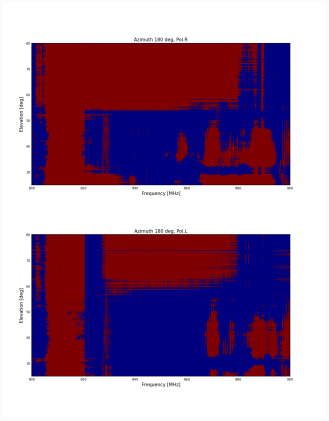
11pm to 1am

Some Preliminary Results

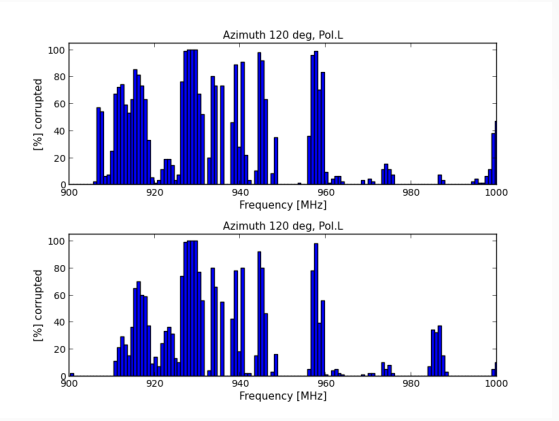
- Frequencies affected by RFI (threshold = +10dB over Tsys)

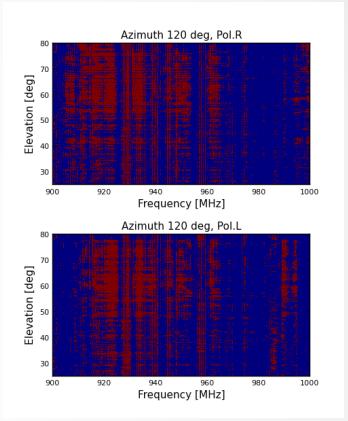
800-900 MHz

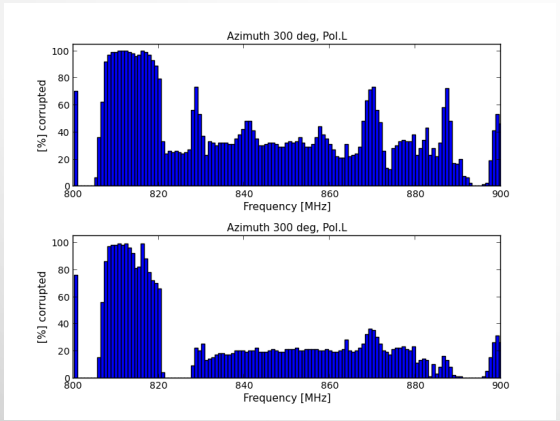


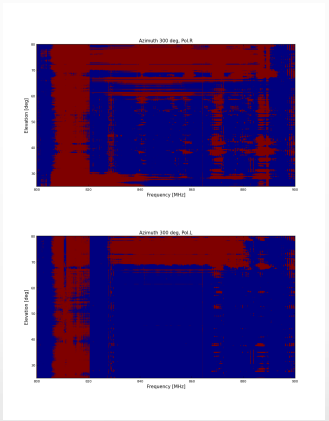


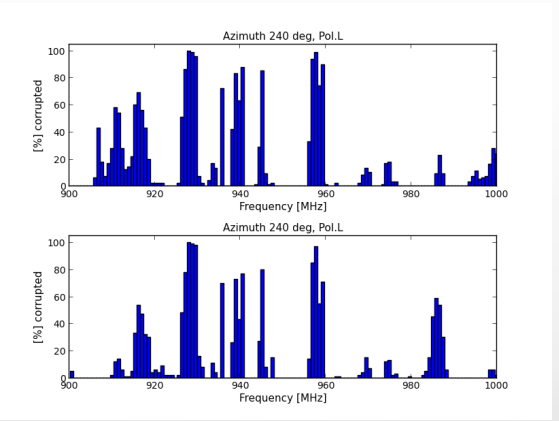
900-1000 MHz

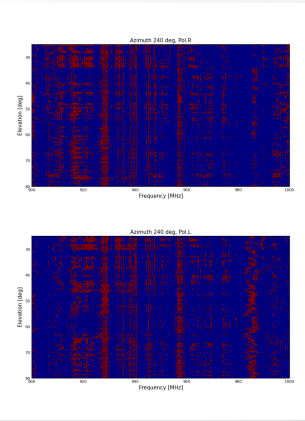








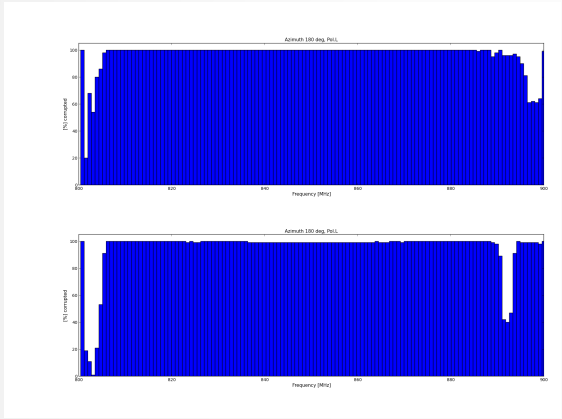




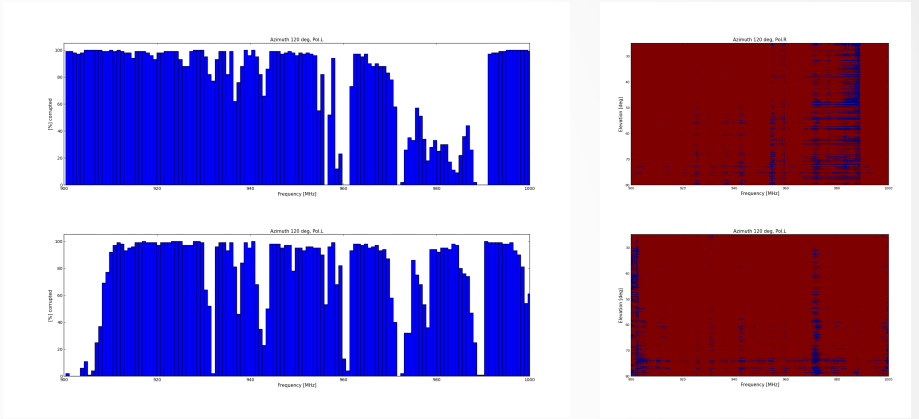
Some Preliminary Results

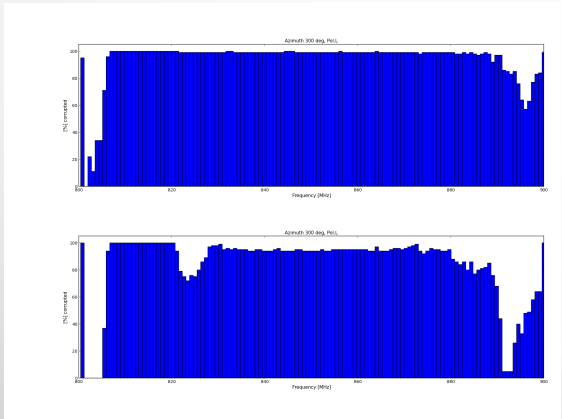
- Frequencies affected by RFI (threshold = +3dB over Tsys)

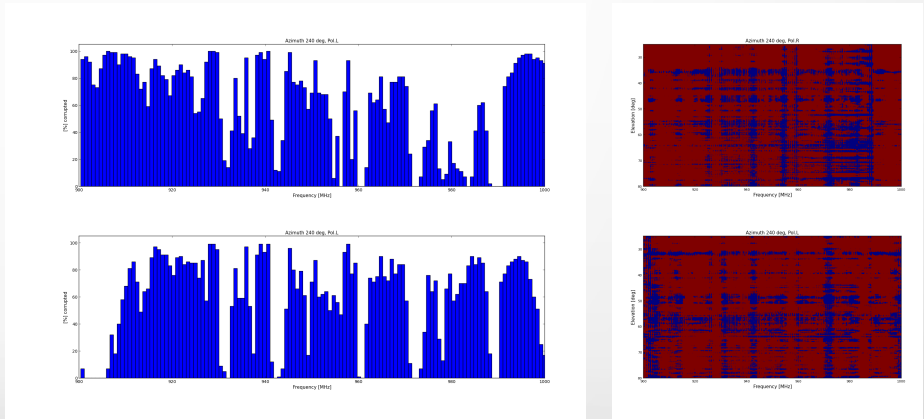
800-900 MHz



900-1000 MHz







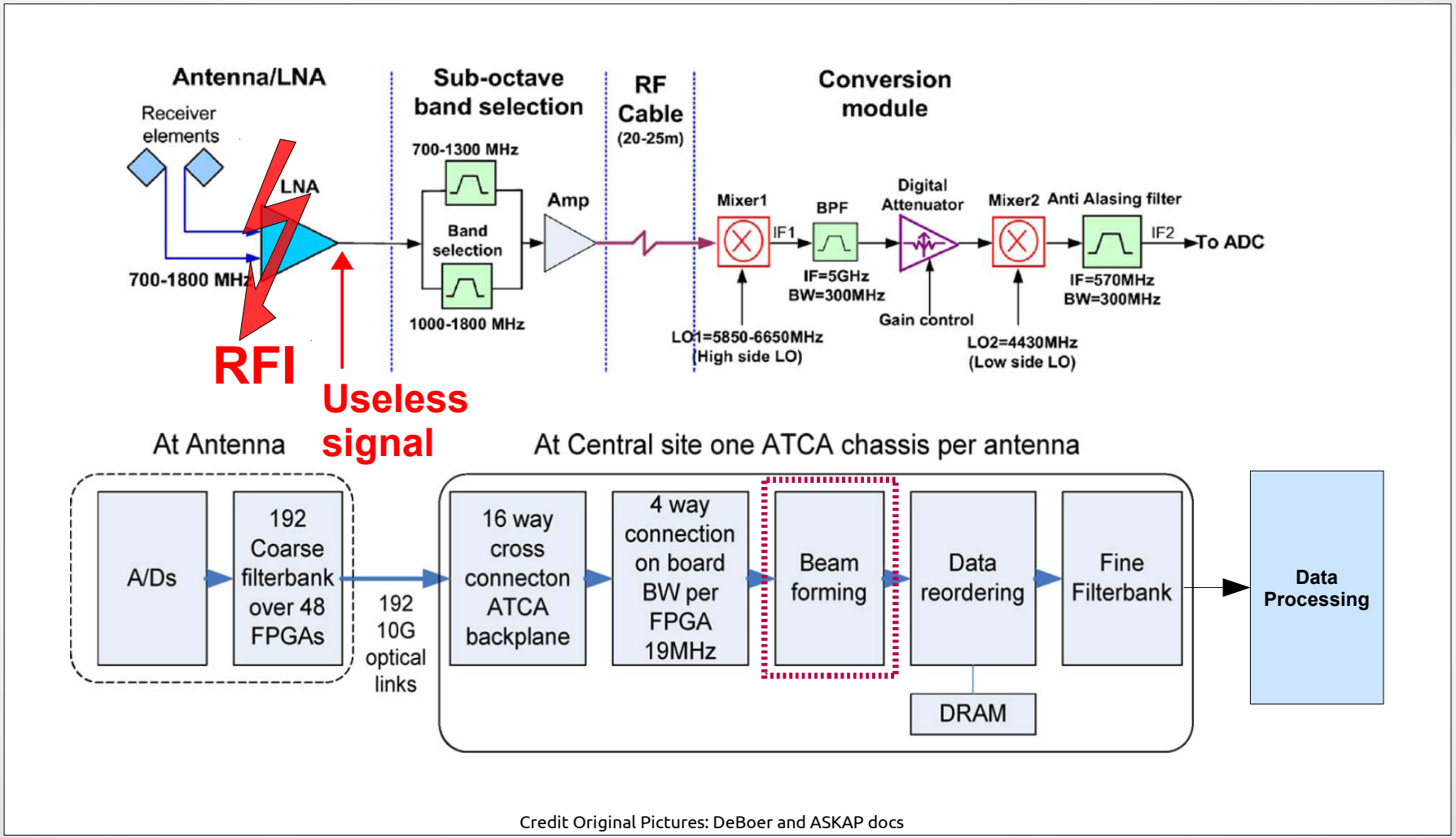
Some Preliminary Results

- GSM900 very strong, narrowband ← Dangerous
- DVB-T not so strong, but wideband ← Dangerous
- Challenging to observe at these frequencies in Effelsberg
- The valley really shields against some RFI
- RFI does depend on telescope position (!)
- A new, RFI aimed system should be used for measurements

Some Preliminary Results

- UHF Survey was a test. Results not very reliable.
  - No easy calibration (due to RFI)
  - Antenna of different type than PAF
  - System not robust enough against saturation
- Better:
  - Use same antenna type as the PAF
  - Robustness against strong RFI
  - Much more data!

The Spoilsport: RFI



Credit Original Pictures: DeBoer and ASKAP docs