

## LOFAR

Detecting the weakest cosmic signals  
in-between strong man-made signals

Dr. Paulus Krüger

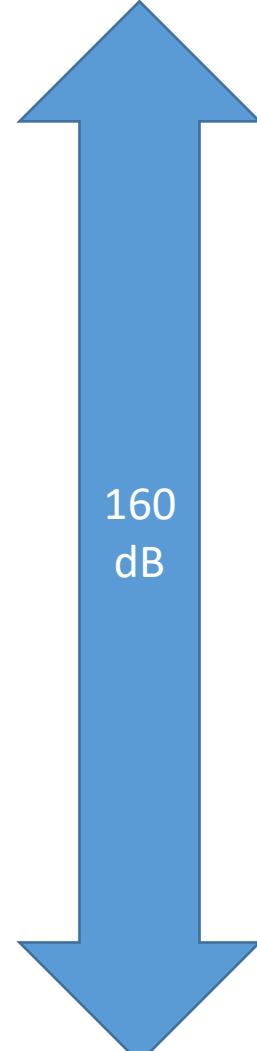




Stadium world record 140dB

**-160dB = 1 in 10 000 000 000 000 000 000**

Whisper  
@ 300m  
-20dB



160  
dB

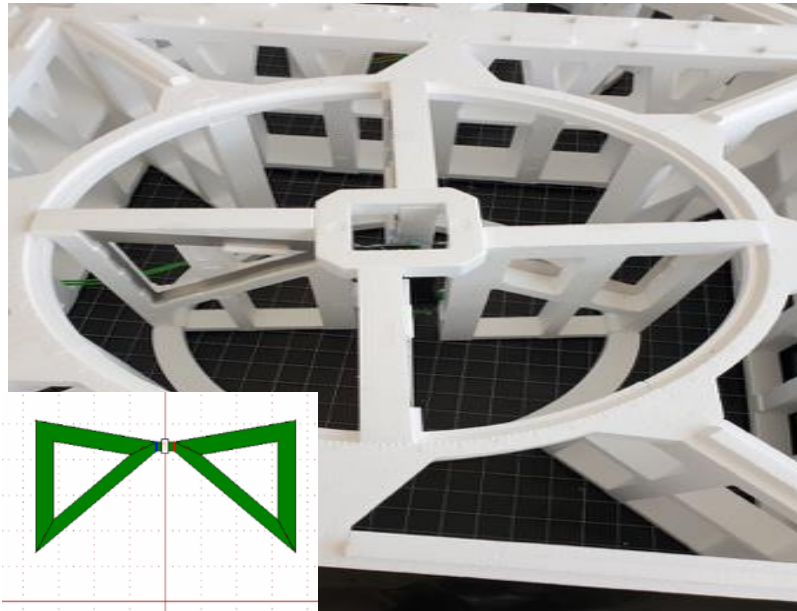
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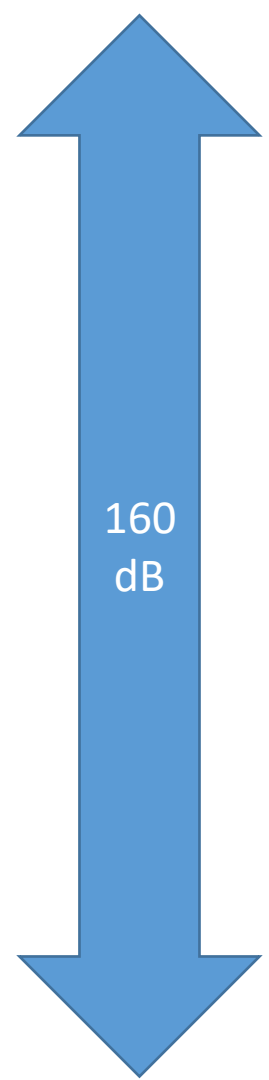
# LOFAR antennas



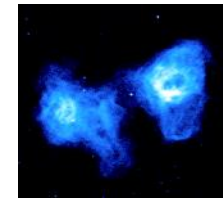
10 - 100 MHz



100 - 300 MHz

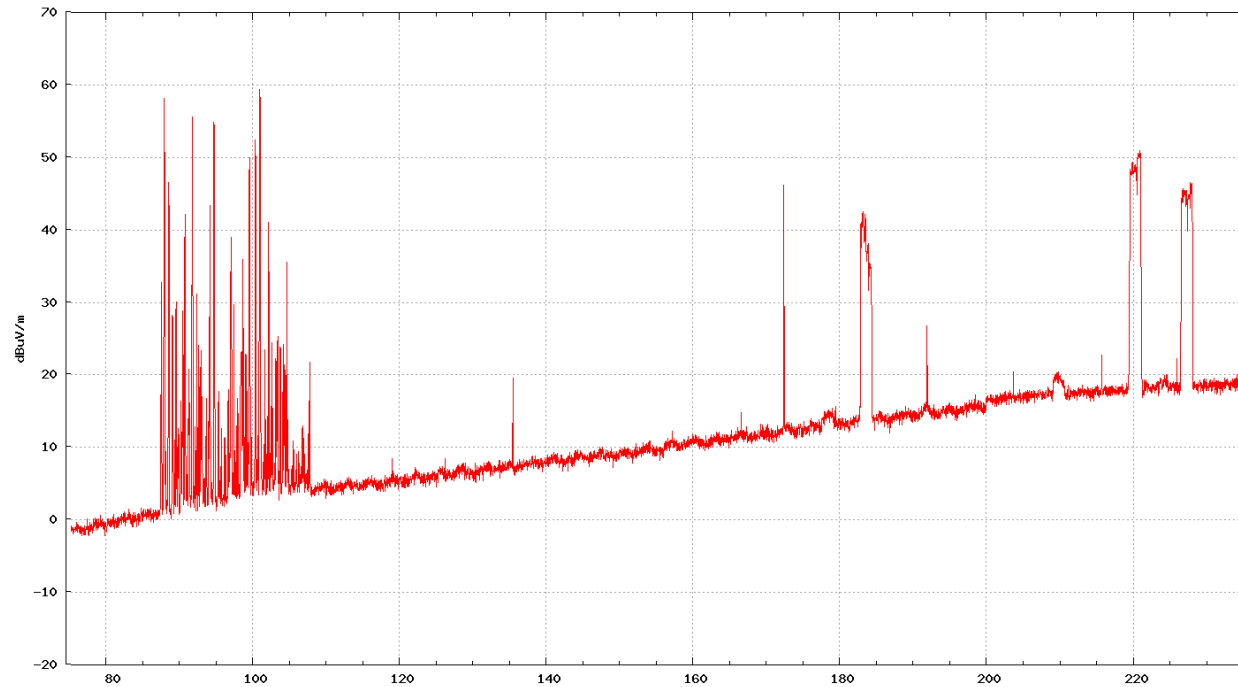


160 dB



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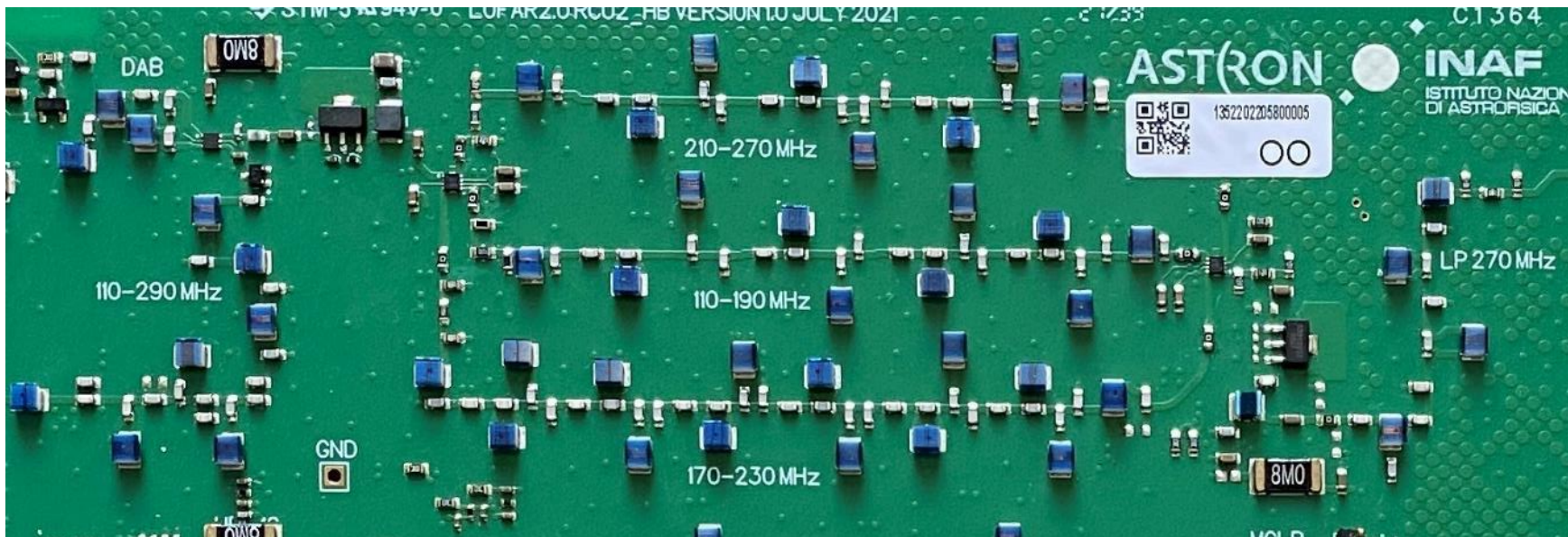
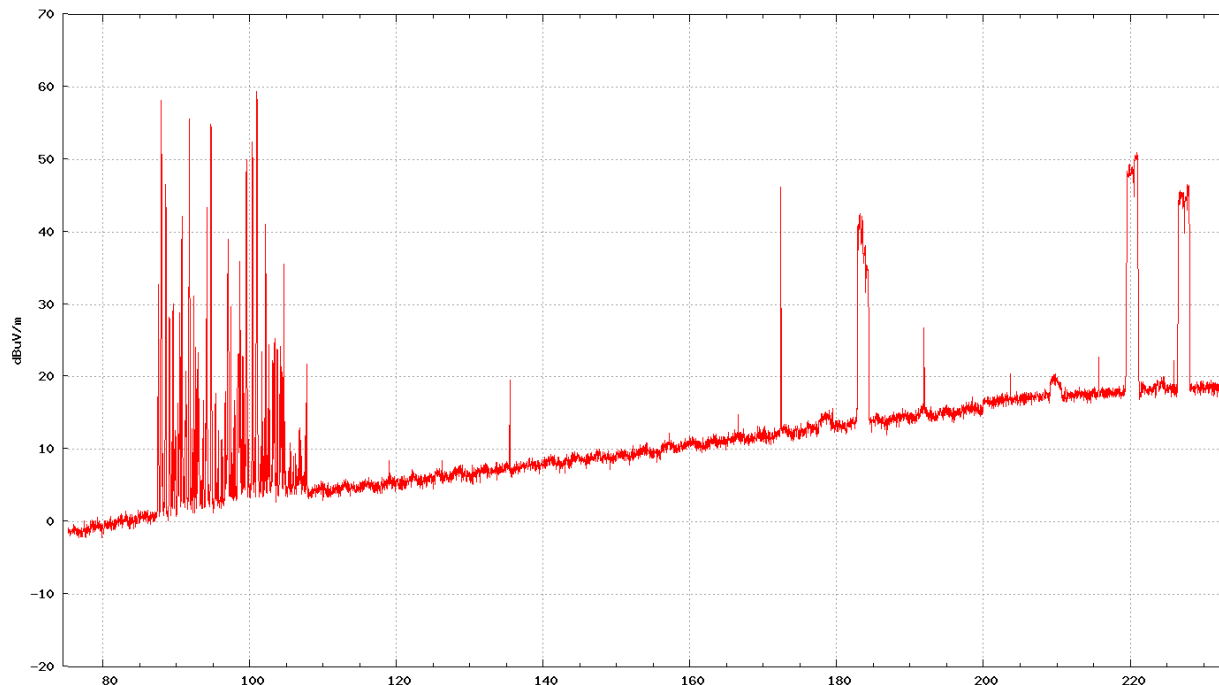
# RF filter banks



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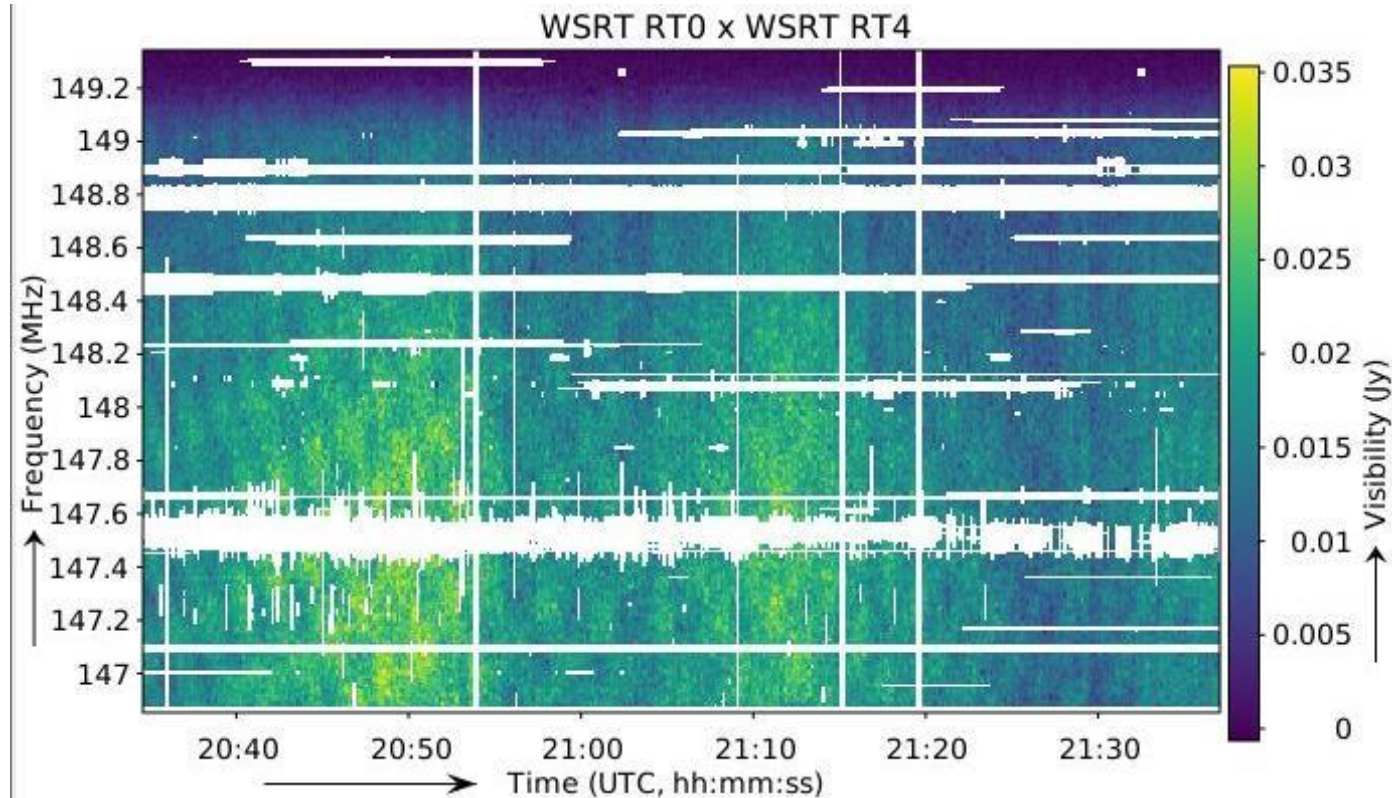
# RF filter banks



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# AOFlagger



Thermal  
Noise

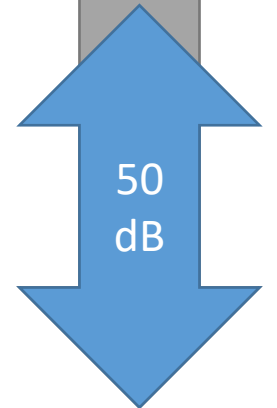
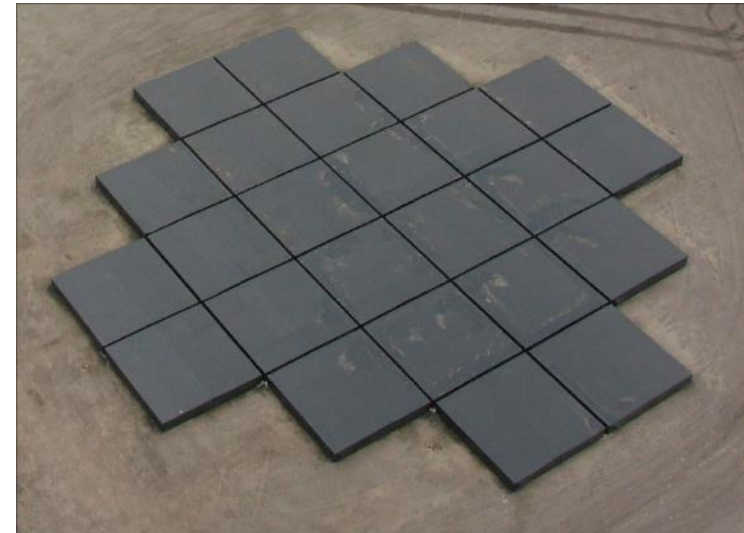
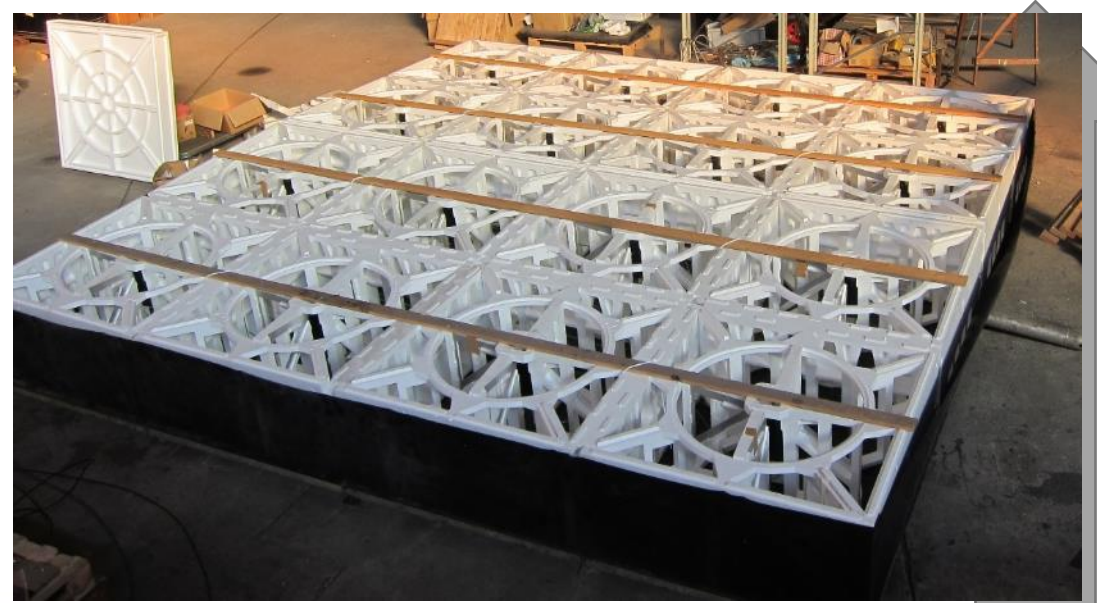
105  
dB

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# Beamforming

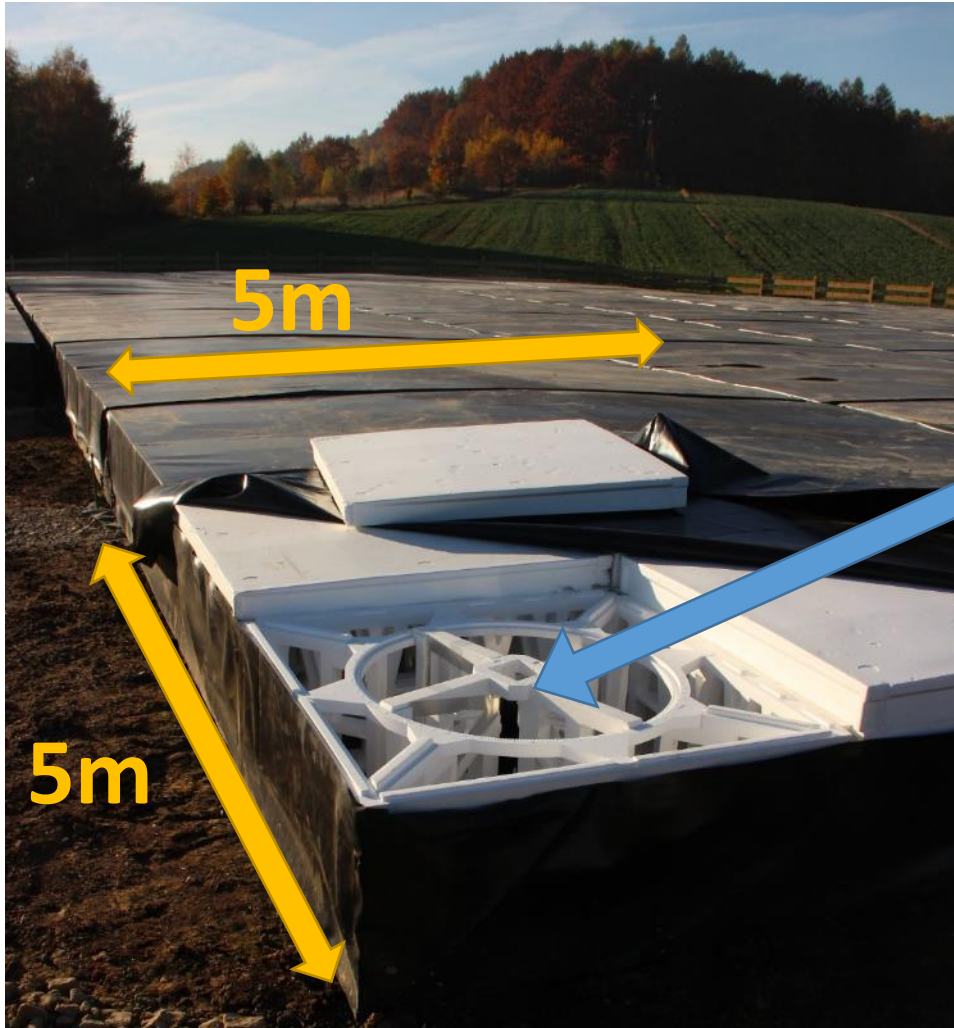
- 40 000 antennas  
(16 elements x 48 tiles x 50 stations)



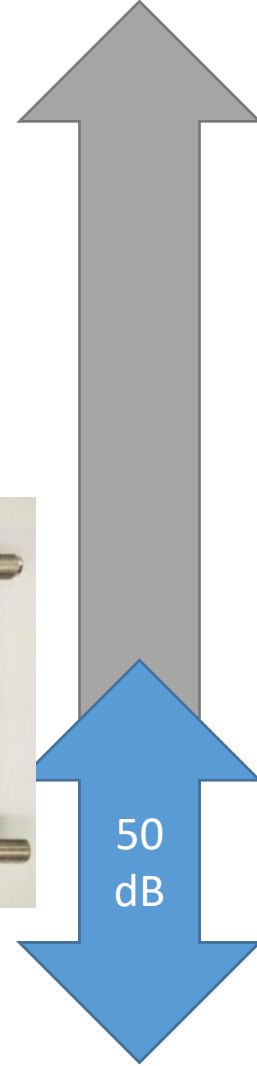
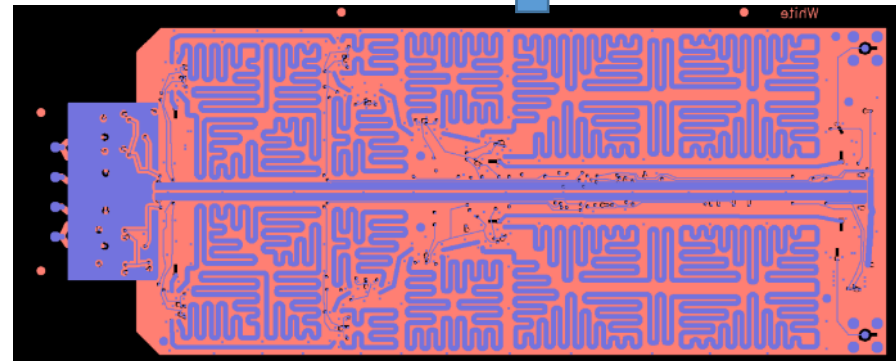
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# Analog beamforming



- Each antenna has '5m delay' switchable delay lines



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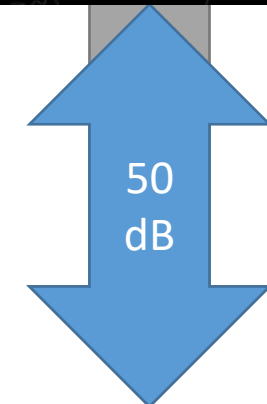
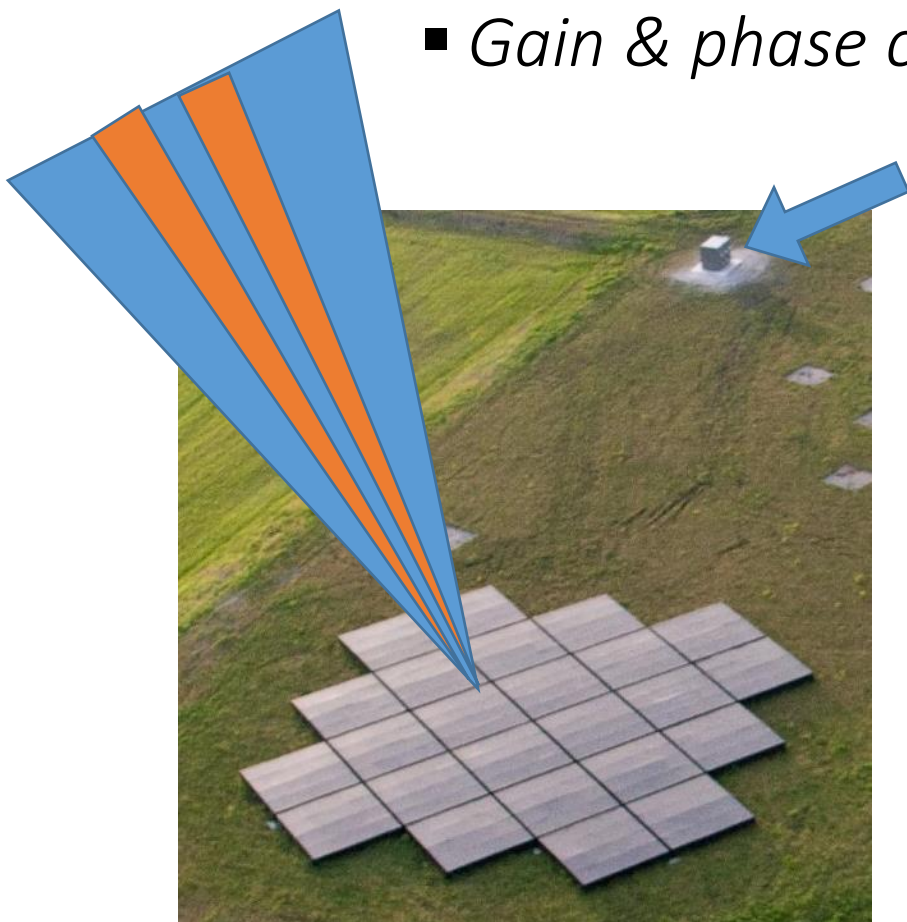
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# Digital beamforming



- *Synchronised clock (white rabbit)*
- *Gain & phase calibration*

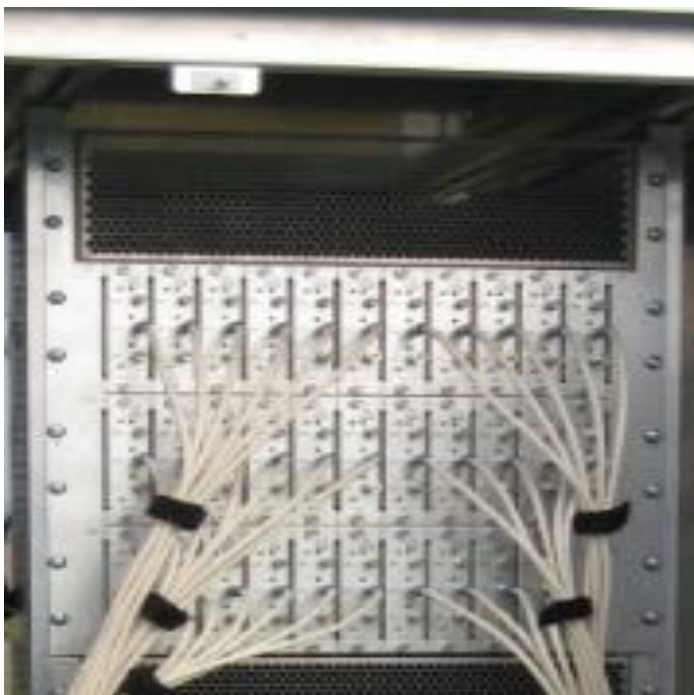


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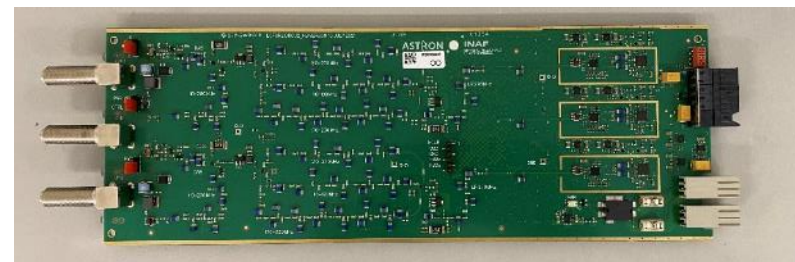
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# Digital beamforming

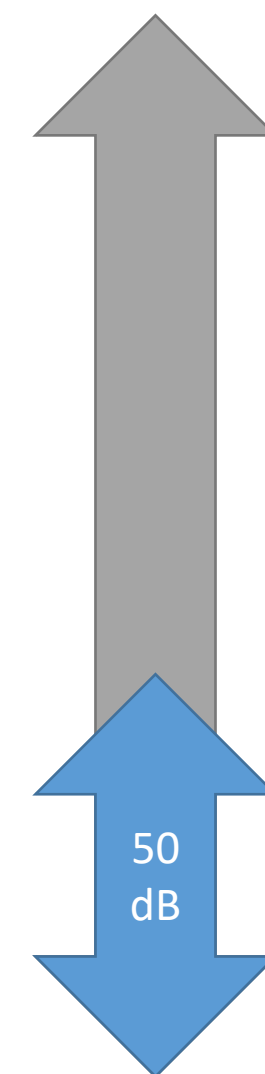
- LOFAR Subrack
  - 96 input SDR: 200MSPS, 14bit, NF<8dB, IIP3>15dBm
  - ADC->FPGA datarate: 300 Gbps
  - FPGA: Channelize, calibrate, beamform
  - Output datarate: few Gbps ethernet
  - Power consumption: 700W



32x Receiver (96 ADCs)



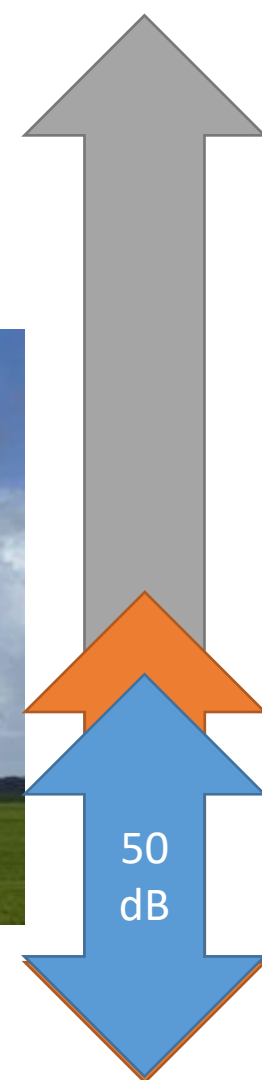
2x UNB2 (8 FPGAs)



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# Problem: Rising RF noise levels

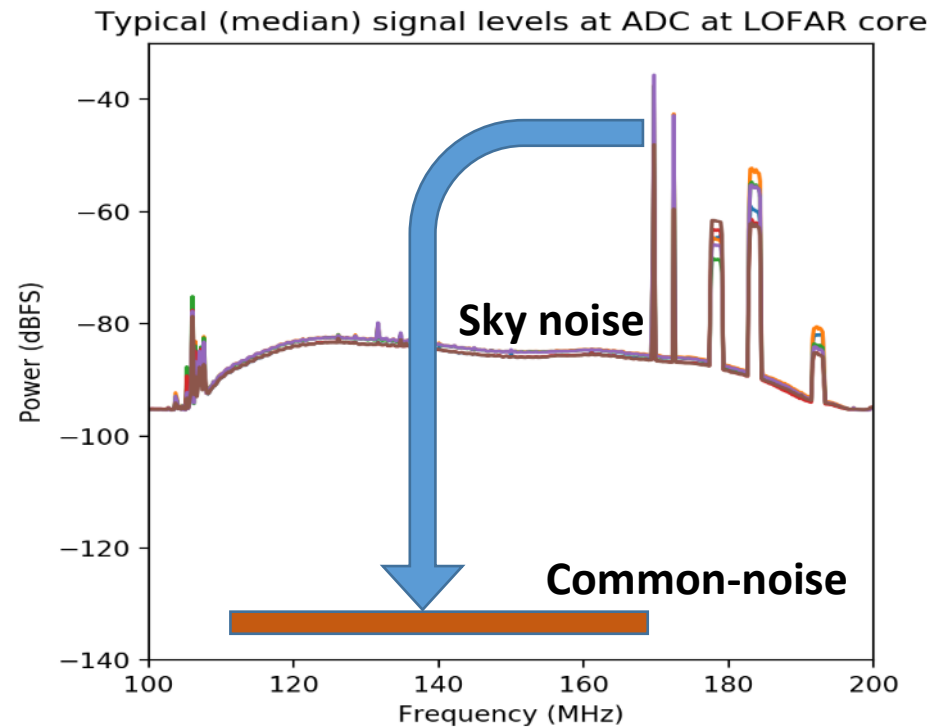


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# Problem: Common-noise

- High dynamic range receivers (>100dBc)
  - Low noise, high linearity
  - Low gain stages for constant level
- ADC dithering (90dBc)
- Good power supply filters
- Very clean clock
- Good shielding

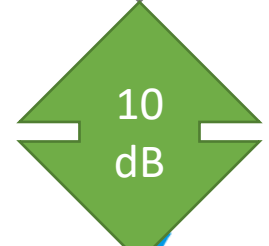
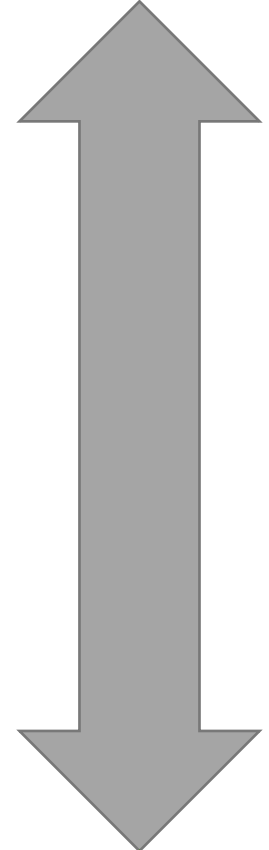
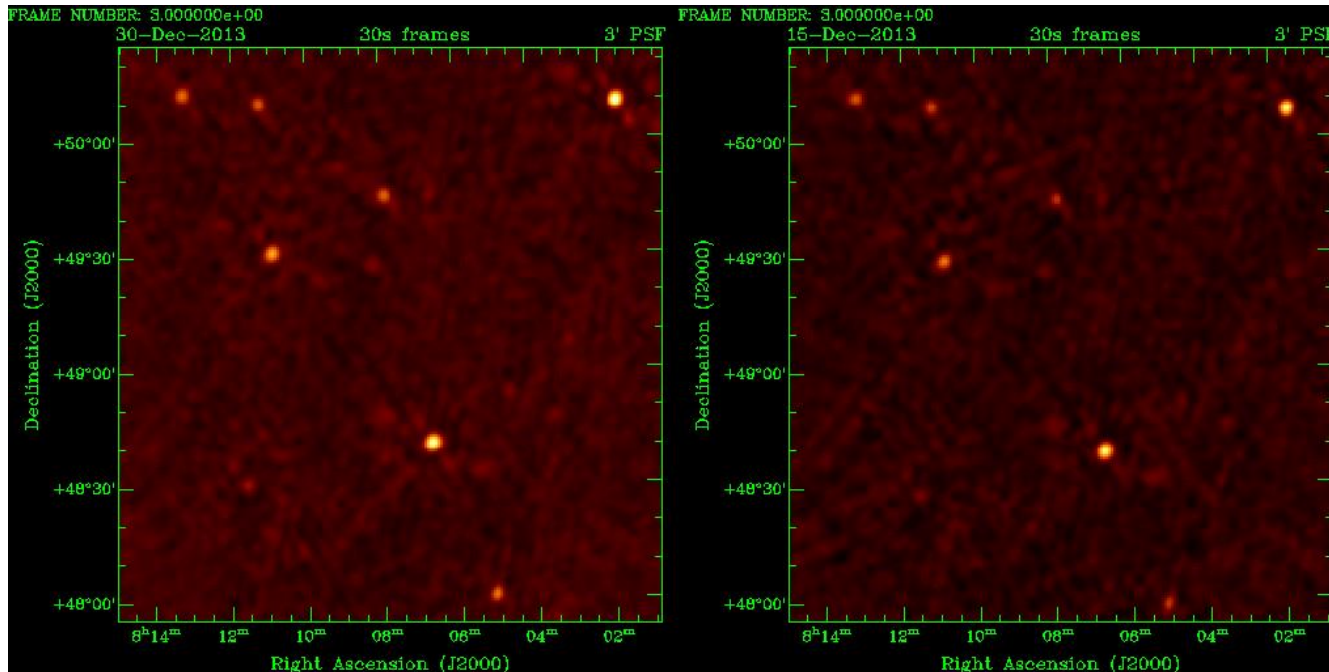


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# Averaging

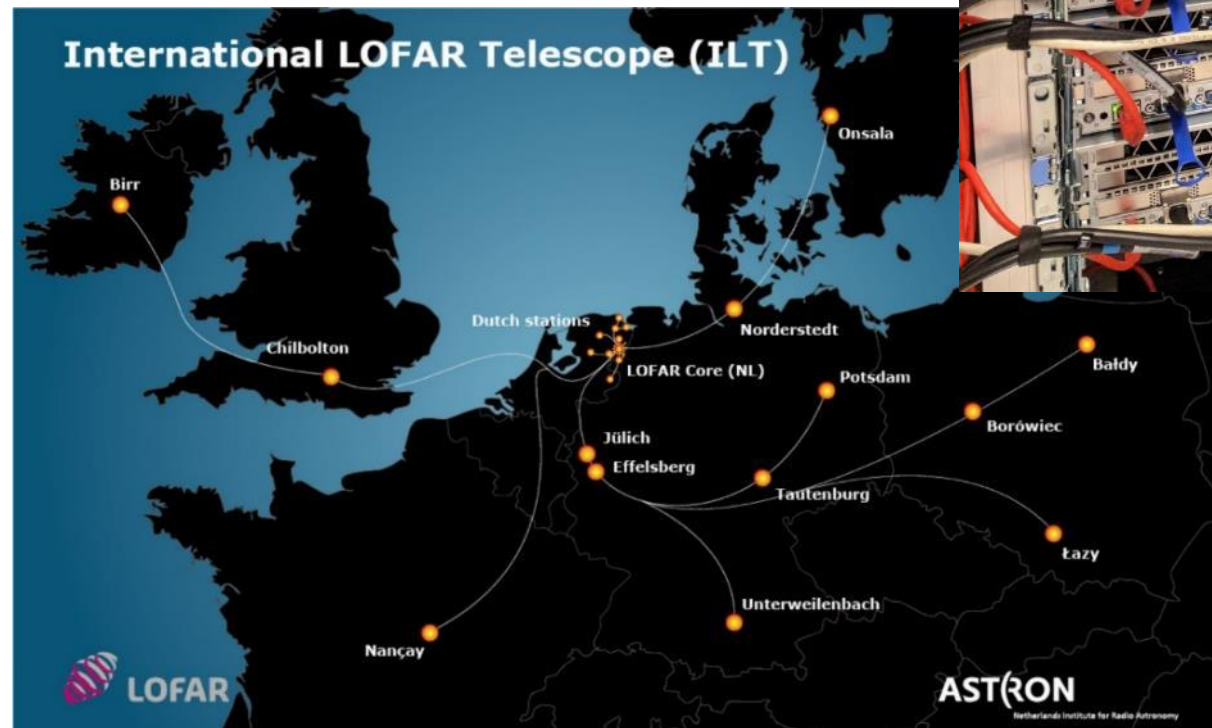
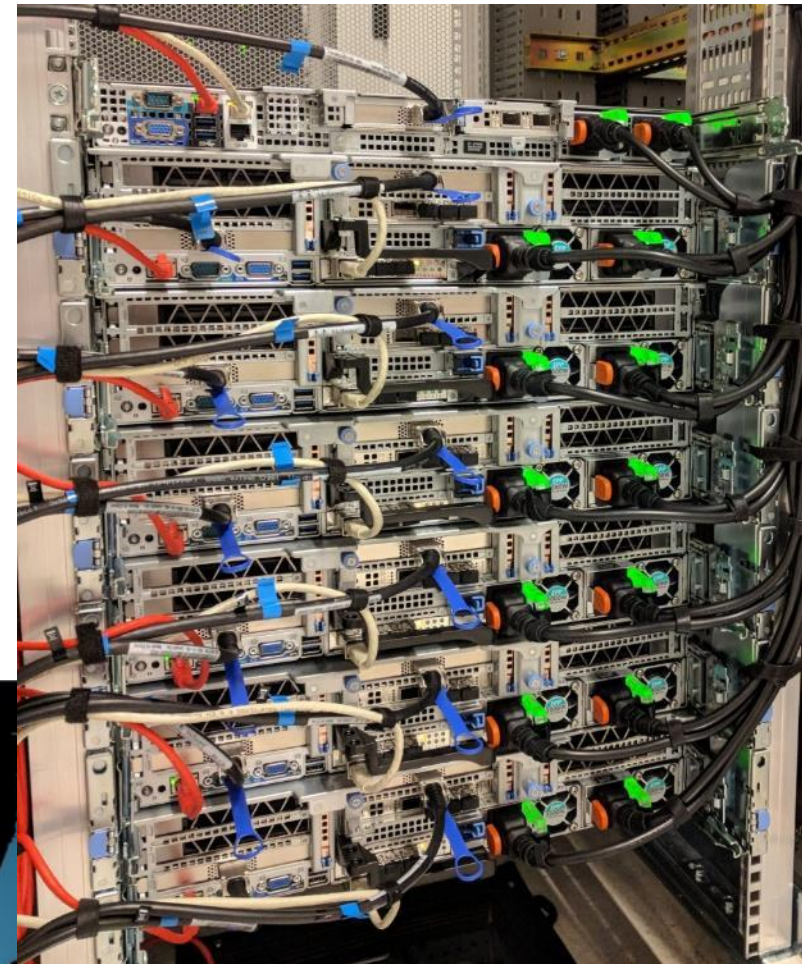
- Integrate over bandwidth & time
- Eg. 100h x 50MHz = 10 000 000 000 000 samples => 65dB



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# Big data

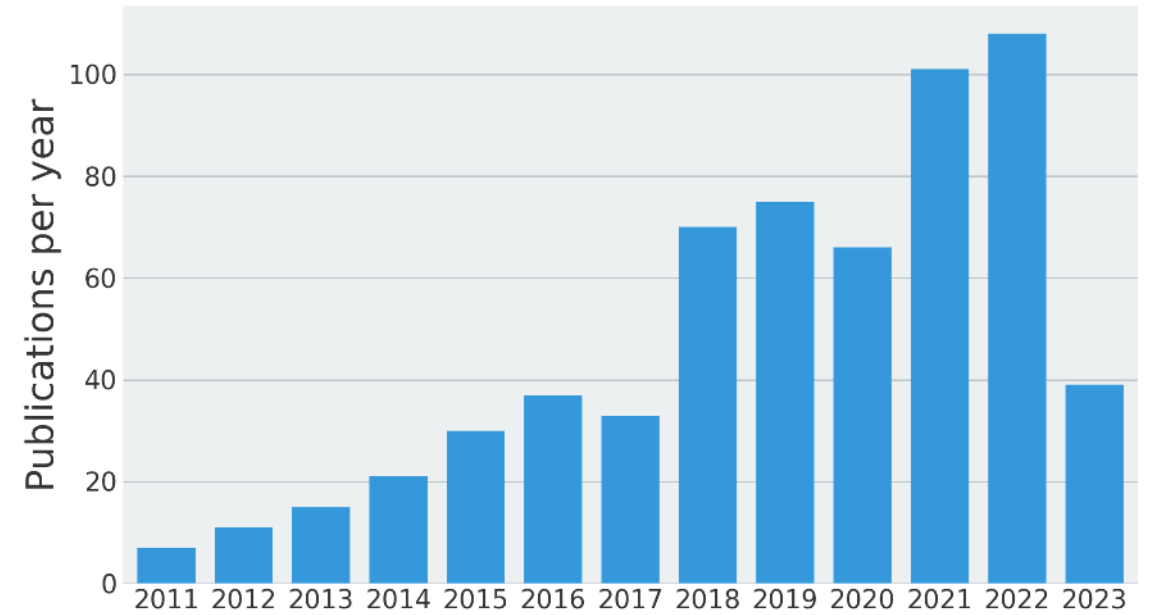
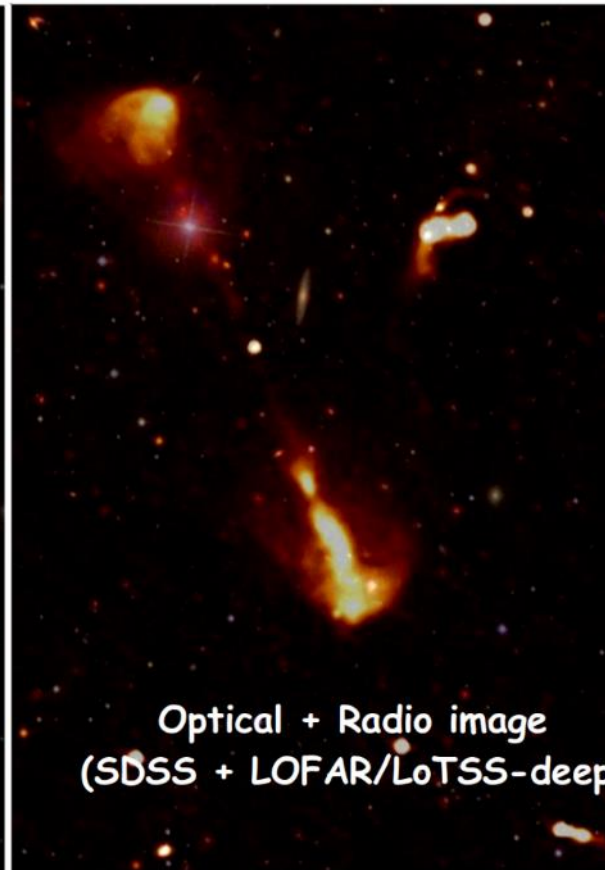
- Raw data rate:  $>10$  Tbit/s
- Real-time processing cluster:
  - Real-time processing 1 Tbit/s
  - Output to disk: 2-10 GB/s
- Storage: 7 PB/yr



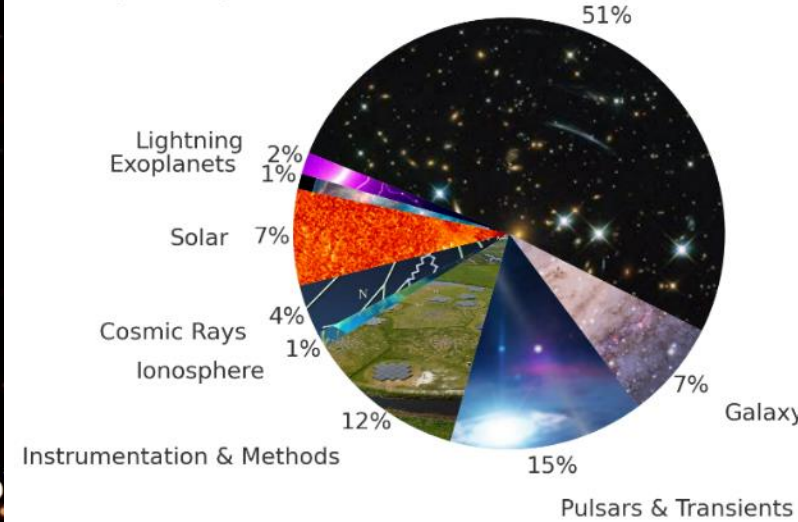
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# Science



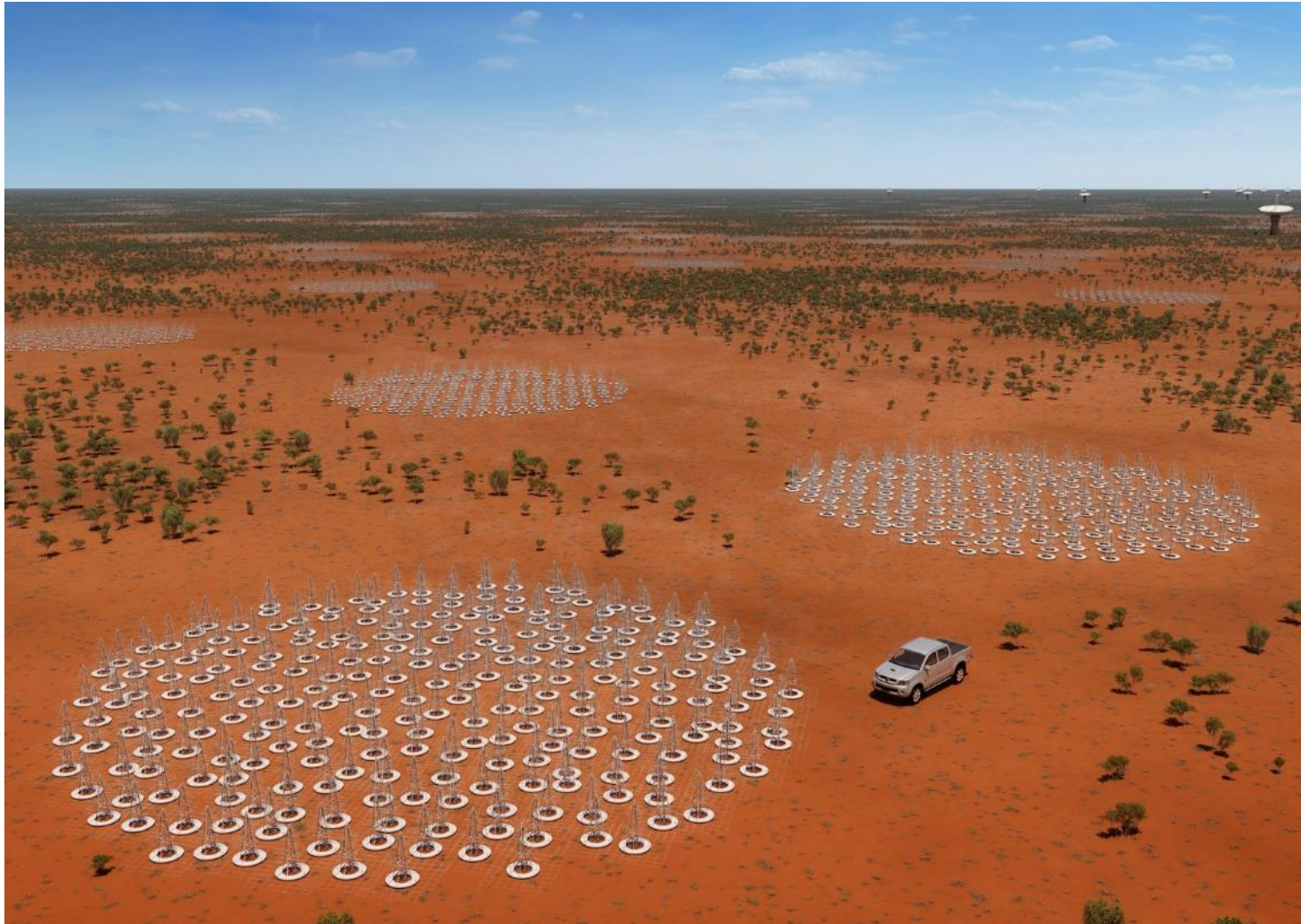
Papers per Science Area



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# Square Kilometer Array (SKA)



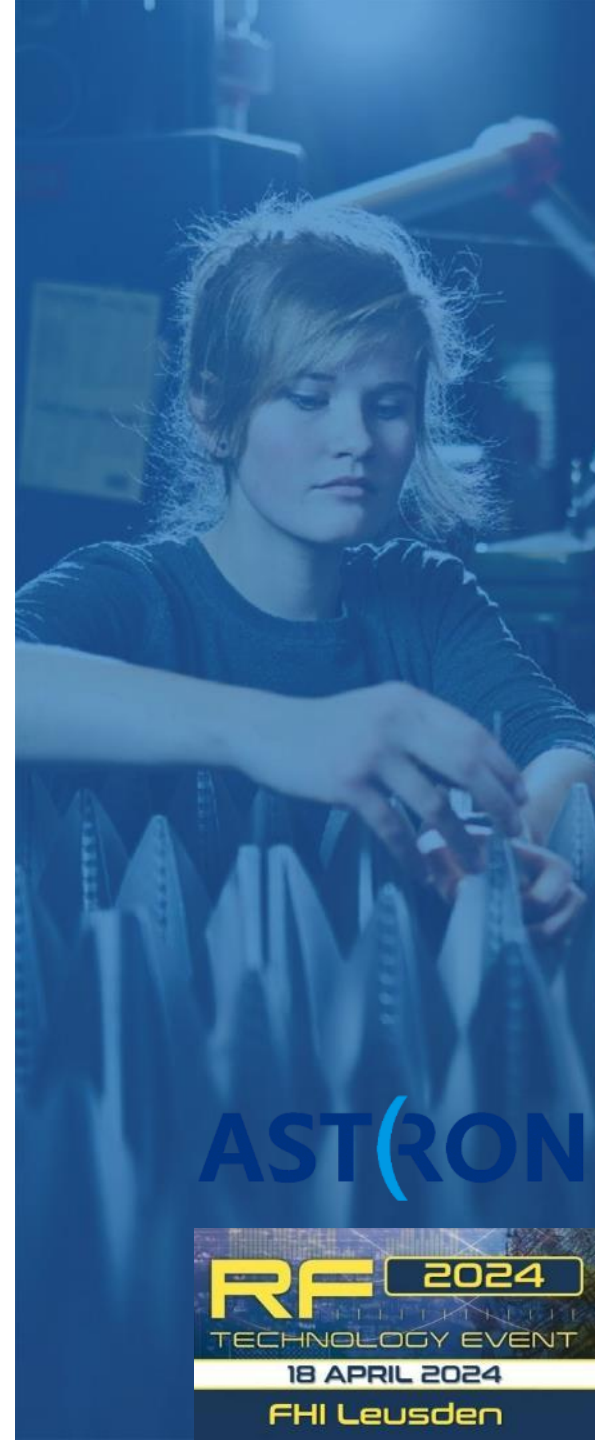
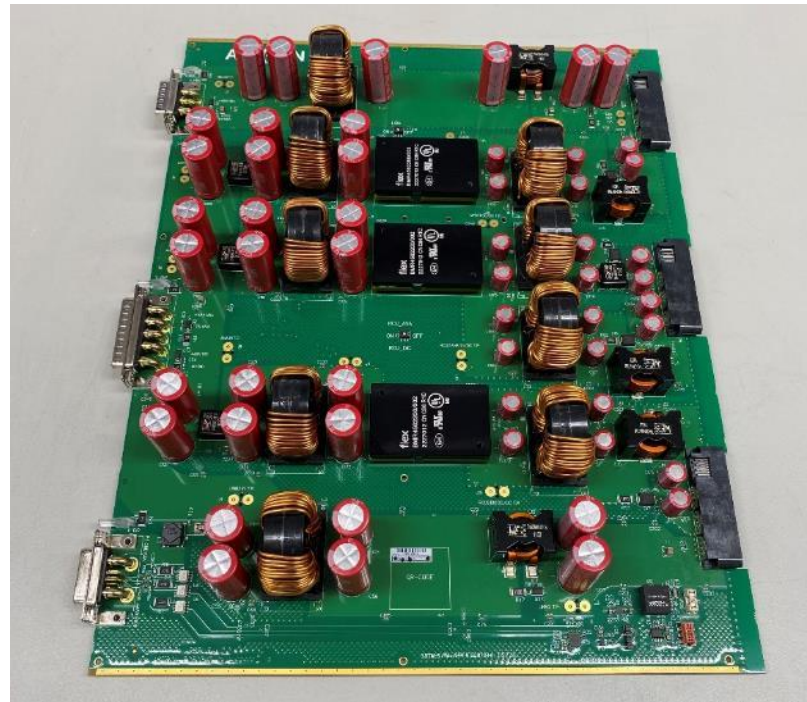
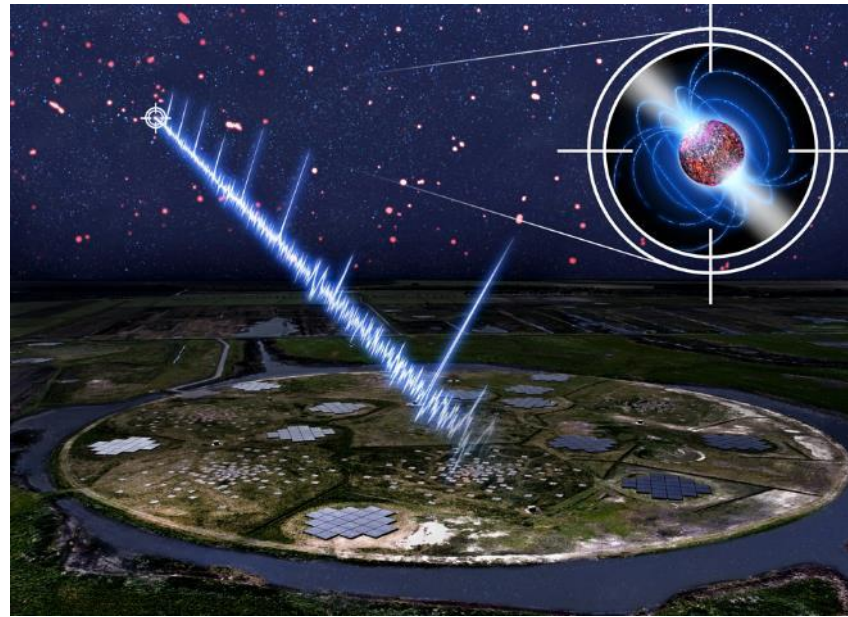
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# Why?

- Science
- *Technology development*
- *Education*

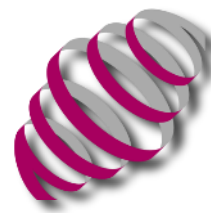


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Netherlands Institute for Radio Astronomy



# LOFAR

## Question?

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