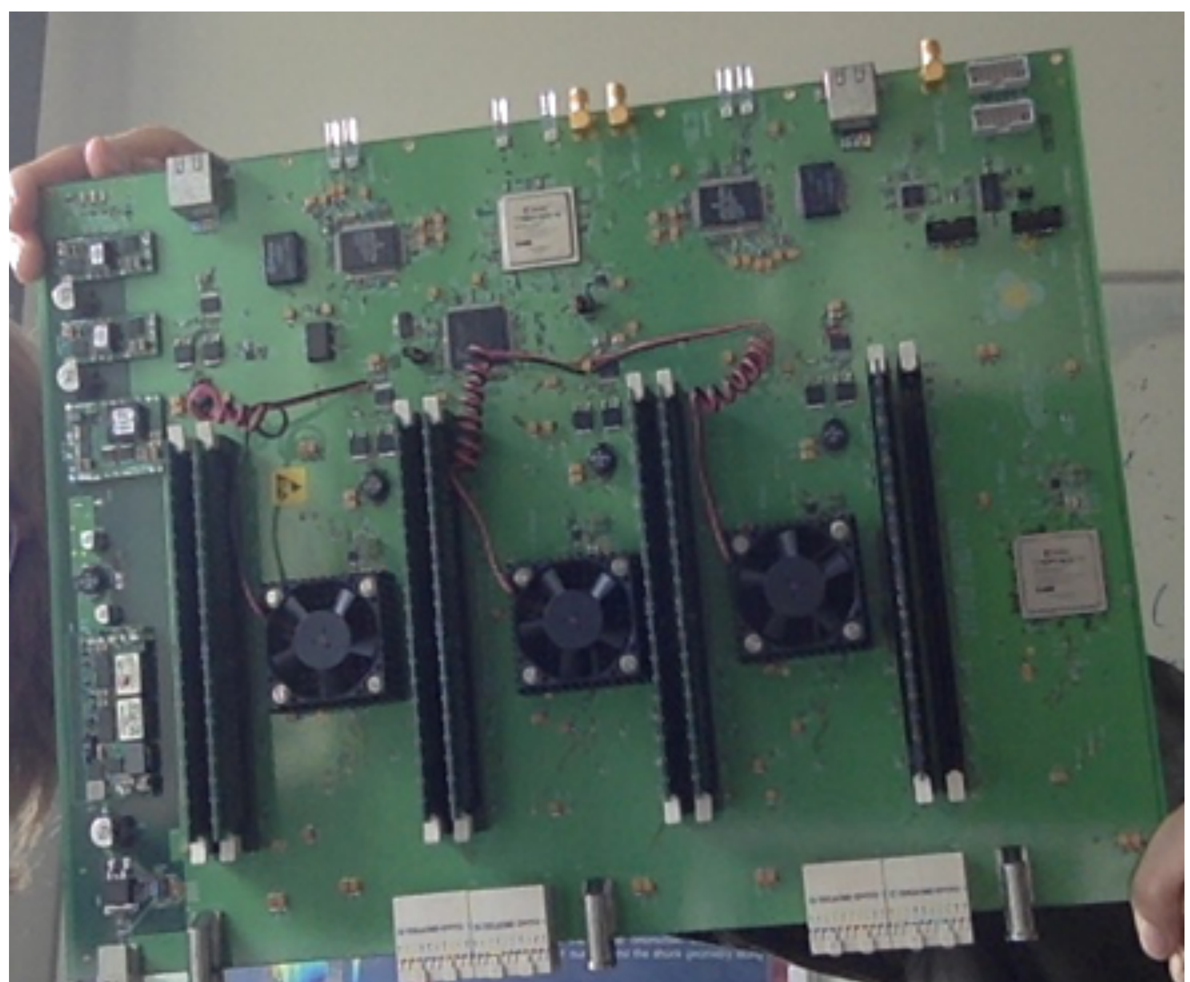
Transient Buffer Board data analysis

Sander ter Veen & Brian Hare

ASTRON Netherlands Institute for Radio Astronomy
LOFAR
university of groningen
kvi - center for advanced radiation technology

LOFAR
DATASCHOOL
2018



Outline

- Introduction to TBBs and TBB science
- Tutorials interspersed with more explanation

Transient Buffer Boards

- Store signal of individual channels (antenna/tile)
- Stores raw data (200 MHz, 5ns samples)
- 5.2 second buffer
    - (most international stations 1.3 s)
- Alternatively, store subbands (N x 195312.5 kHz, 5.12 μs samples)

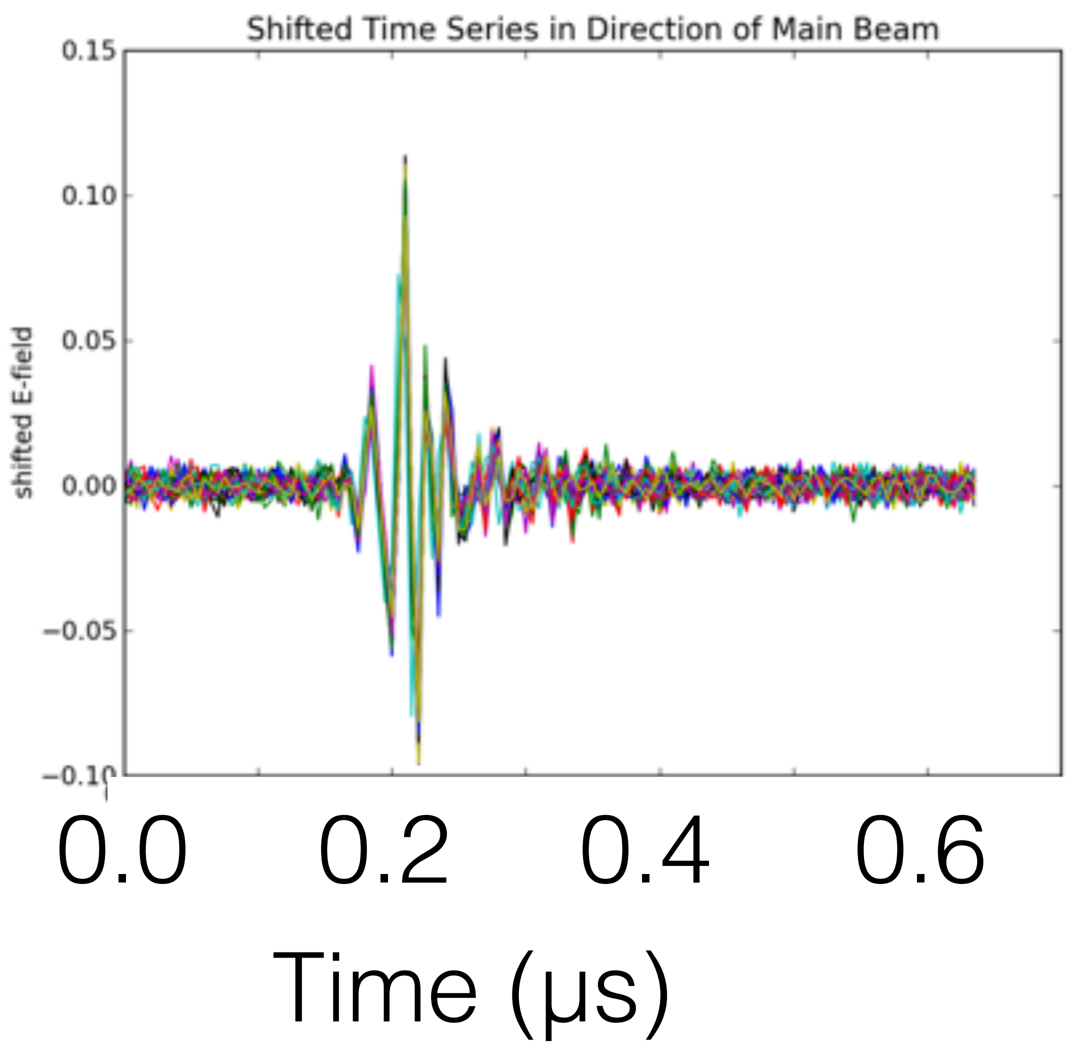
Triggered observations

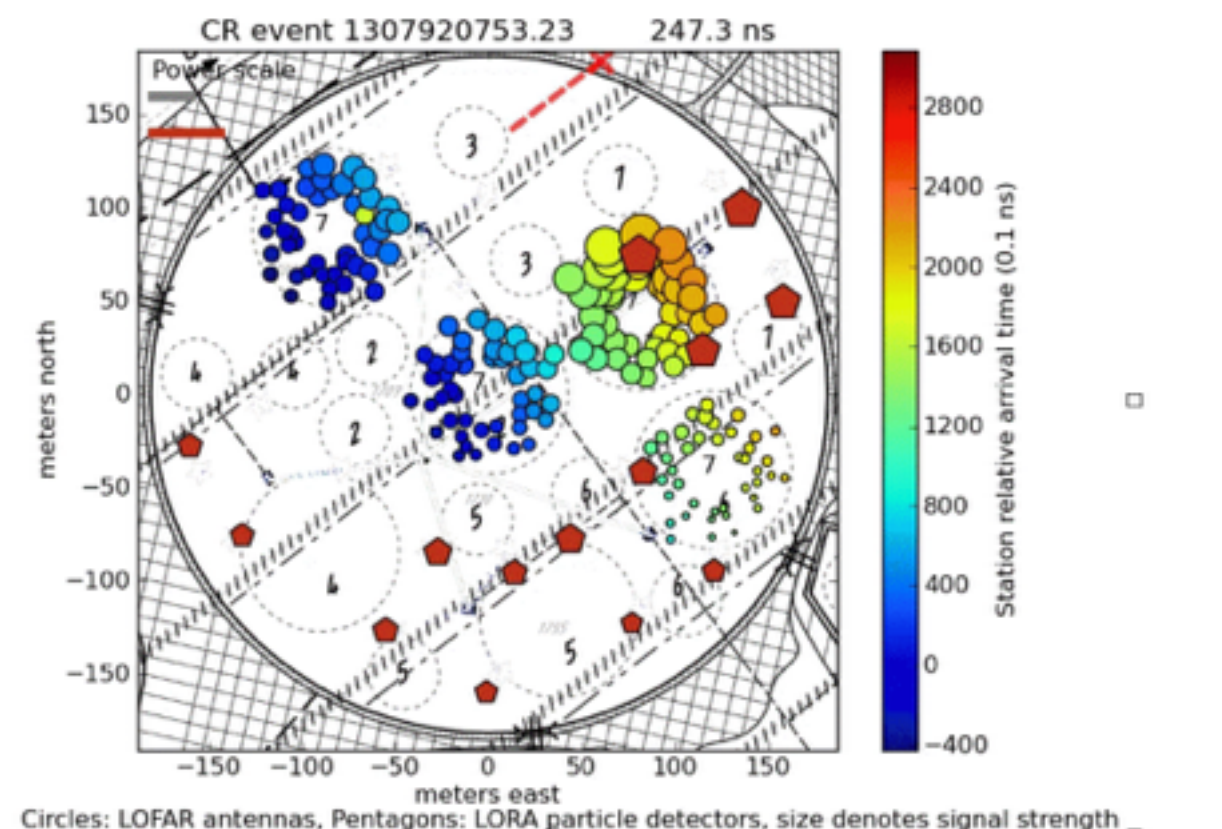
- Use external source to decide there will be interesting data
- Freeze TBBs ASAP
- Read out relevant part of the data (e.g. 2 ms or full 5 seconds)

Triggers

Phenomenon	Trigger source	Trace duration
Cosmic Ray	Particle detector Radio self-trigger	2 ms
Lightning	www.lightningmaps.org Radio self-trigger	2 s
Fast Radio Burst	Detection on LOFAR beam formed data Detection with another telescope (e.g. APERTIF)	5 s

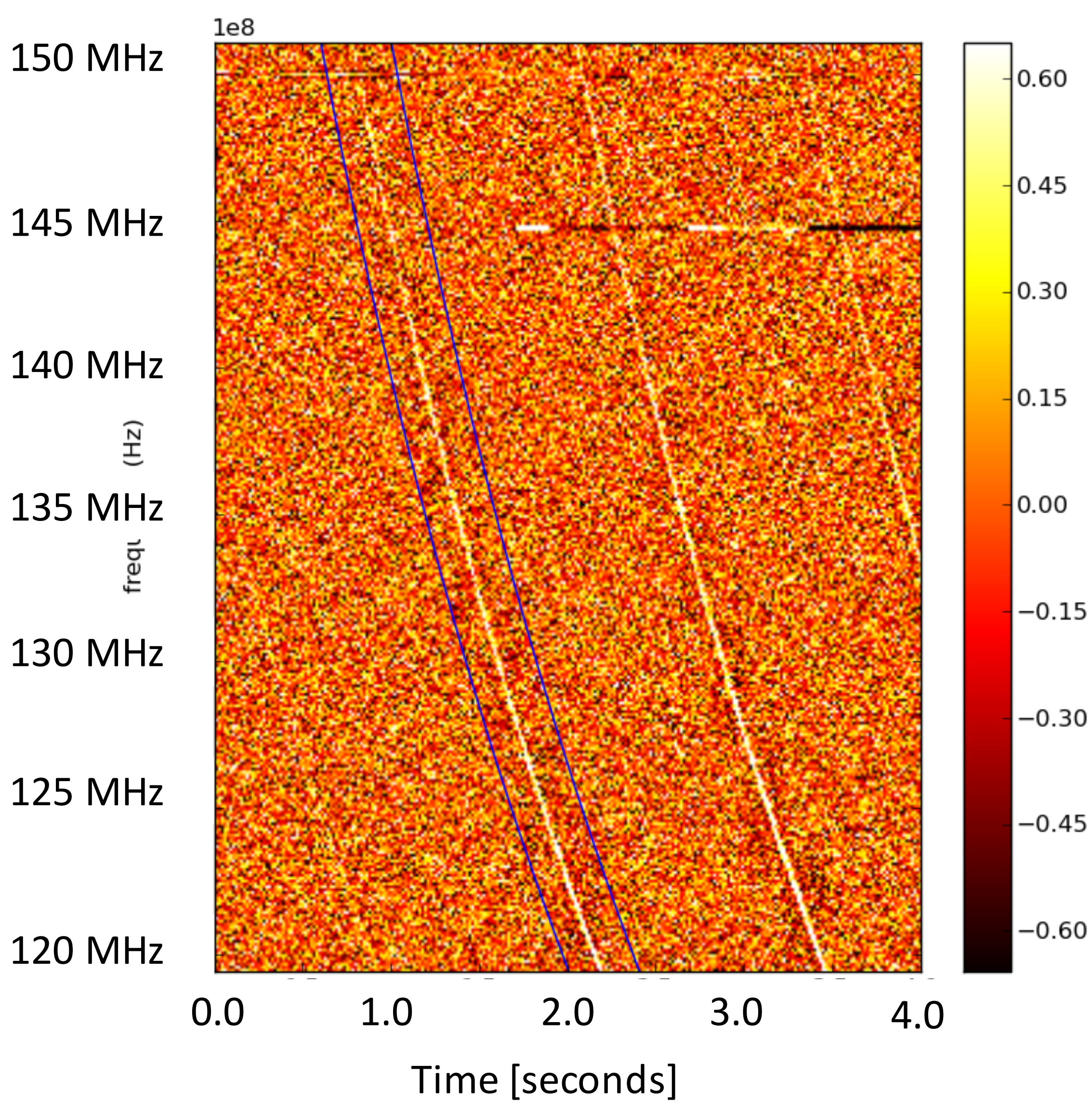
Single antenna - Cosmic Ray data



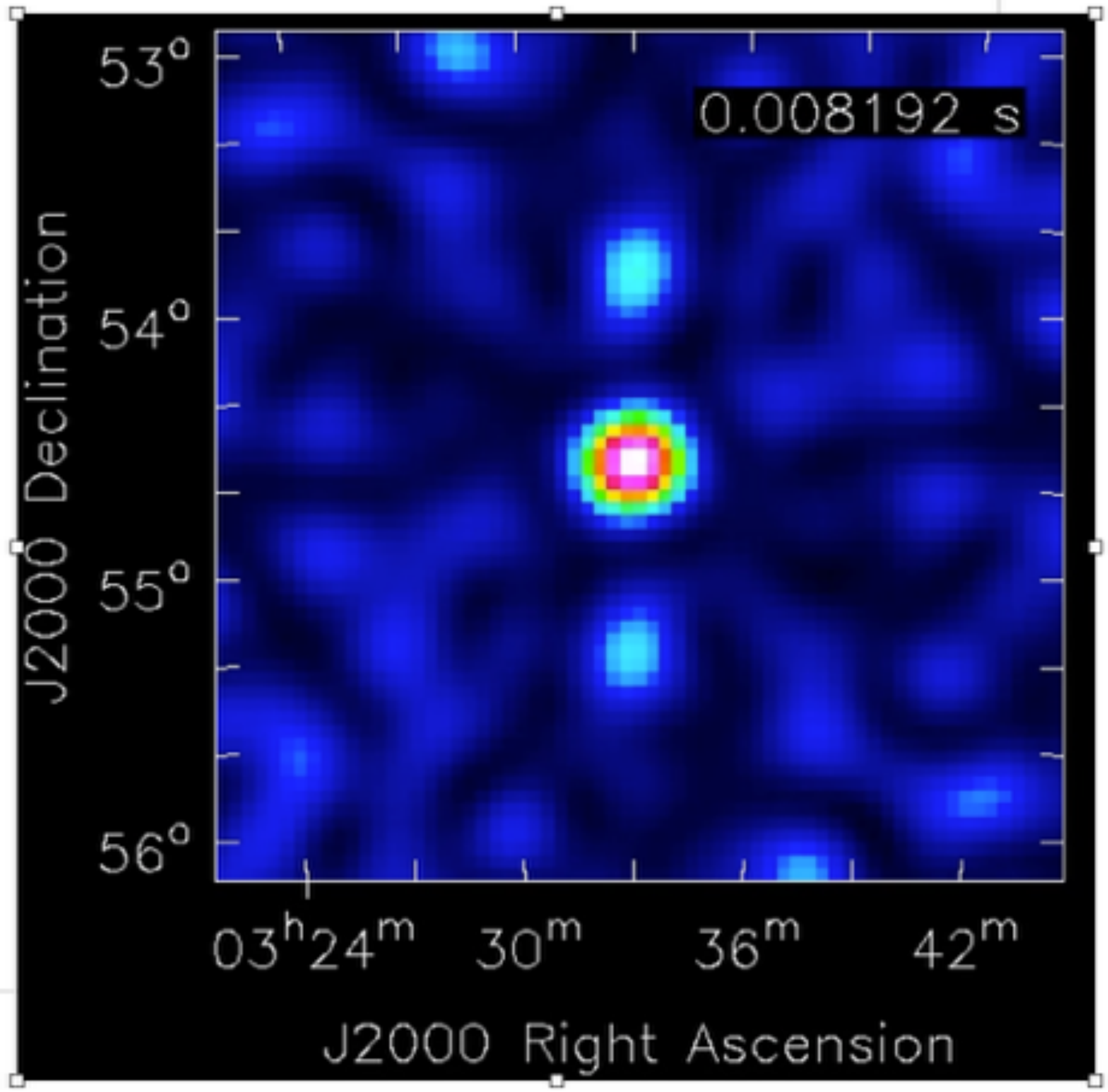


Localisation
Fast Radio Burst

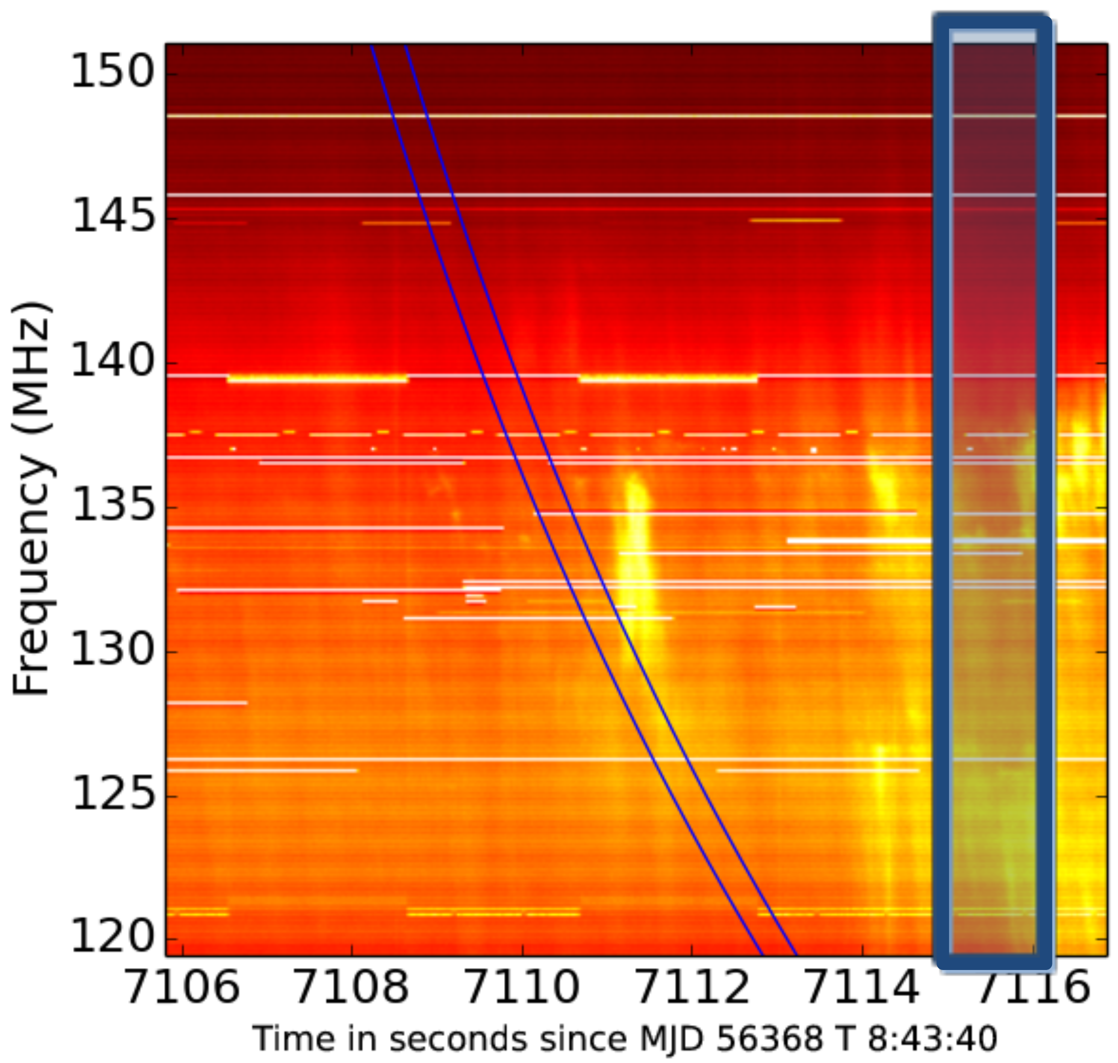
Beam formed data
on PSR B0834+26



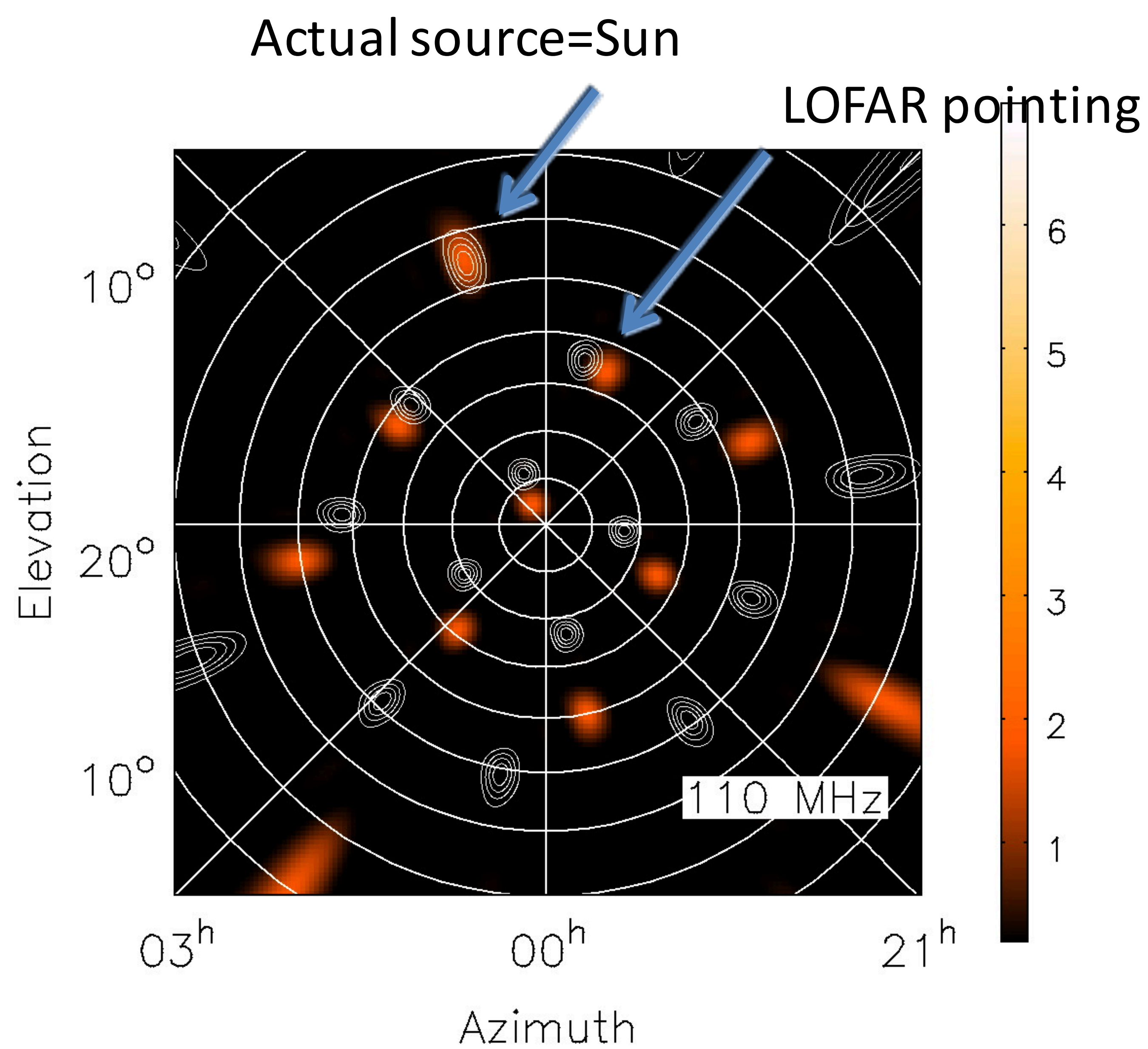
Movie from TBB data
of Crab Pulsar



Solar Radio Burst



Beam formed data



TBB Image

Lightning

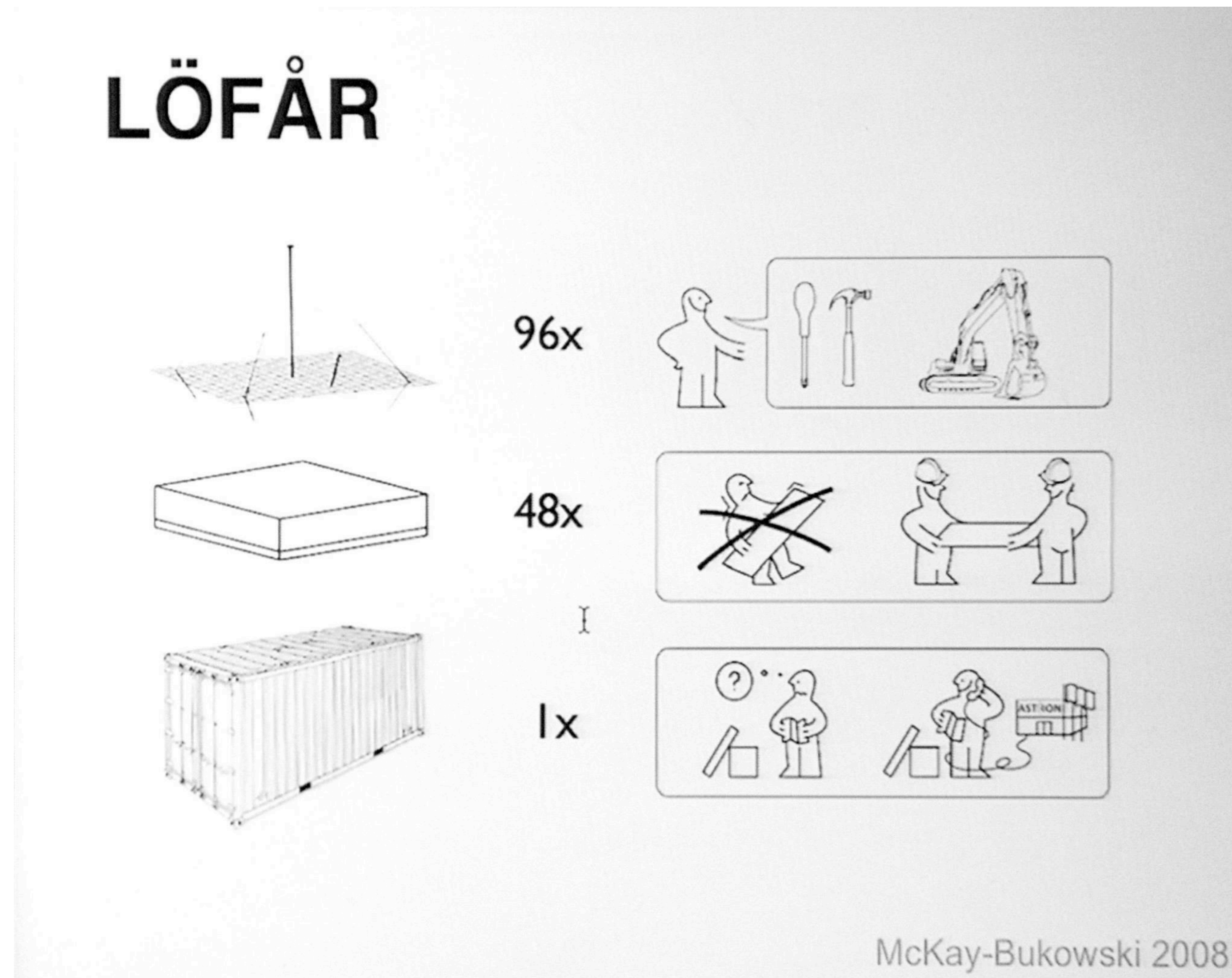
- Topic of todays tutorial

TBB Observations

- Parallel mode: using Filter of main observation (e.g. LBA 10-90 MHz)
- Parallel data read-out
- Expert mode (Talk to me (Sander ter Veen), before submitting a proposal)

Data analysis

- This is just an introduction
- "Build your own telescope"
- Include all appropriate delays



Mapping Lightning with LOFAR

- Lightning is very different from astronomy data
  1) Broadband / impulsive, pulses are 100 ns wide
  2) Sources are at near horizon
  3) Shape of the pulse can change between antennas
  4) Over 100,000 pulses in one flash

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  - Save full trace data
  - Large baselines
  - Dual-polarized

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SHOW VIDEO!

Mapping Lightning with LOFAR

- LoLIM is a software package specifically developed for lightning

- Parts you will use
  - raw_TBB_IO.py
    - Opens the raw data files
  - findRFI.py
    - Searches and removes human-made noise

- Other projects use other software!

raw_tbb_IO

Or the things to think about when reading data

Data format

- HDF5 files
  - Hierarchical data format
- Described in “LOFAR ICD 001 TBB Time series” https://www.astron.nl/lofarwiki/doku.php?id=public:documents:lofar_documents&s[]=lofar&s[]=usg&s[]=icd
- Data of individual antennas/tiles
- Grouped per station (but one file per station, currently)

Antenna connections

- Data is received per antenna at each receiver unit (RCU)
- Each antenna has a name consisting of [Station ID][RSP ID][RCU ID].
- Examples: 005001008 (Station 5, RSP 1, RCU 8)
- Which antenna: RCU + Antenna_set (LBA_INNER, LBA_OUTER, HBA)
- Polarisation
  - For LBA_INNER and HBA, Even RCU: X-pol, Odd RCU Y-pol
  - For LBA-OUTER, even RCU: Y-pol, odd RCU X-pol
- Sometimes antennas are wrongly connected in the field (X-Y swap)

Obtaining data

- UDP transfer
  - Missing blocks (1024 samples, for one antenna)
  - File ends if no data is received => Sometimes multiple files per stations
  - Timestamp offsets between antennas
- LoLIM corrects for these issues

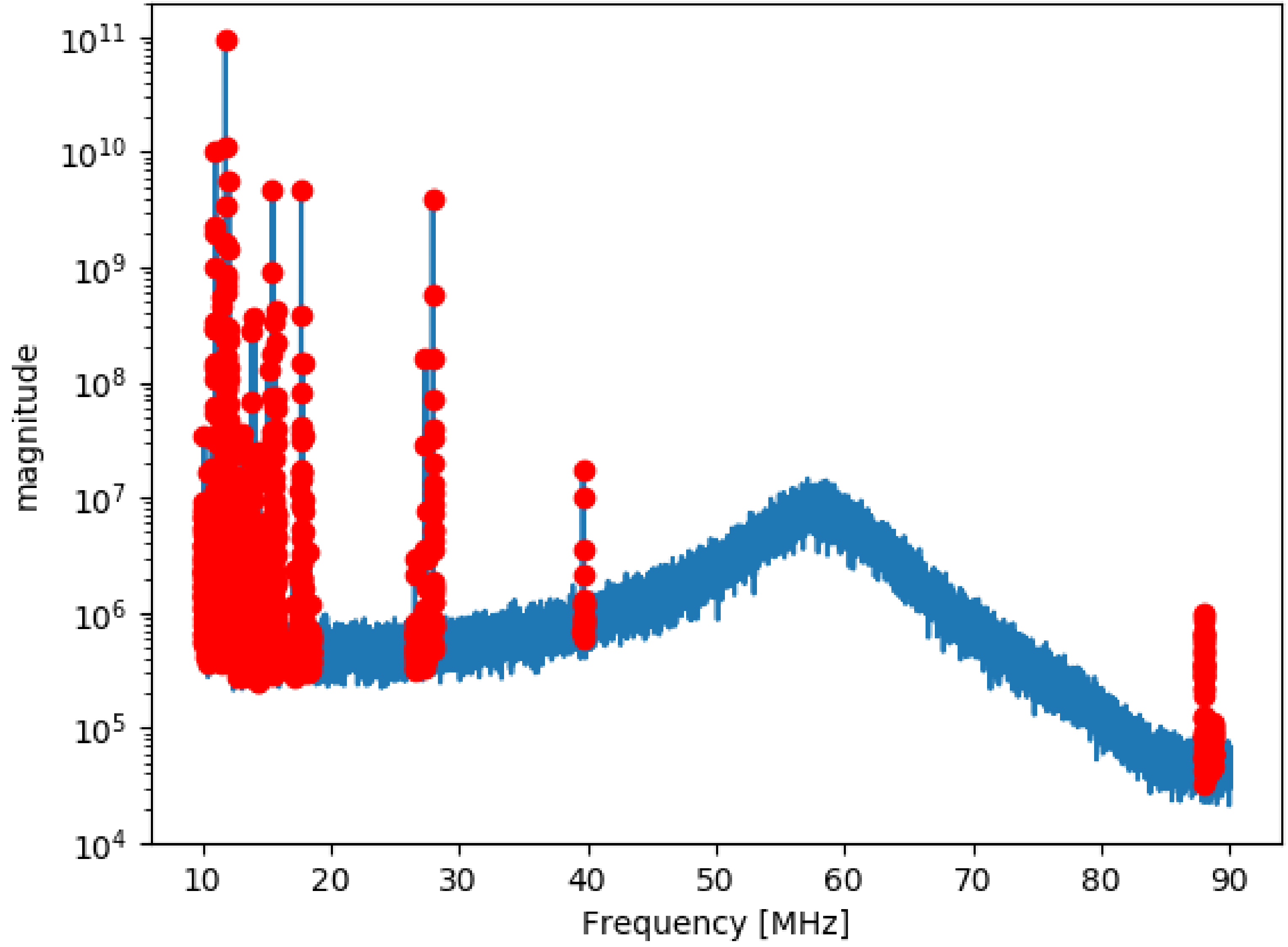
Removing RFI lines

- Data are often polluted by human RFI
- We identify RFI by looking at phase stability
  - Technique borrowed from Cosmic Ray group
- Also bandpass between 30-80 MHz due to large about of RFI below 30 and above 80

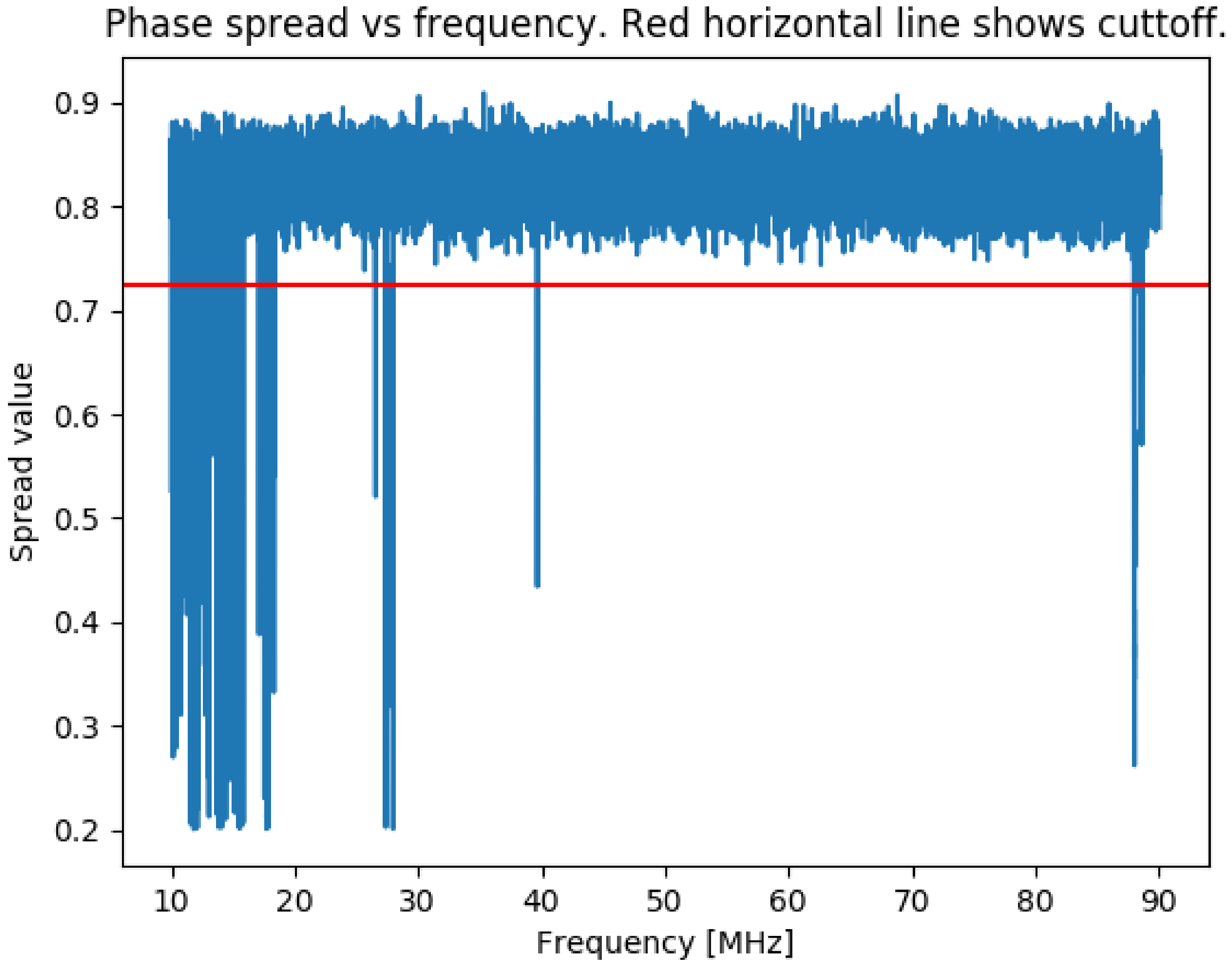
FFT spectrum before cleaning

RFI lines indicated in red

Rest of the spectrum is due to the galactic background and antenna function



Phase Stability



Task 3

Goal: Remove RFI from a block of data, and observe the result

1) Plot a spectrum before RFI cleaning
   - Plot logarithm of absolute value of FFT

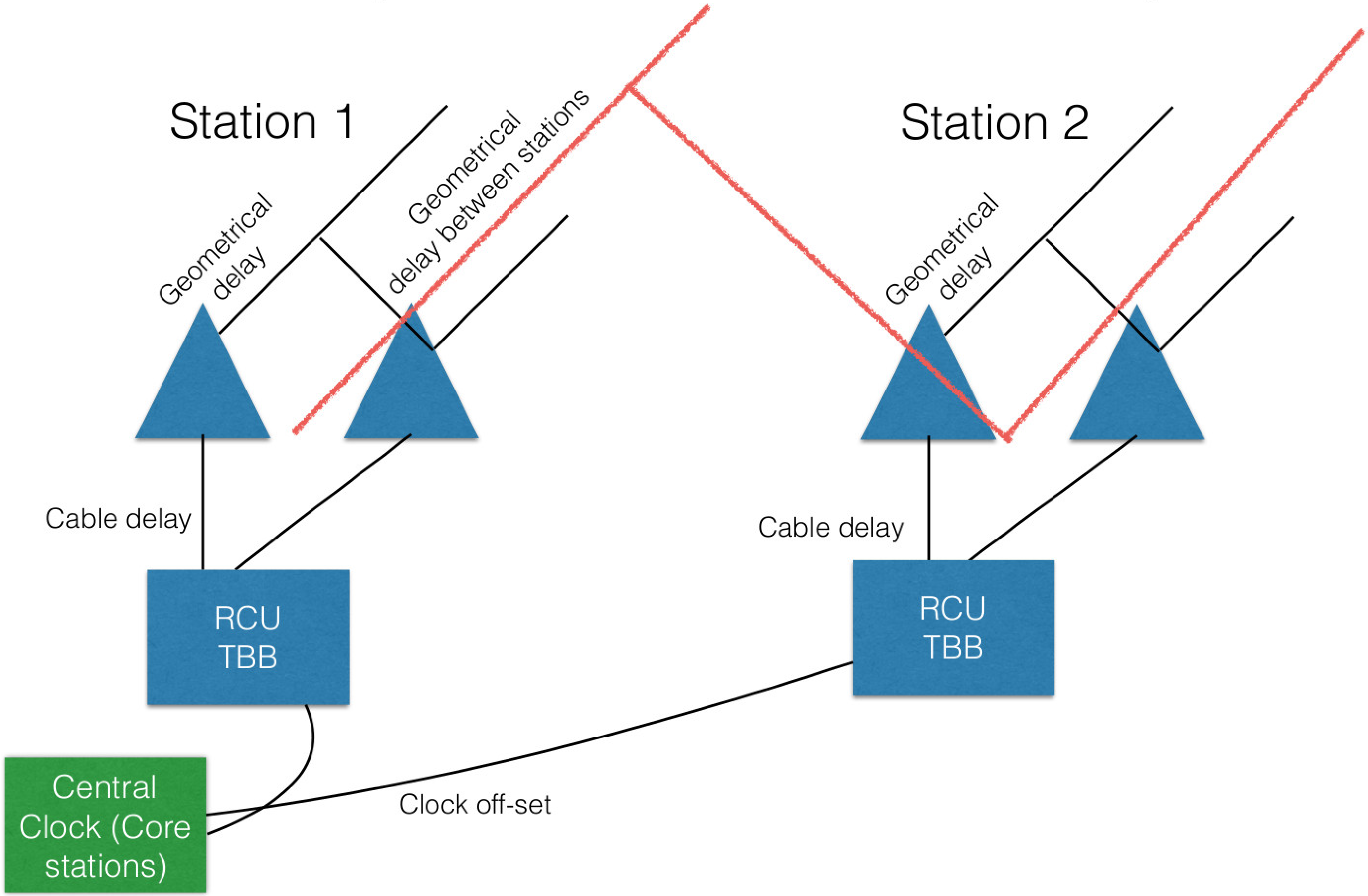
2) Use a noise block to find RFI lines and build filter

3) Remove RFI lines from a block of lightning data and plot FFT

Meta-data

- TBB data sets come with a meta-data in addition to the antenna outputs
- Includes:
  - Observation ID
  - Filter settings
  - Antenna locations
  - Antenna timing calibration
  - Much more…
- Antenna timing calibration is given as phase as a function of frequency. LoLIM software converts this to a time delay in seconds.
- Sometimes this meta-data is missing. If this happens, contact Sander

Build your own telescope



Task 5

- Goal: plot a pulse with antenna delays and geometric delays accounted for

1) Plot a single pulse from the data

  - The tutorial file gives the location of a pulse to plot
  - Find that pulse and plot it
  - Try to remove RFI
  - NOTE: that RFI removal only works on large blocks of data (2**16 data points)
  - You will need to open a large block, remove RFI lines, then find pulse in that block

2) Account for antenna delays and geometric delays

- Find and subtract off antenna delays

- Then find and subtract off geometric delays:

$$T_G = \frac{|\vec{X} - \vec{A}|}{C}$$

$\vec{A}$ - antenna location

$\vec{X}$ - potential source location

C - 3 x 10^8 m/s

T_g- geometric delay

3) Find the correct source location of this pulse

- Two potential locations are given
- If everything is correct, then the correct source location should be clear

Concluding remarks

Tutorial summary

- Opening data
- Routines to get metadata
- Perform RFI flagging
- Correct for station calibration
- Shift for geometrical delay

Build your own telescope!

- e.g. Do proper beamforming
  - Raw data => FFT => Sample shift => Apply phase => Add signals (=> FFT^{-1})
- Do imaging
  - Cross correlate antennas
  - Make an image
- Apply all appropriate delays (e.g. clock-offset)
- Perform calibration

Further information

PyCRTools

- Software package for TBB analysis of cosmic rays
- Own data format (hArrays)
- https://www.astro.ru.nl/software/pycrtools/
- Data previously on public svn, now on protected git repository
    - Ask cosmic ray KSP for access (through SOS)

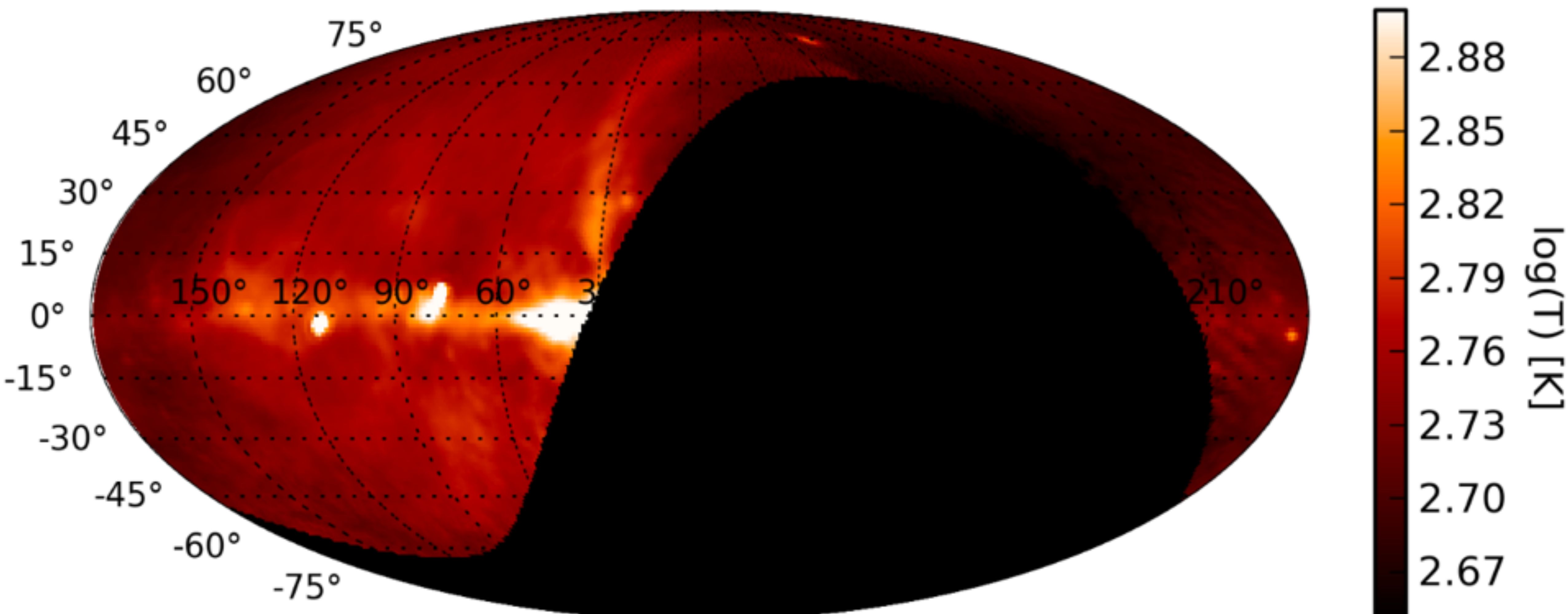
LOFAR Papers

- https://www.astron.nl/radio-observatory/lofar-science/lofar-papers/lofar-papers
- On cosmic rays and lightning
- Papers by Buitink, Nelles, Corstanje, Hare, Schellart, Scholten, ter Veen

Studying large-scale structures and polarization of the Northern sky facilitating single-station data of the Low Frequency Array (LOFAR)

Dissertation

Jana Köhler



130 MHz map

- http://hss.ulb.uni-bonn.de/2016/4408/4408.pdf

Sander's Thesis

Chapter 2: TBB data acquisition

Chapter 4: FRB localisation

http://hdl.handle.net/2066/147186