All-sky radio searches for SETI

Dr. Sander ter Veen

(Prof. Dr. Heino Falcke, Emilio Enriquez,
LOFAR Key Science Project “Cosmic Rays”)

Radio transmitters

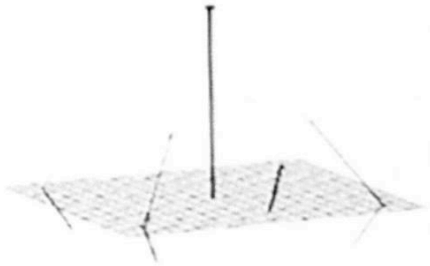
- Leakage radiation
  - Radio station
  - Communication
  - Radar
- Narrow band signals
  - Energy effective
  - Natural signals are broader
- Beacon


1st Generation
Dwingeloo
1 antenna
2nd Generation
Westerbork Synthesis Radio Telescope
14 antennas
3rd Generation
LOFAR
> 50.000 Antennas

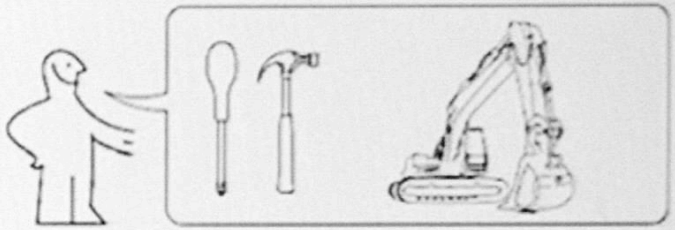
LÖFÅR

52x

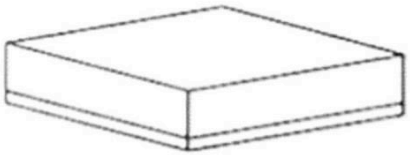
10-90 MHz



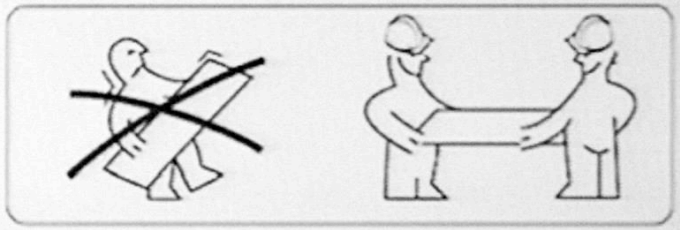
96x



110-250 MHz



48x



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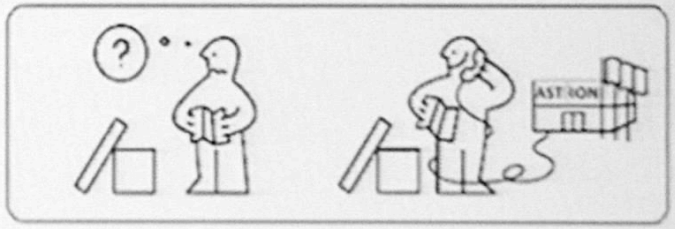
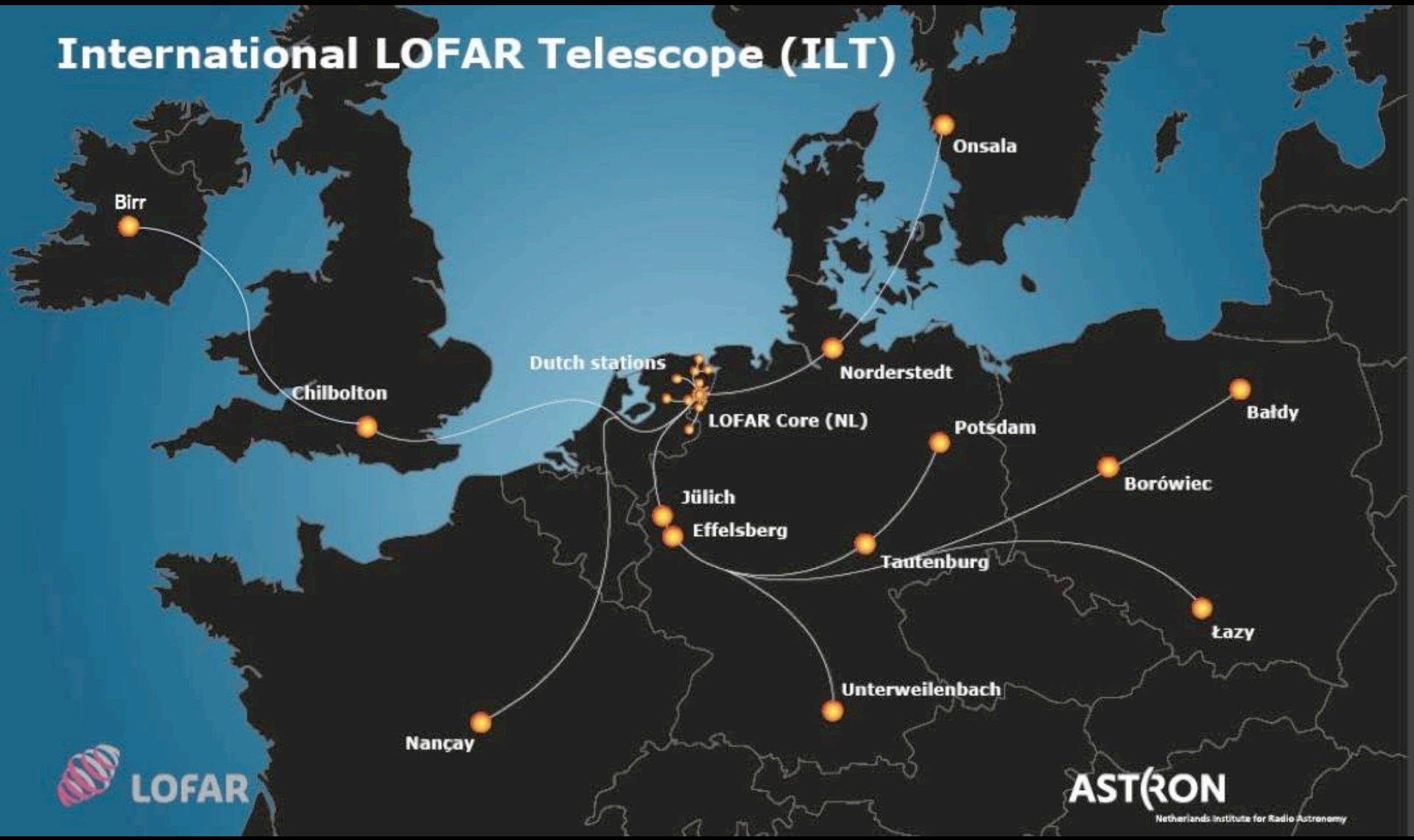
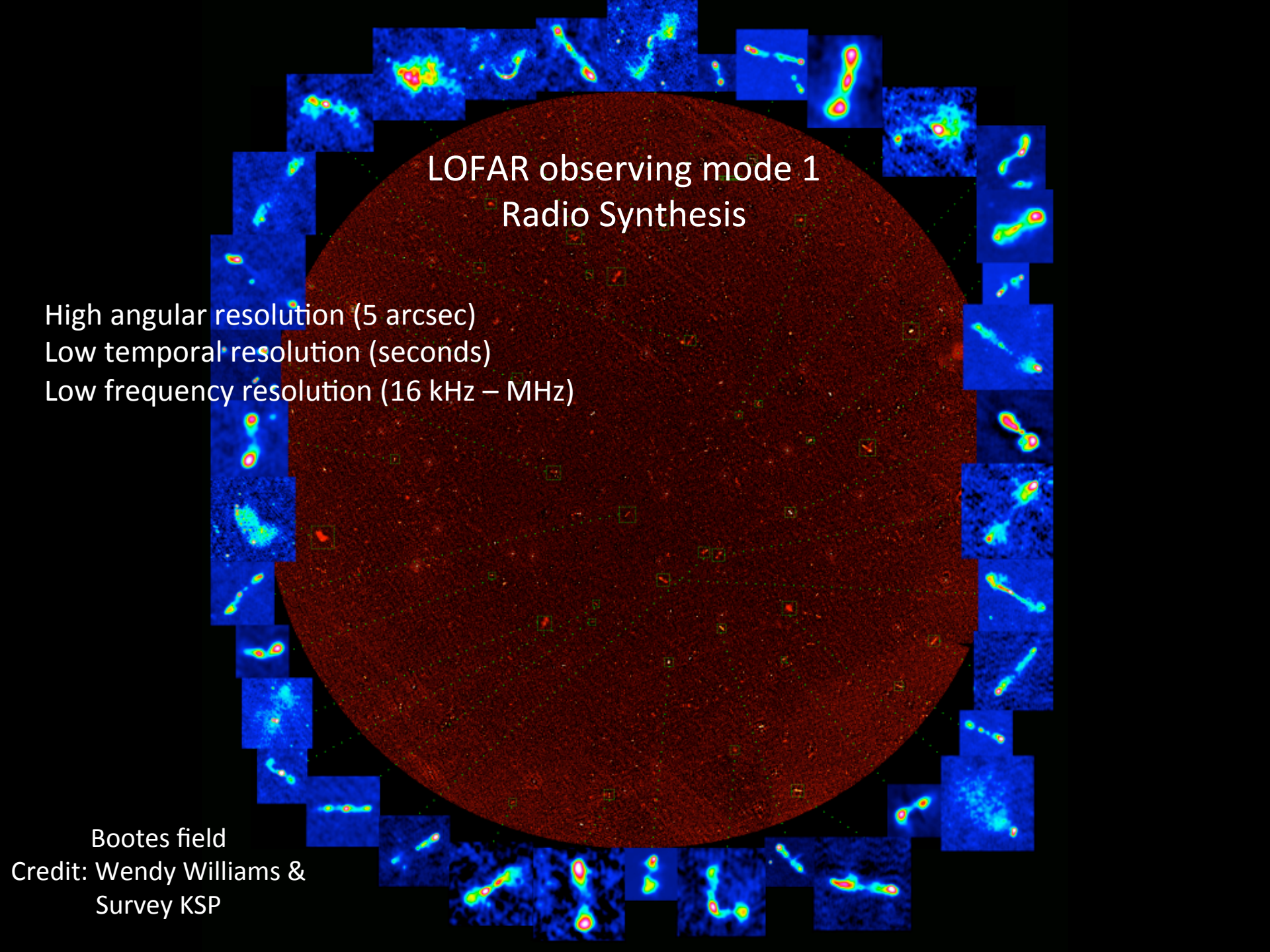


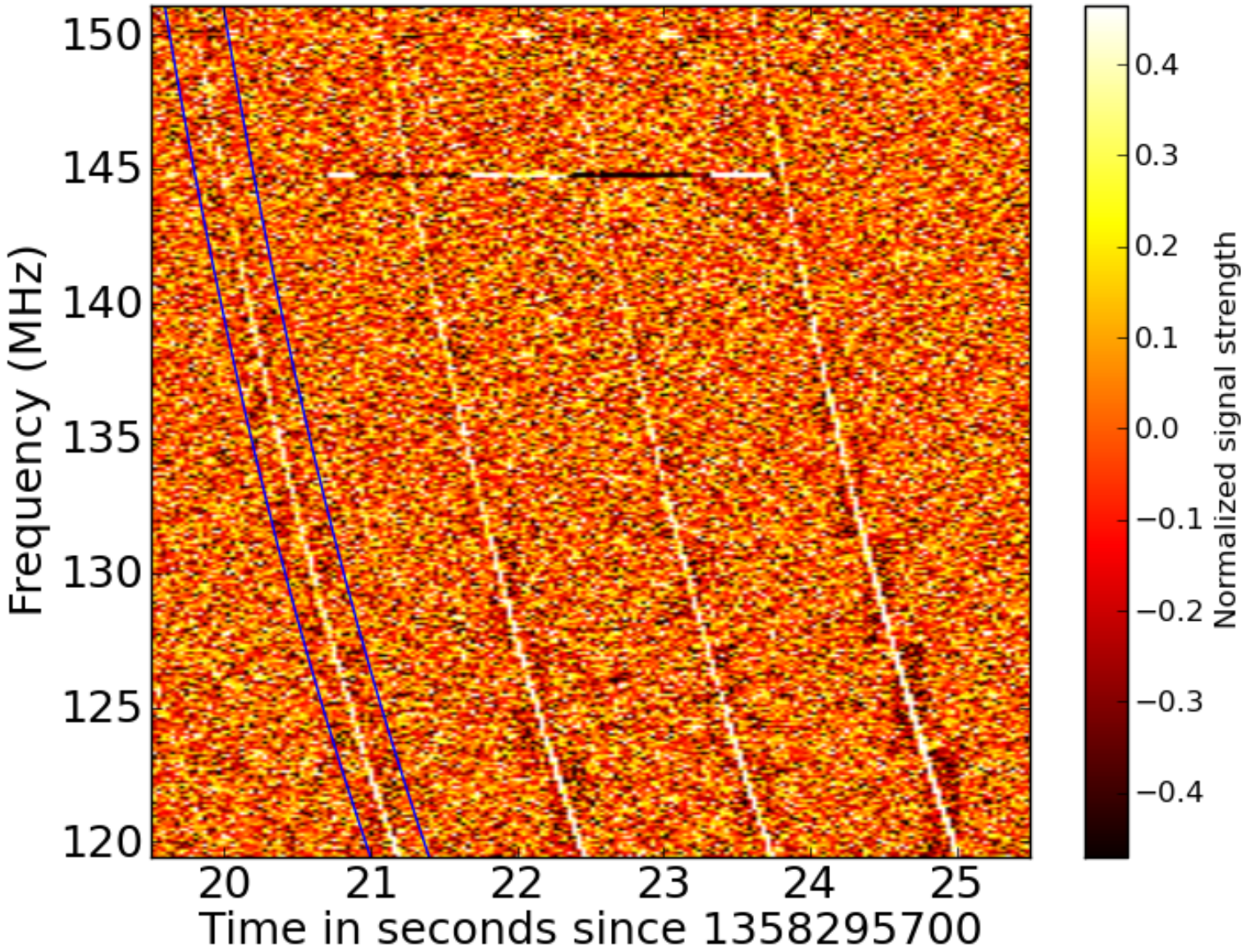
McKay-Bukowski 2008

A LOFAR (Core) Station


International LOFAR Telescope (ILT)
Onsala
Birr
Dutch stations
Norderstedt
Chilbolton
LOFAR Core (NL)
Potsdam
Bałdy
Borówiec
Jülich
Effelsberg
Tautenburg
Łazy
Unterweilenbach
Nançay
LOFAR
ASTRON
Netherlands Institute for Radio Astronomy

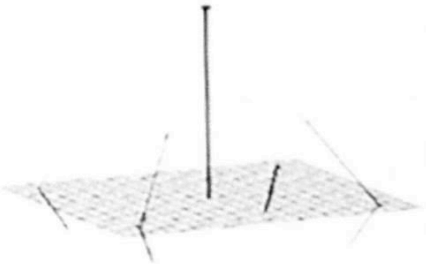

LOFAR observing mode 1
Radio Synthesis
High angular resolution (5 arcsec)
Low temporal resolution (seconds)
Low frequency resolution (16 kHz – MHz)
Bootes field
Credit: Wendy Williams &
Survey KSP

LOFAR observing mode 2
Beam formed data
High temporal resolution (µs – ms)
Medium-high frequency resolution (16 kHz – Hz)
Low spatial resolution (2-30 arcmin)



LÖFÅR

52x



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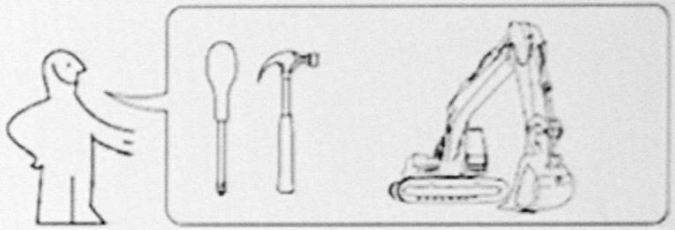

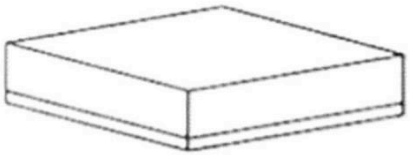

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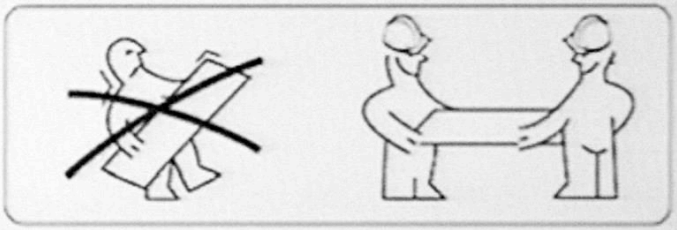
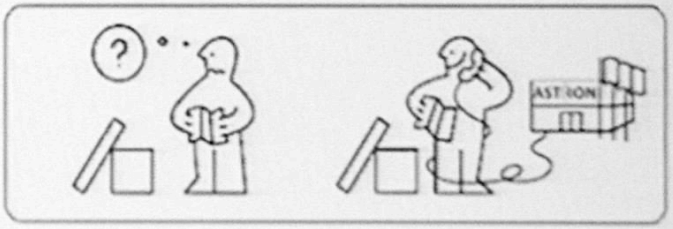
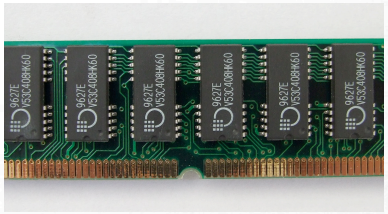


1x





48x

McKay-Bukowski 2008

Transient Buffer Board

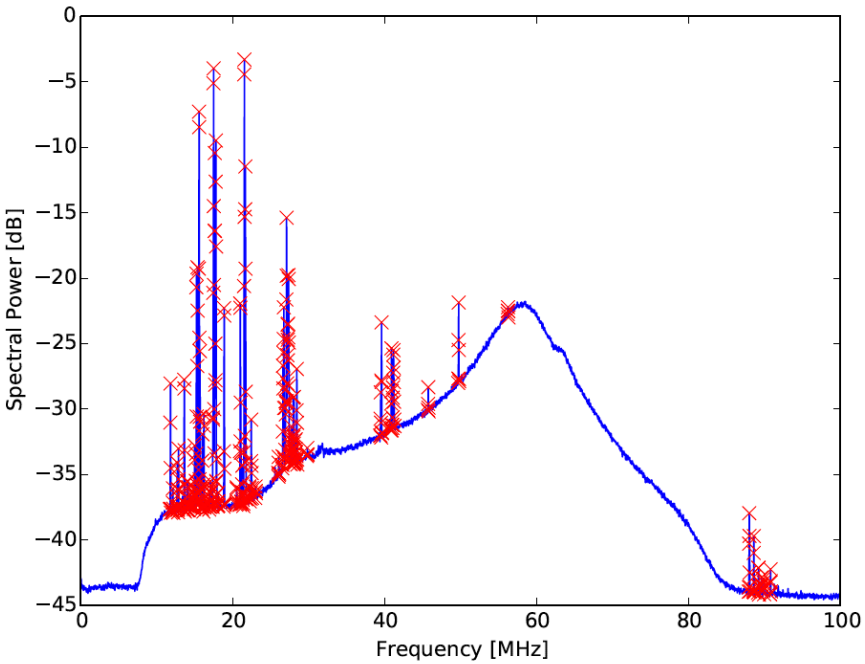
- RAM Ring buffer for each antenna
- Records:
  - Raw data (100 MHz) for 5.2 seconds
  - 1 to 487 channels of 195.3125 kHz for 5.2 s – 42 min.
- Frozen and stored after a trigger
- Full buffer 192 GB per station

Spectrum

Time =>

Fast Fourier Transform (FFT)

Frequency



Spectrum

Time =>

Frequency =>

Dynamic Spectrum

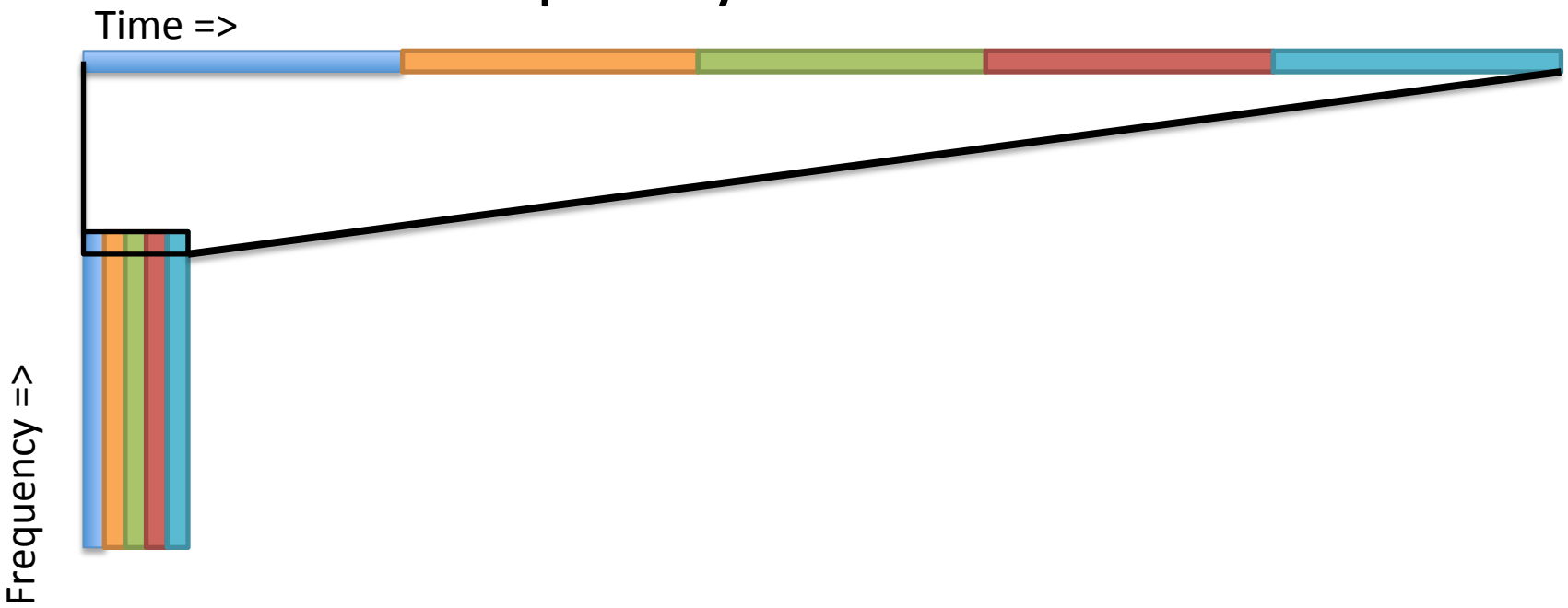
Time =>

- Choose frequency and time resolution

Frequency =>

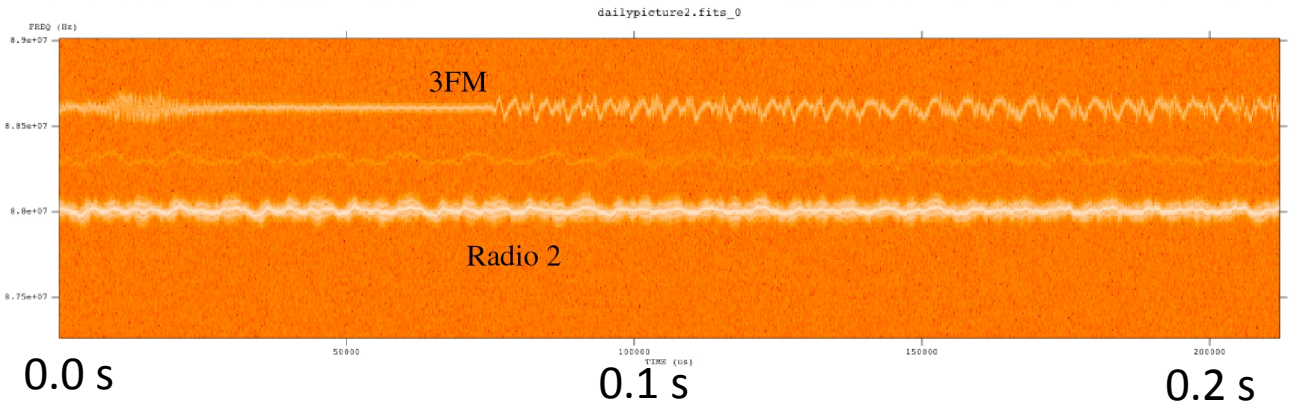
Dynamic Spectrum

- Increase frequency resolution



LOFAR TBB busy week

30-03-09 - 03-04-09



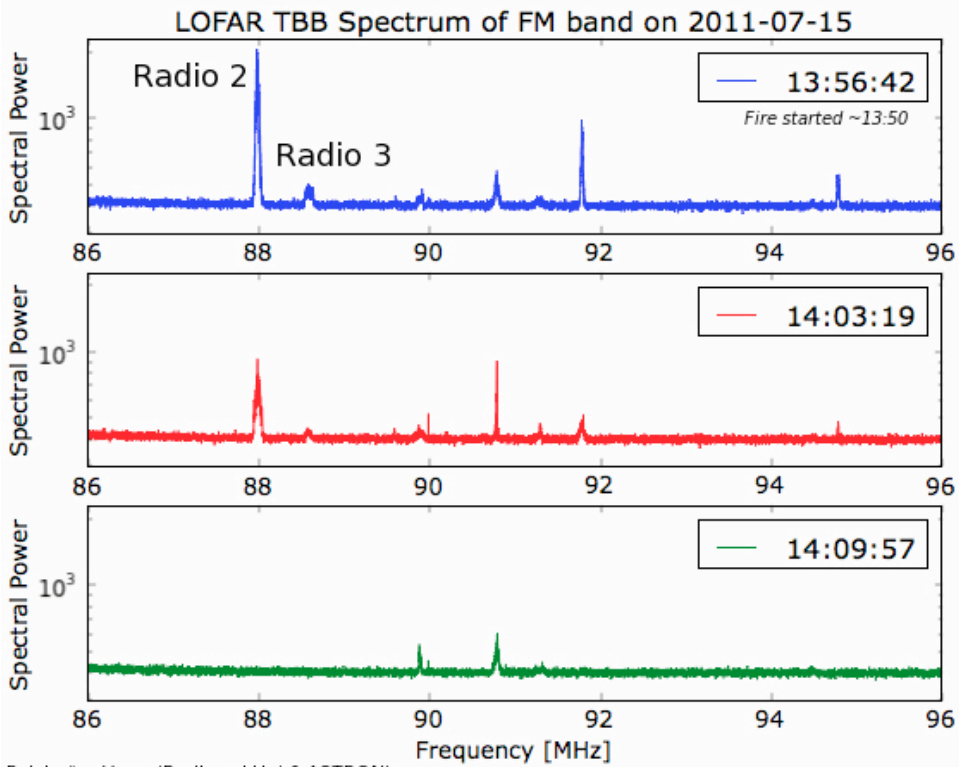
88.6 MHz

88.0 MHz

0.0 s

0.1 s

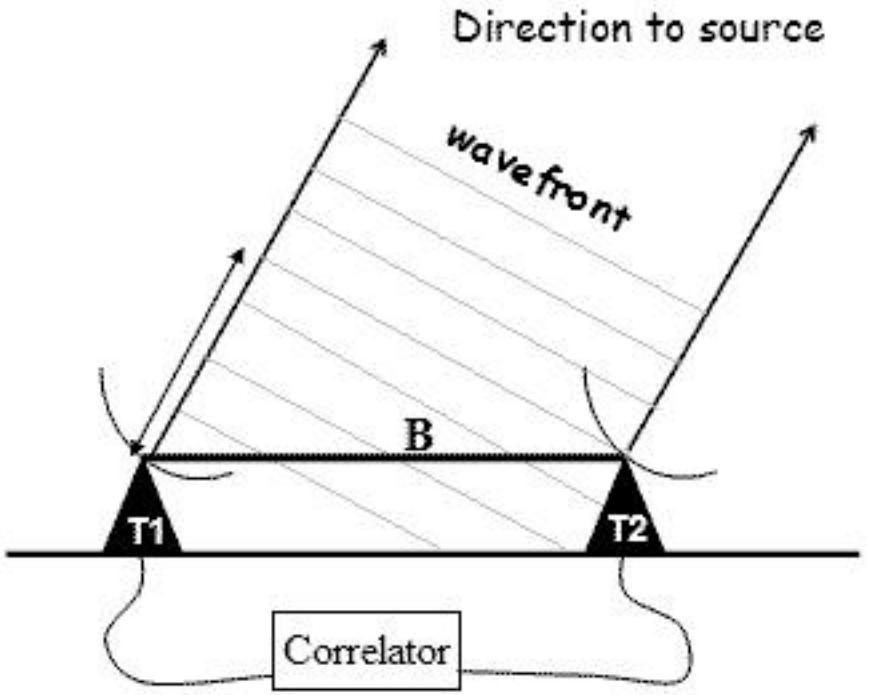
0.2 s



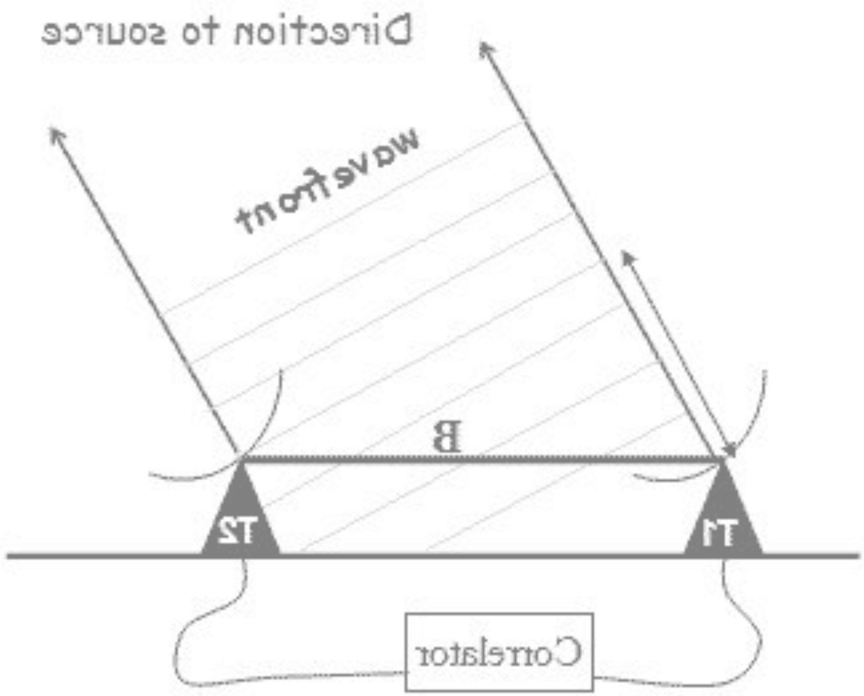
Falcke/ter Veen (Radboud Uni & ASTRON)

Beam forming

Resolution ~ Wavelength / **Distance**

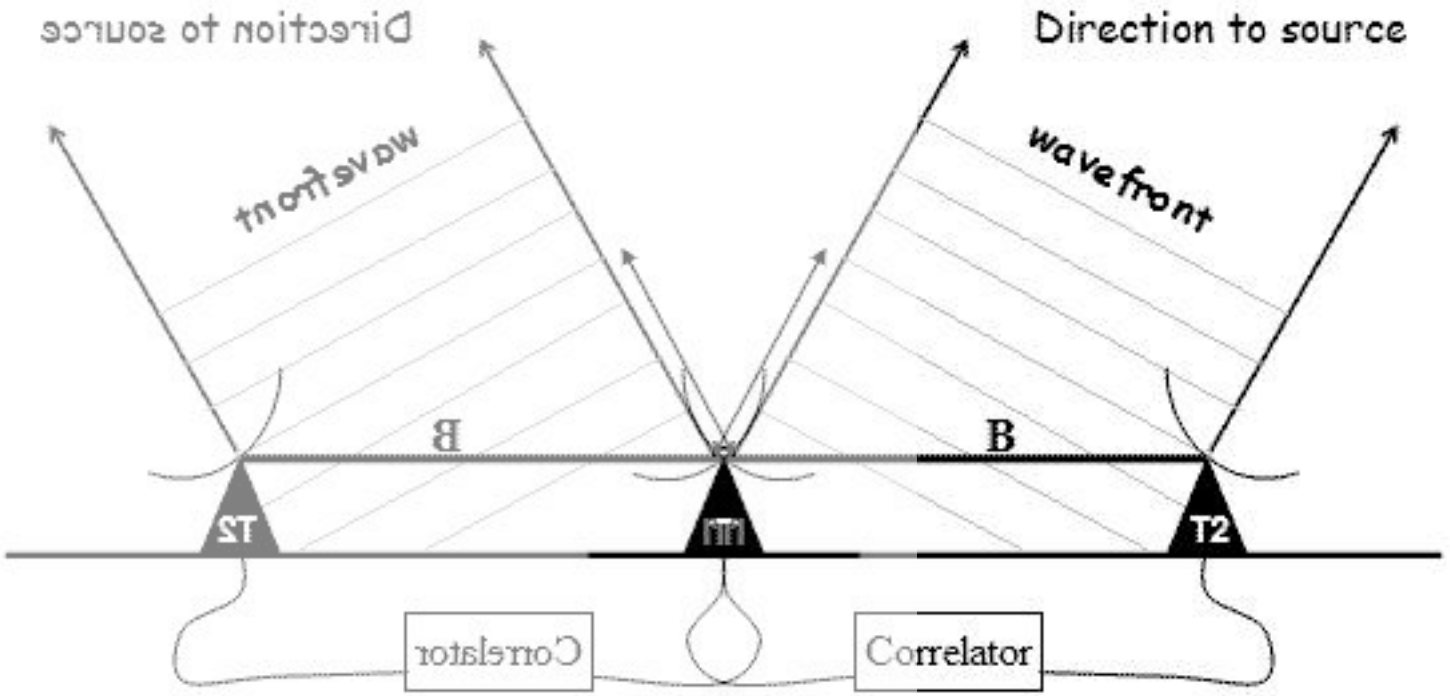


Beam forming

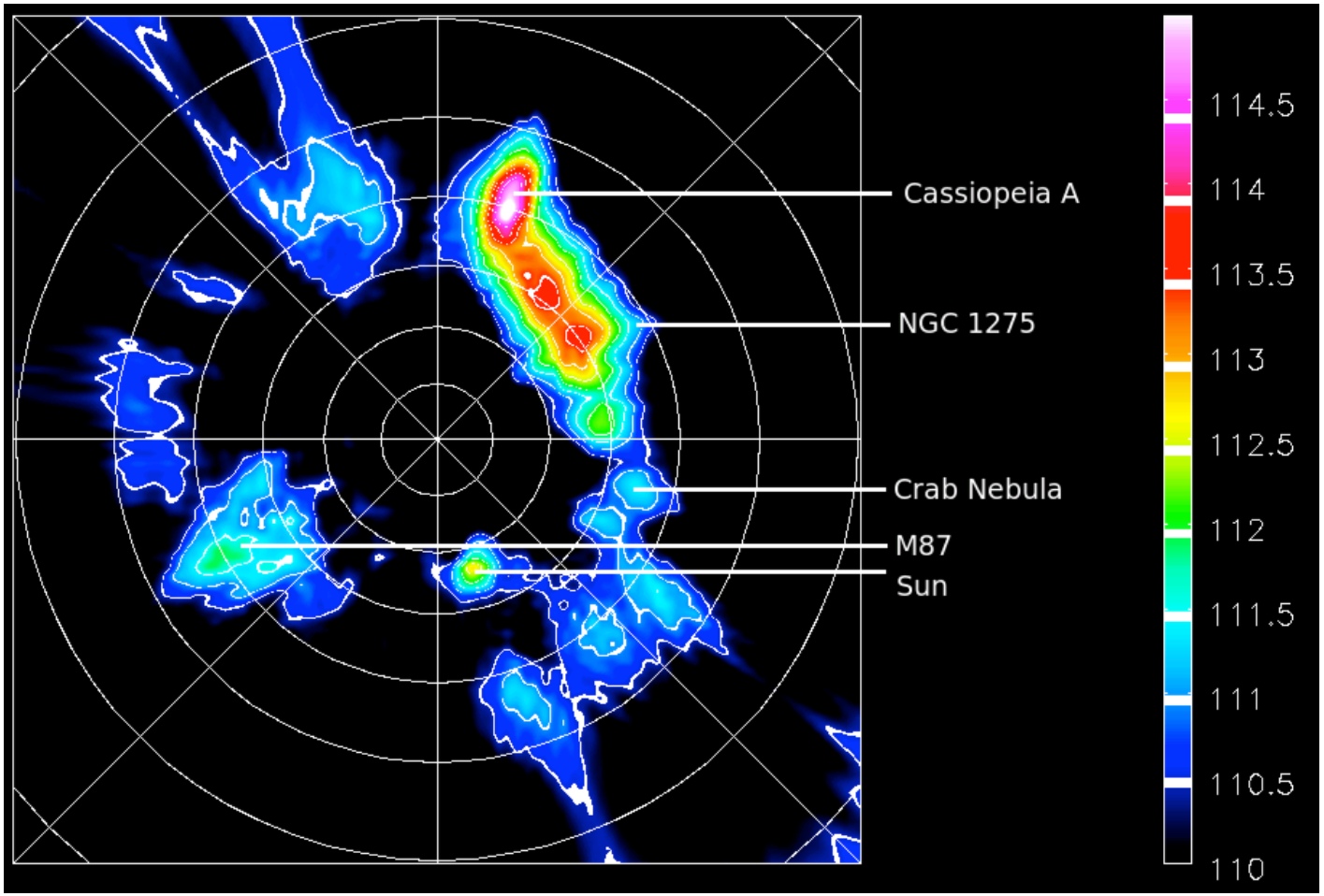


Beam forming

in different directions simultaneously

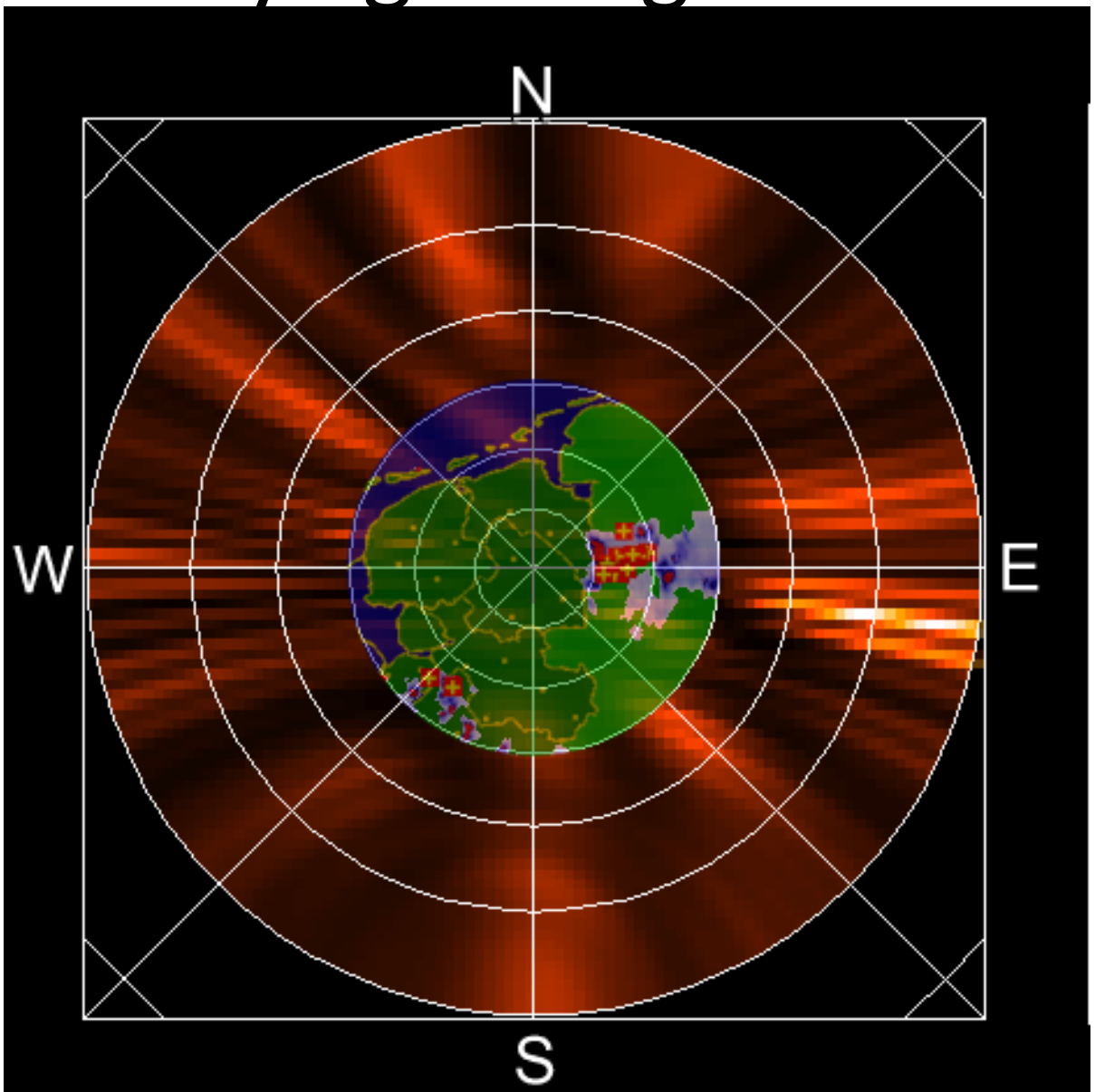


All-Sky beam forming



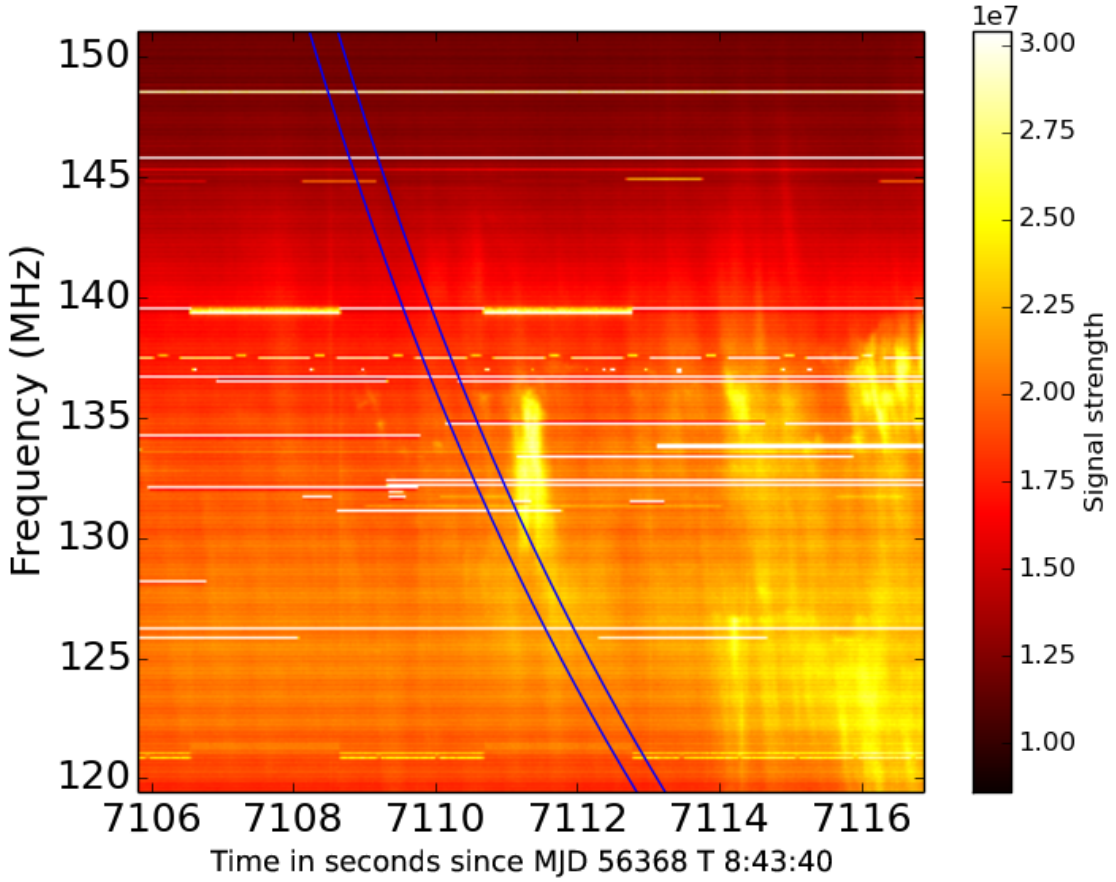
1 LOFAR station, credit Sef Welles

All-sky lightning detection



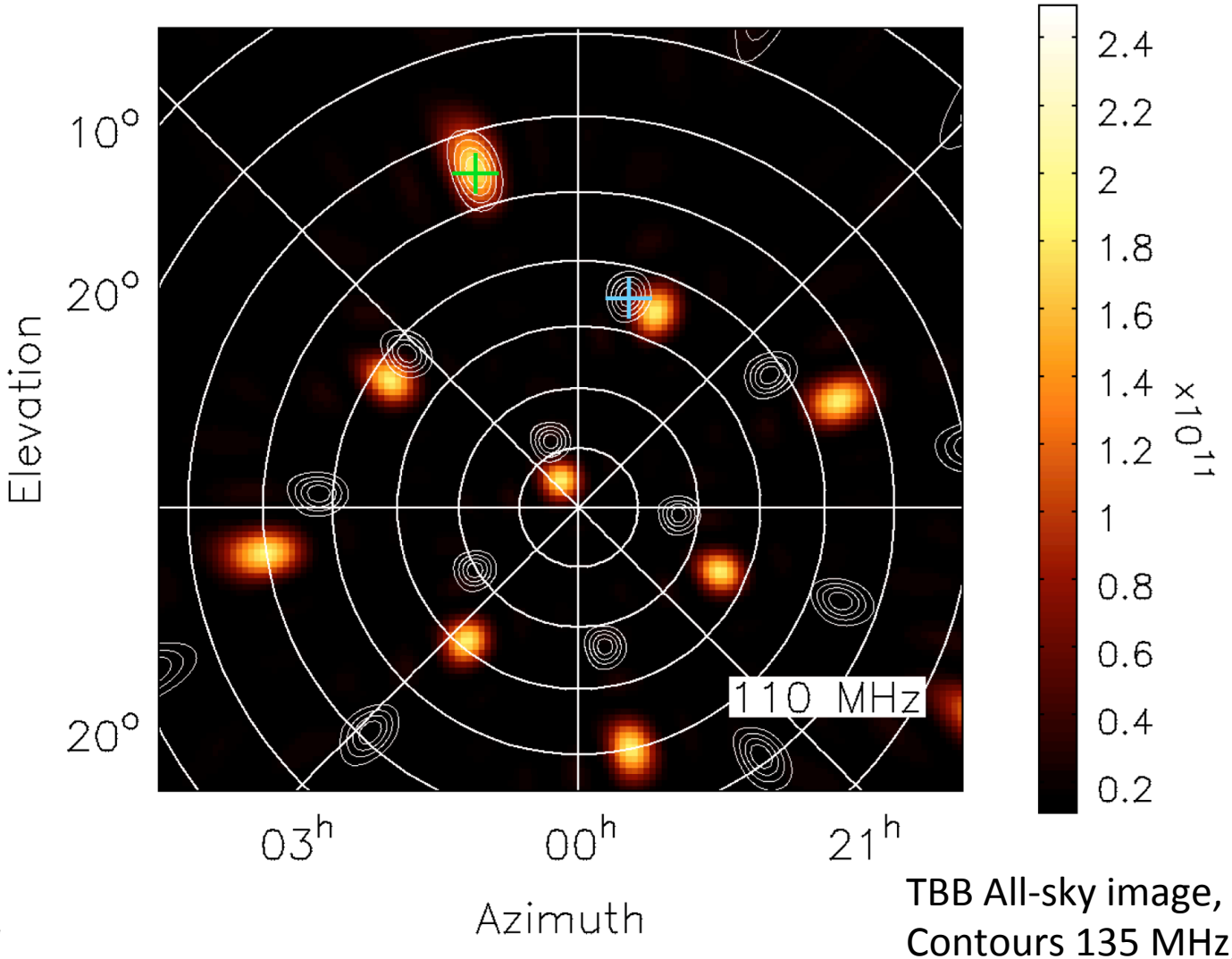
1 LOFAR station,
Only 6 antennas

Localisation of a transient source



Beam Formed data

Localisation of a transient source

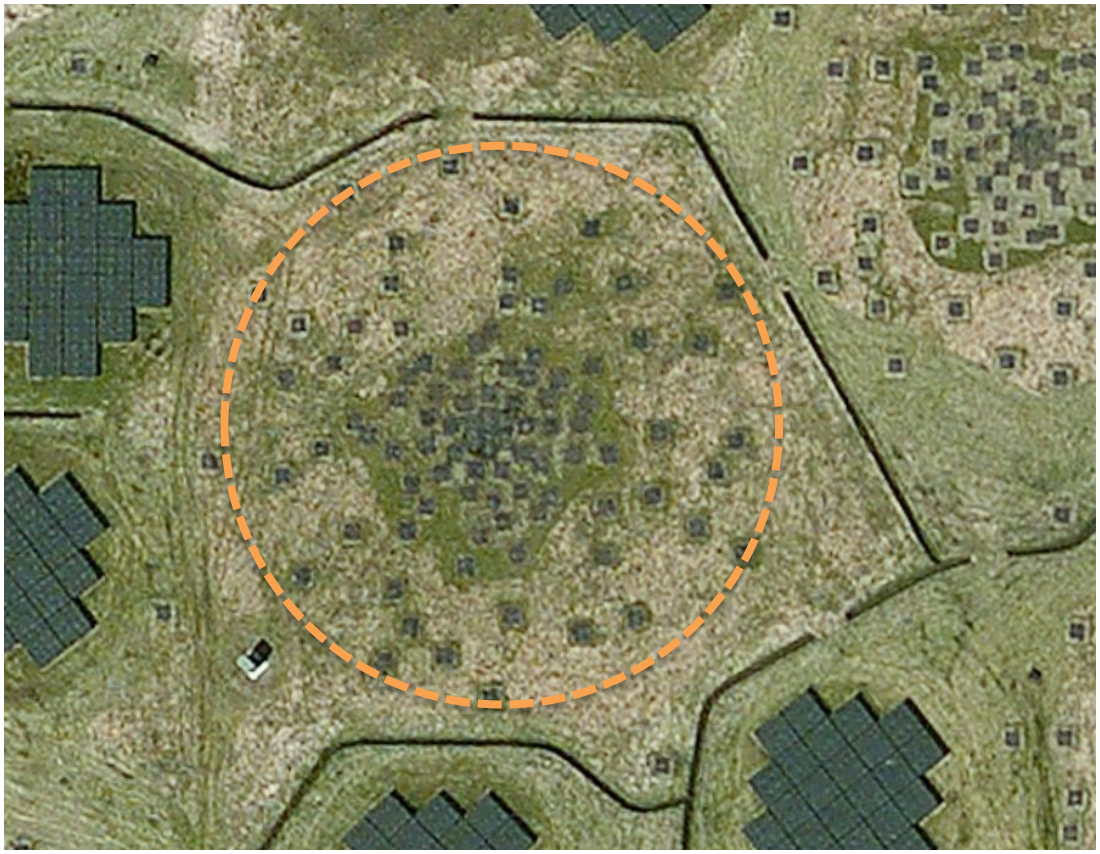


TBB All-sky image, 1 station.
Contours 135 MHz, Color 110 MHz

Zooming in

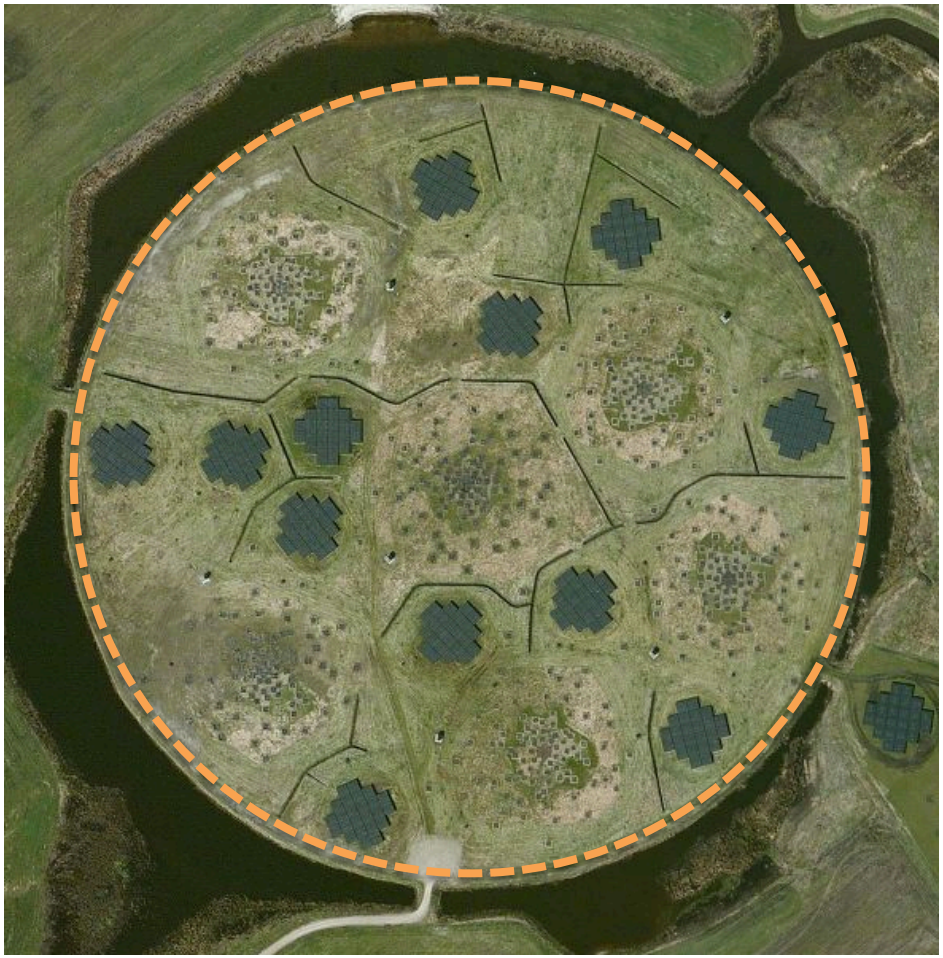
Stations	1
Configuration	Inner
Diameter	32.3 m
Resolution 15 MHz	46.2 deg
Pointings 15 Mhz	39
Resolution 45 MHz	15.4 deg
Pointings 45 MHz	348
Resolution 75 MHz	9.24
Pointings 75 MHz	967

Zooming in



Stations	1
Configuration	Outer
Diameter	81.3 m
Resolution 15 MHz	18.3 deg
Pointings 15 Mhz	246
Resolution 45 MHz	6.1 deg
Pointings 45 MHz	2214
Resolution 75 MHz	3.66
Pointings 75 MHz	6149

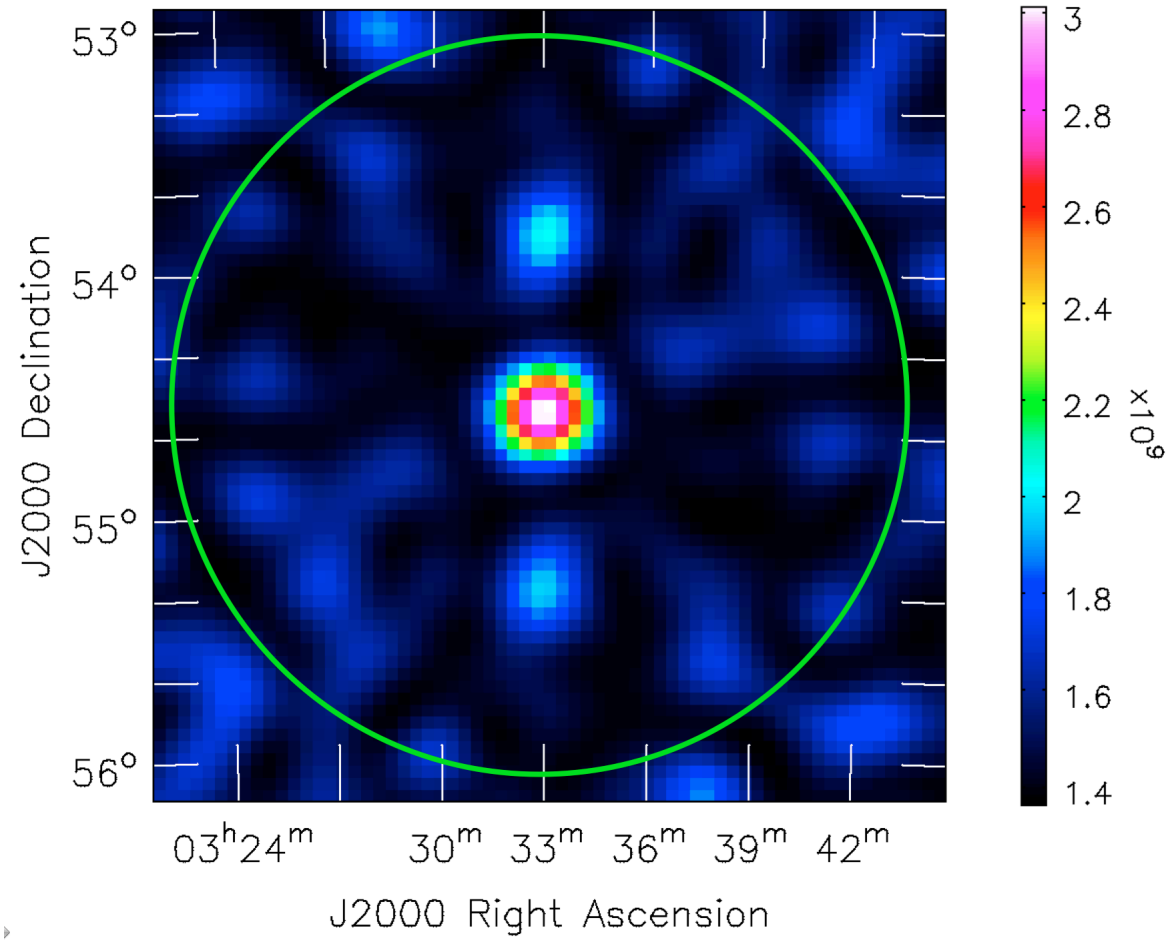
Zooming in



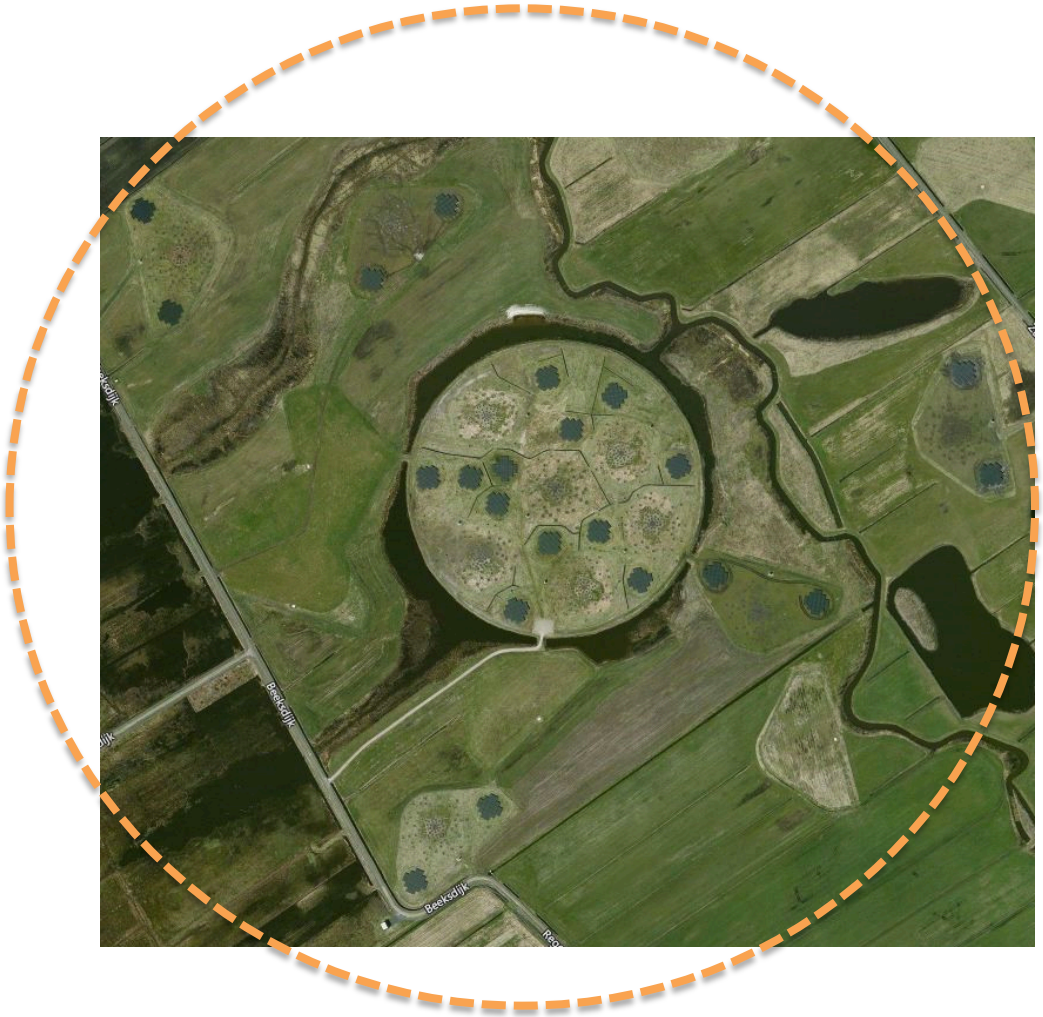
Superterp

Stations	6
Configuration	Outer
Diameter	300 m
Resolution 15 MHz	5.0 deg
Pointings 15 Mhz	3350
Resolution 45 MHz	1.7 deg
Pointings 45 MHz	30156
Resolution 75 MHz	1.0
Pointings 75 MHz	83727

Image of a pulsar pulse with the Superterp



Zooming in



Stations	12
Configuration	Outer
Diameter	600 m
Resolution 15 MHz	2.5 deg
Pointings 15 Mhz	13400
Resolution 45 MHz	0.85 deg
Pointings 45 MHz	120624
Resolution 75 MHz	0.5 deg
Pointings 75 MHz	334908

Zooming in

Stations	24
Configuration	Outer
Diameter	2400 m
Resolution 15 MHz	0.6 deg
Pointings 15 Mhz	214400
Resolution 45 MHz	0.21 deg
Pointings 45 MHz	482500
Resolution 75 MHz	0.12 deg
Pointings 75 MHz	1334000

Even sharper: Add remote stations up to 100 km

Zooming in

Stations	1	1	6	12	24
Configuration	Inner	Outer	Outer	Outer	Outer
Diameter	32.3 m	81.3 m	300 m	600 m	2400 m
Resolution 15 MHz	46.2 deg	18.3 deg	5.0 deg	2.5 deg	0.6 deg
Pointings 15 Mhz	39	246	3350	13400	214400
Resolution 45 MHz	15.4 deg	6.1 deg	1.7 deg	0.85 deg	0.21 deg
Pointings 45 MHz	348	2214	30156	120624	482500
Resolution 75 MHz	9.24 deg	3.66 deg	1.0 deg	0.5 deg	0.12 deg
Pointings 75 MHz	967	6149	83727	334908	1334000

Alternative method

- If there is a dominant signal in your frequency channel, the phase difference between two antennas (stations) will be constant

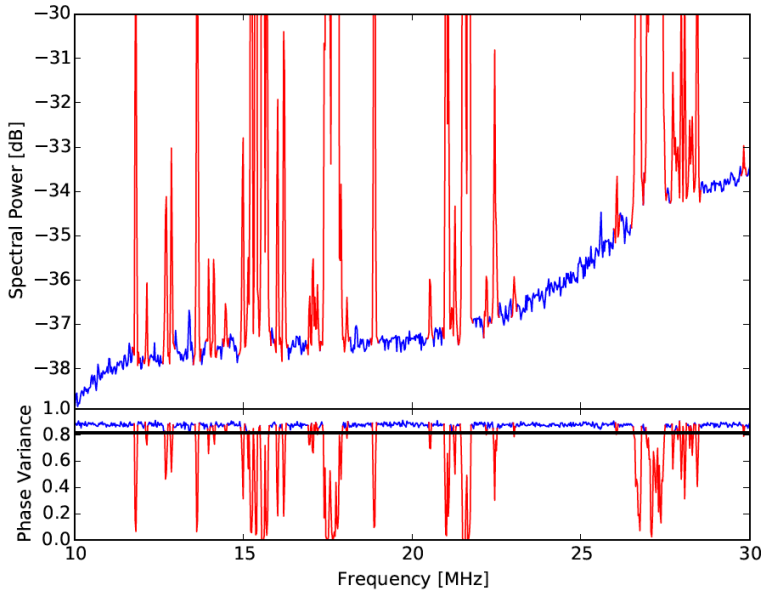


Fig. 3. Close-up of the power spectrum in a frequency range with several RFI sources. **Flagged frequencies are shown in red; the lower panel shows the phase variance, with the black horizontal line denoting the threshold for flagging.** Although the RFI-quiet noise level would follow a smooth curve, fitting the curve and RFI flagging using the excess power are interdependent.

Alternative method

- If there is a dominant signal in your frequency channel, the phase off-set between two antennas (stations) will be constant

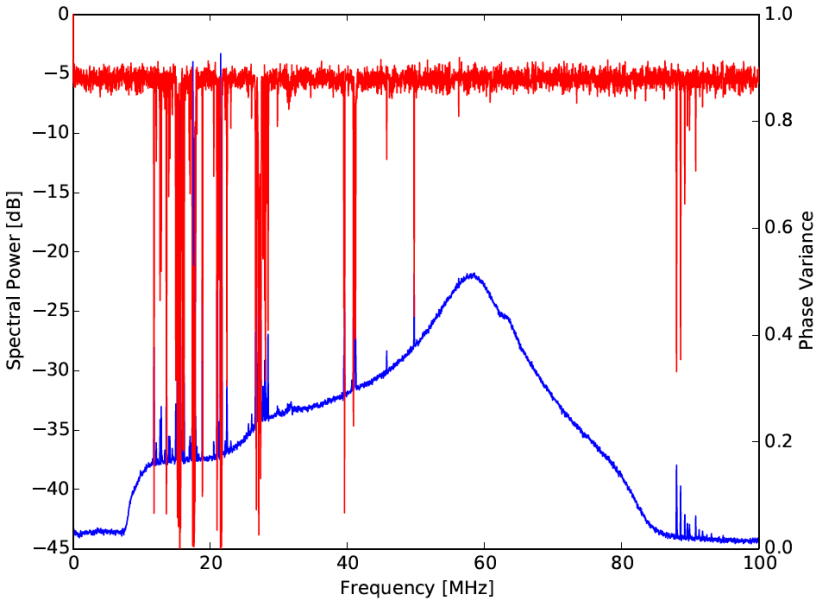


Fig. 2. Example power spectrum from 2 ms of LOFAR time series data (lower curve). The phase variance is shown in the upper (red) data points. It consistently becomes lower whenever a narrowband transmitter is seen in the power spectrum.

Alternative method

- If there is a dominant signal in your frequency channel, the phase off-set between two antennas (stations) will be constant

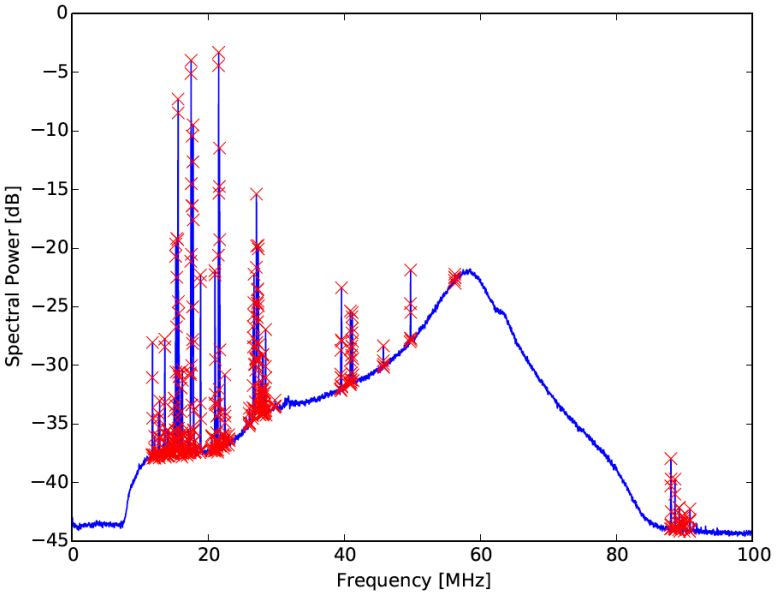
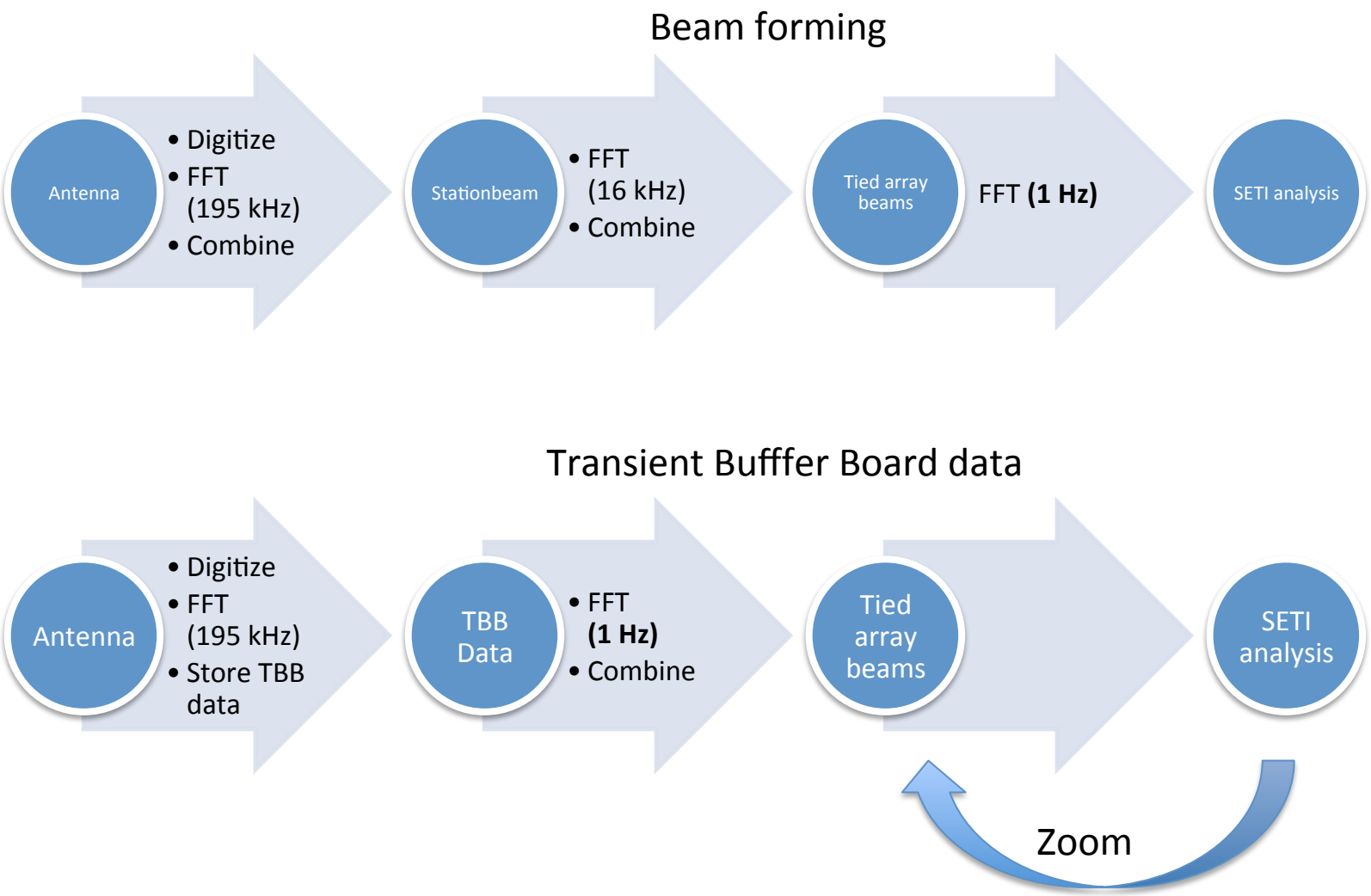


Fig. 1. Example power spectrum from 2 ms of LOFAR data, averaged over 48 LBA antenna dipoles, with crosses indicating channels with detected transmitters.

Processing chain



Numbers TBB (8 min)

Subbands	5	400
Datasize 1 stations	192 GB	15 TB
Datasize 24 stations	4.6 TB	370 TB
Datasize Remote stations	3.1 TB	246 TB
Datasize Dutch stations	7.7 TB	616 TB
Recording time (slow)	3 hours	10 days
Recording time (fast)	0.5 hours	2 days
Number of antennas Core	1152	
Number of antennas Dutch	1920	

Numbers beam formed (8 min)

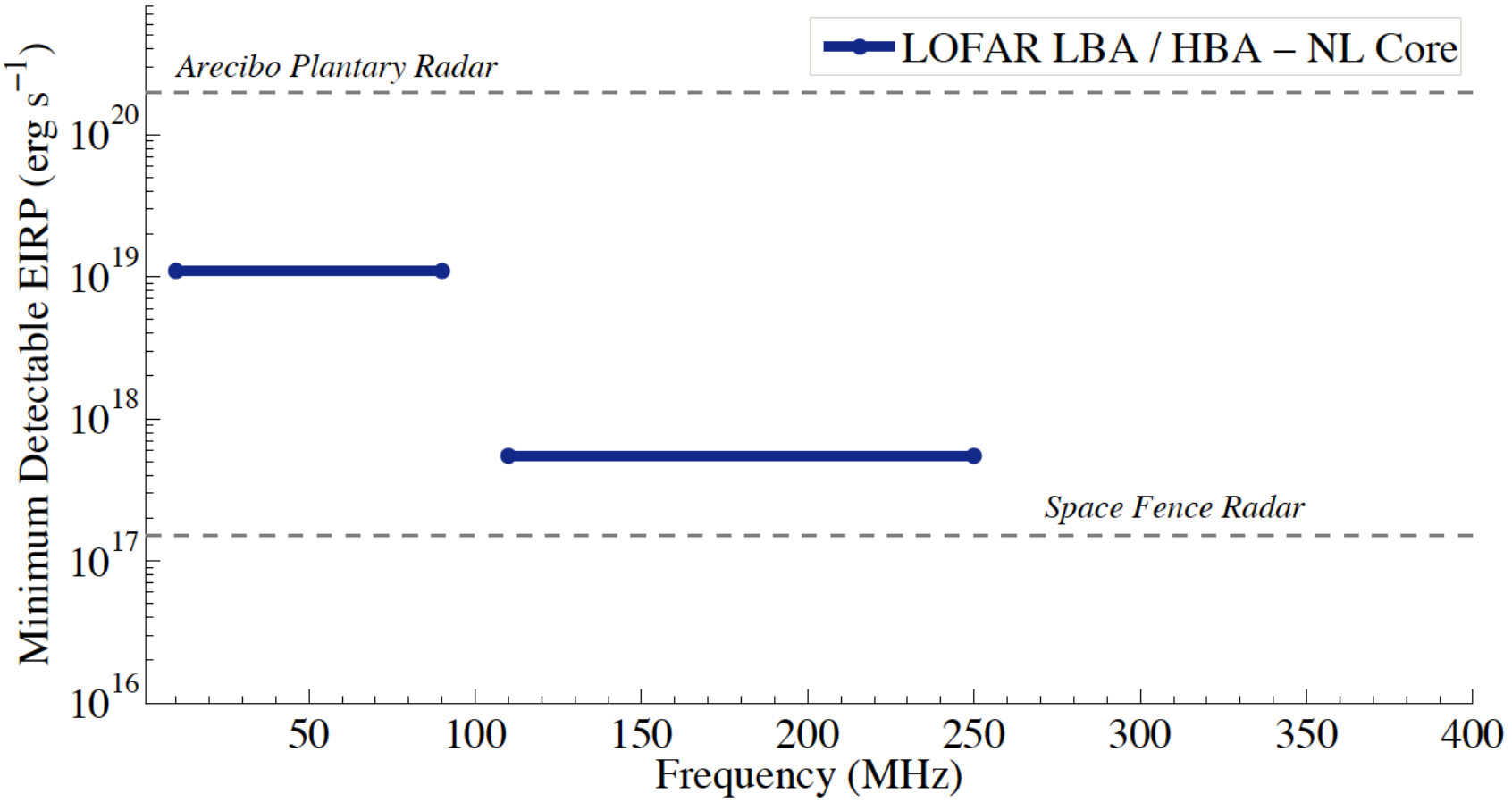
	15 MHz	75 MHz
Subbands	400	
Datasize 1 beam	0.53 TB	
Pointings	214400	1334000
Datasize	114000 GB	707000 GB
Recording time (1 beam)	1190 days	7411 days
Recording time (7 beams)	170 days	1060 days
Recording time (19 beams)	62 days	390 days

When is TBB prefered?

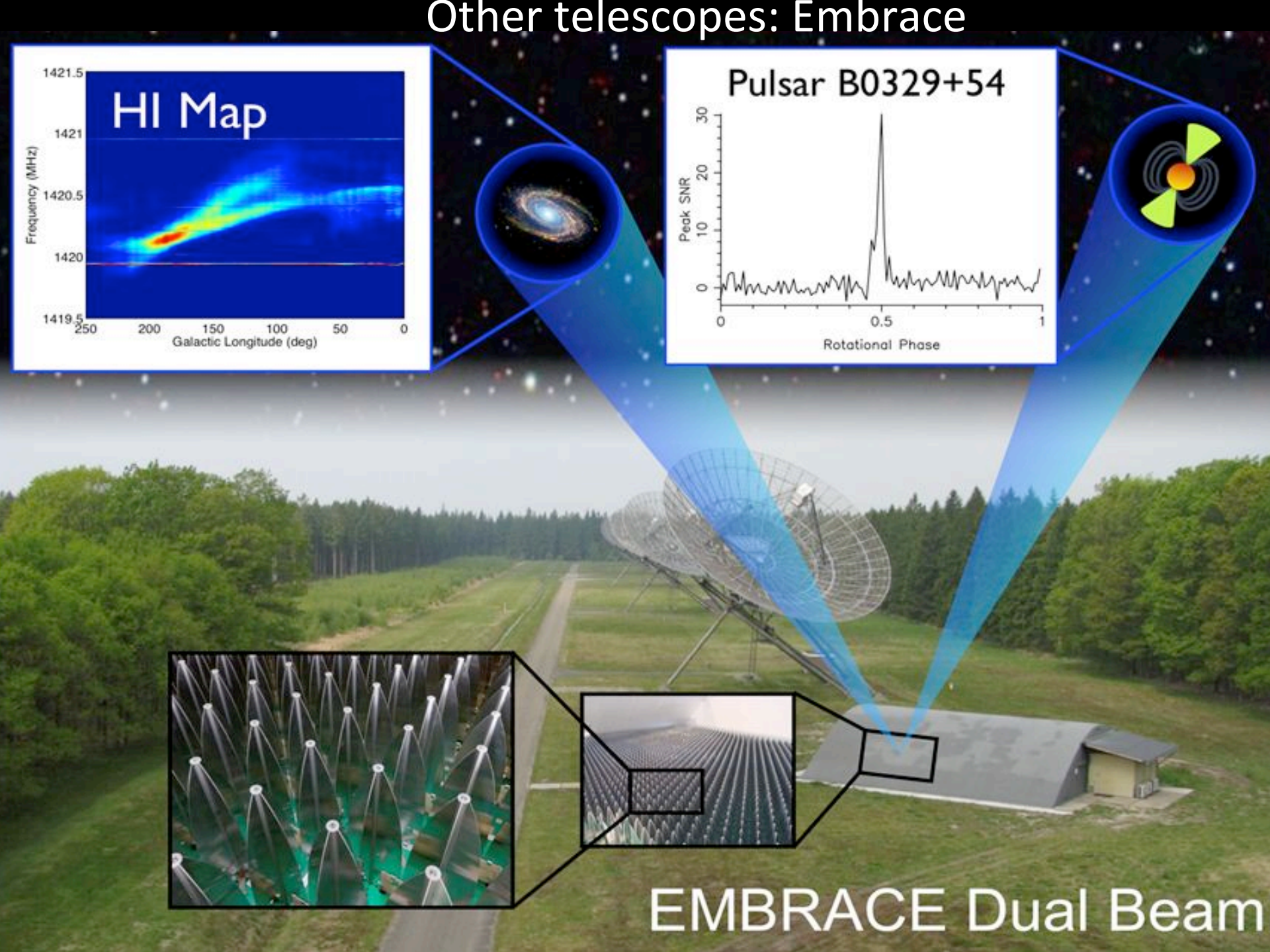
	Number of beam
Data size (Core)	1152
Data size (Dutch)	1920
Recording (1 beam)	360
Recording (7 beams)	2520
Recording (19 beams)	6840
Calculations	?

Sensitivity

12 minute integration time; Reference sources at 5 pc

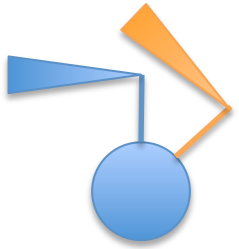


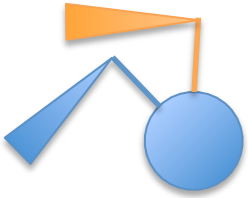
Other telescopes: Embrace



Horizon transmitters

- Leakage radiation is most likely towards the exo-horizon
- Radiation will vary with spin of exo-planet
- Different dopplershift transmitters at different latitudes





Conclusions

- Newly developed radio telescope can have the capability of all-sky recording
- Benefits
  - Bad element rejection
  - Short observing time
  - Limited (initial) data storage
  - No need to analyse every position
    - Zoom in on significant signals
    - Use constant phase offset to identify
  - Flexibility in data analysis
- Large computing power required