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Netherlands Institute for Radio Astronomy

LOFAR: the LOw Frequency ARray

ASTRON, Dwingeloo, The Netherlands

LOFAR data school 2021

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LOFAR: Lots Of Flimsy Antenna Rigs

ASTRON, Dwingeloo, The Netherlands

LOFAR data school 2021

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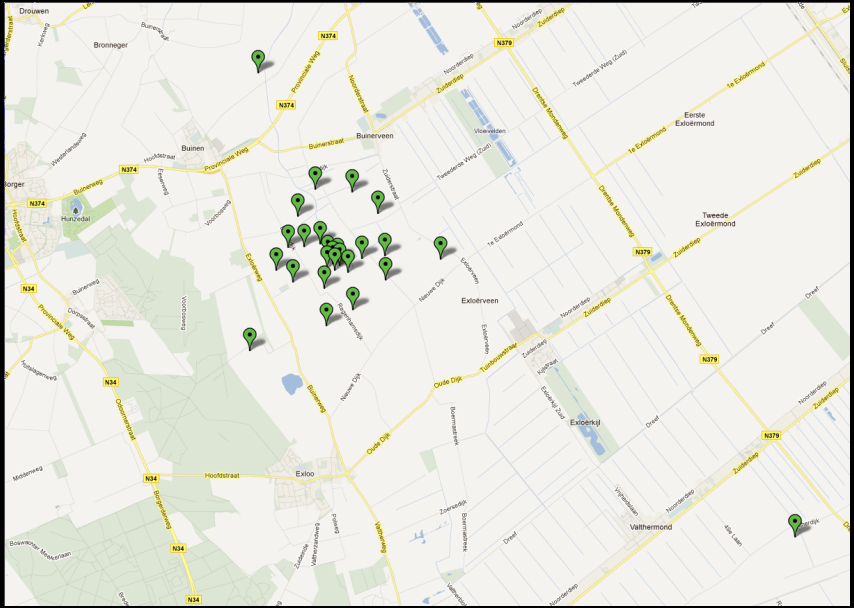
Outline

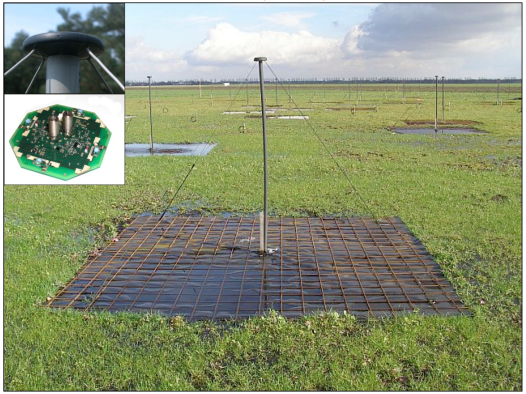

Onsala
Irbene
Birr
Dutch stations
Chilbolton
Norderstedt
Bałdy
Potsdam
Borówiec
Jülich
Effelsberg
Łazy
Tautenburg
Nançay
Unterweilenbach
Medicina


Borkum
Nationaal Park Nederlandse Waddenzee
Schiermonnikoog
Hollum
West-Terschelling
Waddenzee
Norden
Großheide
Marienhafe
Wittmund
Krummhörn
Aurich
Friedeburg
Uithuizen
Hinte
Ihlow
Emden
Wiesmoor
Delfzijl
Moormerland
Hesel
Uplengen
Dollart
Dokkum
Winsum
Bedum
Damwâld
Kollum
Buitenpost
Stiens
Oranjewijk
Groningen
Leer
Jemgum
Apen
Barradeel
Franeker
Leeuwarden
Burgum
Haren
Hoogezand
Winschoten
Weener
Barßel
Harlingen
Baarderadeel
Roden
Eelde
Rhauderfehn
Drachten
Zuidlaren
Weendam
De Koog
Den Burg
Grou
Norg
Papenburg
Wünseradiel
Akkrum
Sneek
Gieten
Friesoythe
Gorredijk
Assen
Stadskanaal
Wymbritseradiel
Oosterwolde
Esterwegen
Heerenveen
Hijkersmilde
Den Helder
Den Oever
Nijefurd
Lorup
Julianadorp
Wieringen
Wolvega
Ter Apel
Börger
Kleine Sluis
Wieringerwerf
Lemmer
Lathen
Sögel
Werlte
Lindern
IJsselmeer
Dwingeloo
Beilen
Schagen
Emmer-Compascuum
Medemblik
Stadskanaal
Emmen
Lastrup
Warmenhuizen
Enkhuizen
Osteinde
Hoogeveen
Lähden
Löningen
Heerhugowaard
Emmeloord
Blokzijl
Meppel
Klijnhaven
Meppen
Alkmaar
Hoorn
Urk
Zuidwolde
Haselünne
Heiloo
Ens
Staphorst
Coevorden
Twist
Castricum
Markermeer
Swifterbant
Hasselt
Dedemsvaart
Emlichheim
Geeste
Bippen
Heemskerk
Purmerend
Lelystad
Kampen
Dronten
Zwolle
Ommen
Lingen
Fürstenau
IJmuiden
Zaandam
Dalfsen
Neuenhaus
Lohne
Haarlem
Westpoort
Elburg
Hattem
Amsterdam
Almere
Heerde
Vriezenveen
Emsbüren
Lunne
Heemstede
Nunspeet
Raalte
Spelle
Recke
Amstelveen
Weesp
Epe
Niverdal
Almelo
Harderwijk
Salzbergen
Mettingen
Hillegom
Huizen
Ermelo
Rijssen
Oldenzaal
Bad Bentheim
Rheine
Ibbenbüren
Nieuw-Vennep
Putten
Vaassen
Deventer
Hengelo
Losser
Hilversum
Nijkerk
Uddel
Goor
Enschede
Neuenkirchen
Katwijk
Katwijk
Apeldoorn
Ochtrup


Drouwen
Bronneger
Buinen
Buinerveen
Hunzedal
Exloërveen
Exloërkijl
Exloo
Valthermond
Eerste Exloërmond
Tweede Exloërmond
N374
N379
N34
Provinciale Weg
Buinerstraat
Hoofdstraat
Nieuwe Dijk
Oude Dijk
Zuiderdiep
Noorderdiep
Tweede Weg (Zuid)
1e Exloërmond
Dwarsdiepweg
Dreef

Antenna types

Low Band Antenna (LBA)



- 10–90 MHz
- All digital beam forming

High Band Antenna (HBA)

- 110–240 MHz
- 4*x*4 antennas per analoguely beam formed tile
- Tiles beam formed digitally

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Break-out Assignment

In the break-out rooms, you have 5 minutes to make a Venn-like drawing/diagram showing:

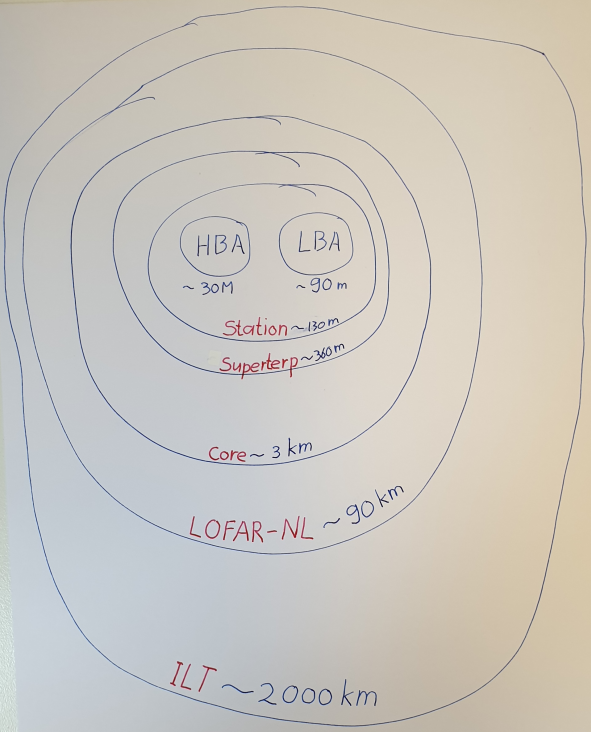
- Station
- HBA antenna field
- Core
- International Lofar Telescope (ILT)
- Superterp
- LBA antenna field
- LOFAR-NL

Label the circles with:

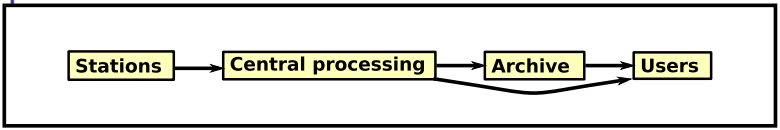
- Name
- Approximate diameter

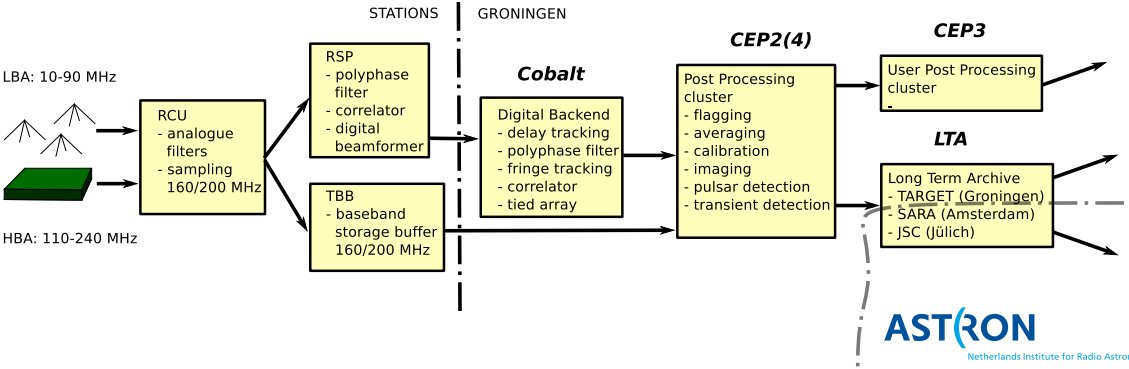
Compare your diagram to those of your break-out room peers. Use the internet if necessary.

SEE YOU IN 5 MINUTES!


HBA
LBA
~ 30M
~ 90 m
Station ~ 130 m
Superterp ~ 360 m
Core ~ 3 km
LOFAR-NL ~ 90 km
ILT ~ 2000 km

Signal/data path





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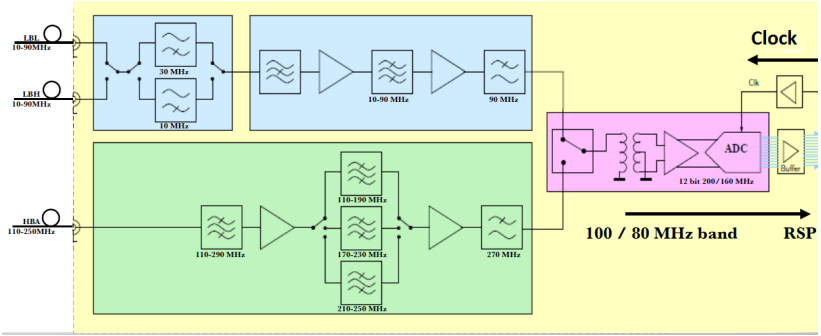
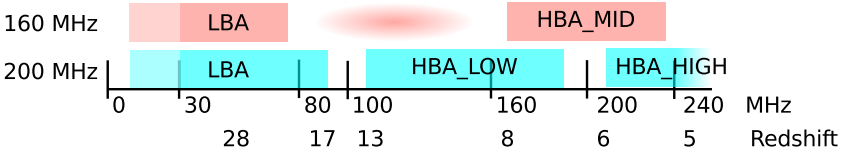
Outline

The Receiver Unit (RCU) *M. Norden*





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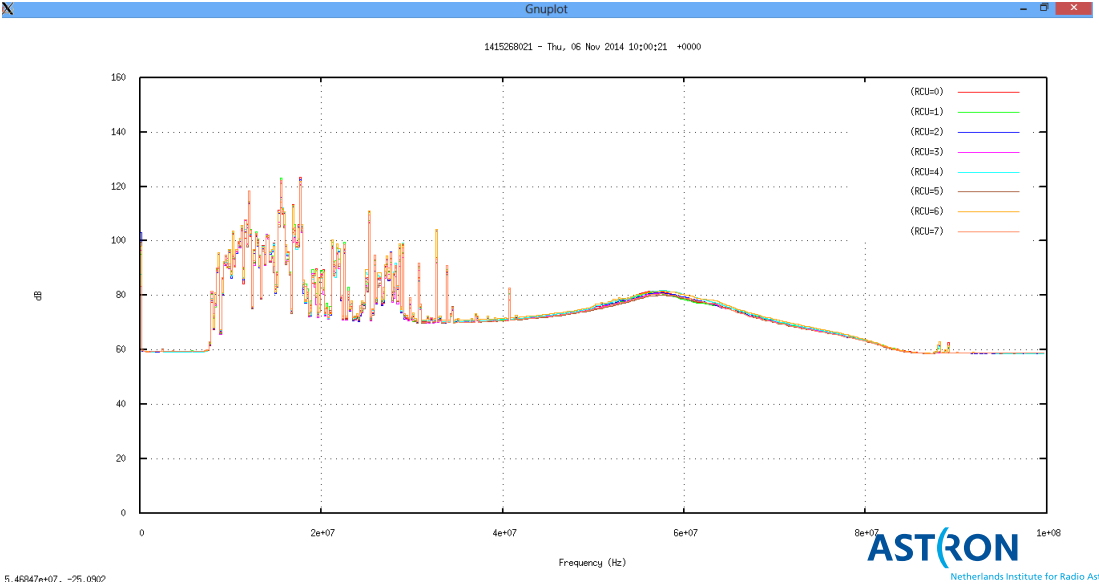
LBA dipole spectra



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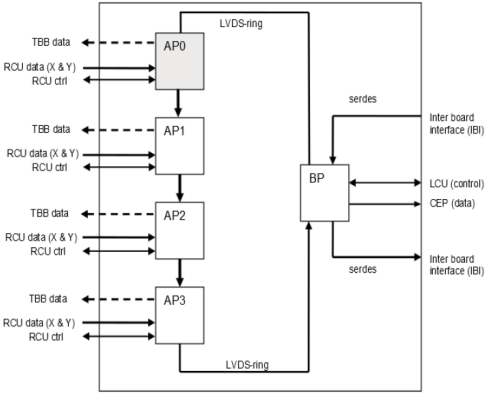
Remote Station Processing (RSP) *M. Norden*



- Make 512 sub bands (polyphase filter)
- Beam forming
- Cross correlation
- Data transport to Central Processing

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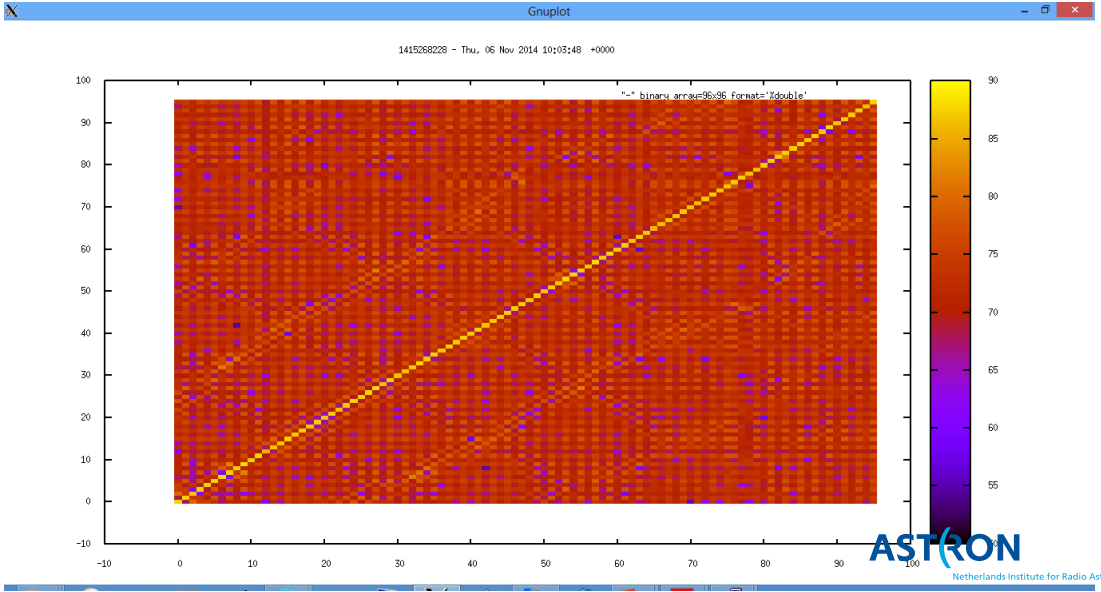
Station cross correlation



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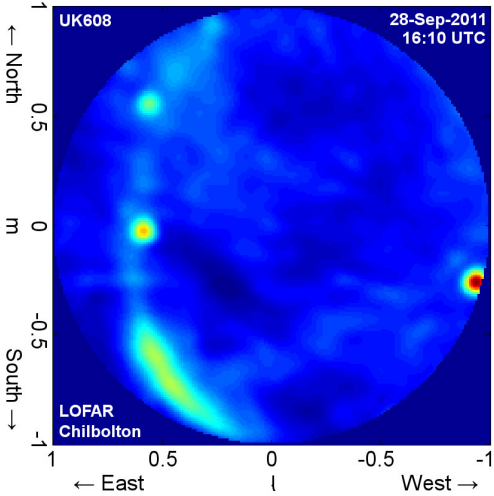
Station cross correlation



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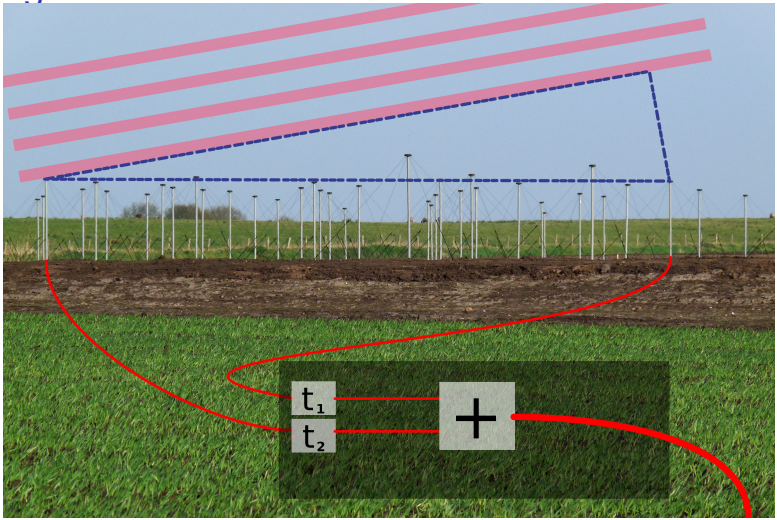
Beam forming



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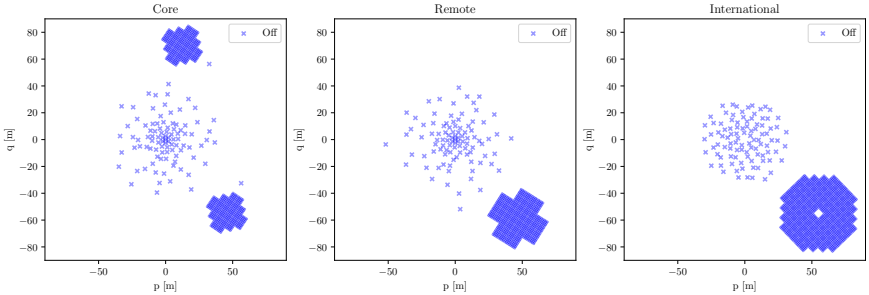
Break-out Assignment

Discuss in merits of dishes vs phased array stations. Within your group:

- Come up with 3 concepts/domains where phased arrays have the advantage
- Come up with 3 concepts/domains where dishes have the advantage
- Agree among your group who will input which word into the following word clouds. Each person can enter at most one word per word cloud.
- You have 5 minutes.

Station types



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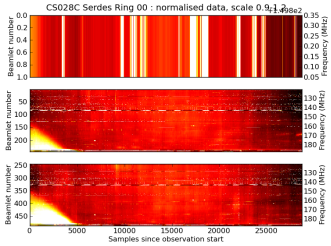
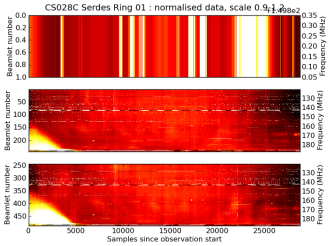
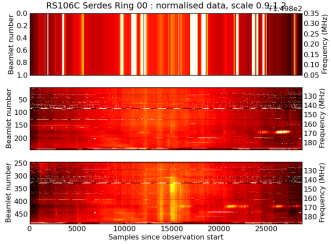
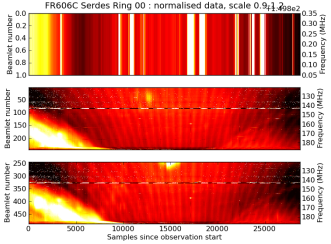
Dynamic spectra









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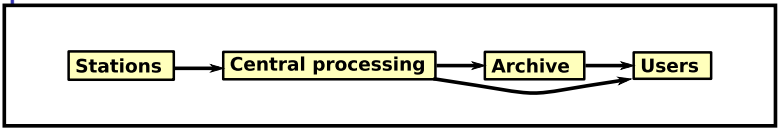
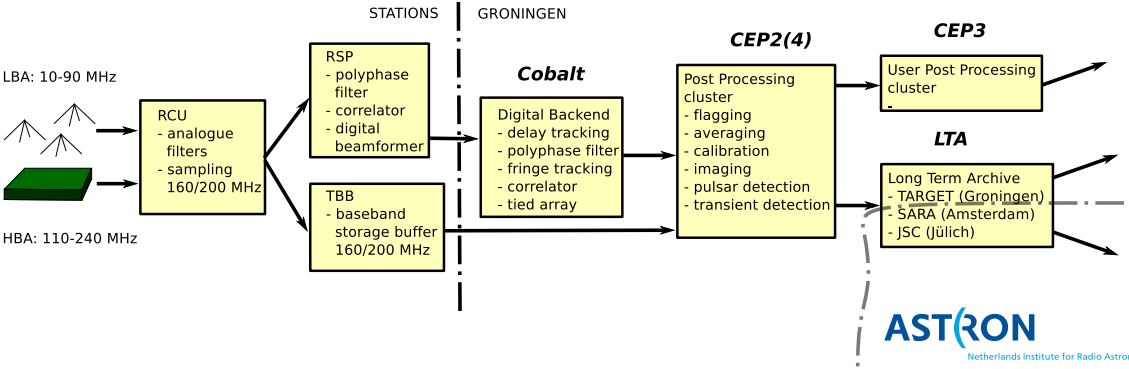
Outline

Outline

Signal/data path





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Digital backend: COBALT

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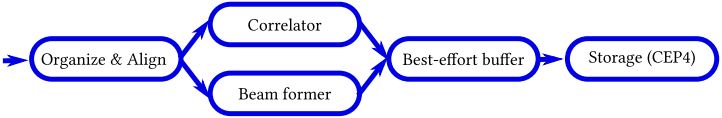
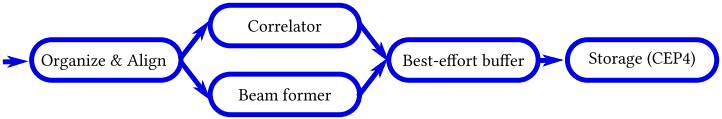
(Re)organize and coarse alignment (CPUs)



- Sort incoming data by sample time
- Flag missing data
- Transpose data from “per station: all sub bands” to “per sub band: all stations”
- Coarse delay compensation: error 2.56 μs
- Ship data to GPUs

Correlator (GPUs)



Per station

- Polyphase filter
- Compensate remaining phase slope due to coarse delay step
- station sub band bandpass correction

Per baseline per channel

- Compute

$$\begin{pmatrix} x_i x_j^* & x_i y_j^* \\ y_i x_j^* & y_i y_j^* \end{pmatrix} \tag{1}$$

- Average to 0.25 – a few s

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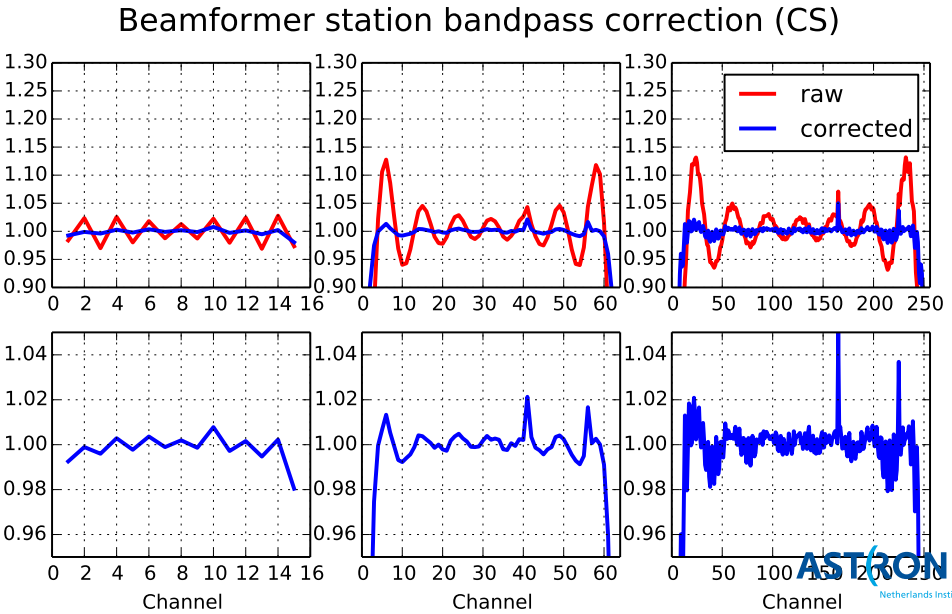
Sub band bandpass correction



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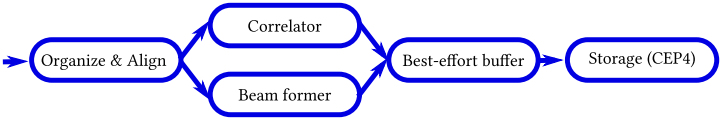
Beam former (GPUs)



Per station

- 256pt FFT
- phase slope correction
- sub band bandpass correction
- 256pt inverse FFT

Combine all fields

- Complex Voltage: $\sum_i \mathbf{e}_i$ OR
- Coherent Stokes: $\mathrm{Stokes}(\sum_i \mathbf{e}_i)$ OR
- Incoherent Stokes: $\sum_i \mathrm{Stokes}(\mathbf{e}_i)$
- Average to 5.12 μs – $\sim$0.01 s (Stokes modes)
- Can be done on dozens of “tied array” beams simultaneously
- Output data rates up to 100 Gbit/s!

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Further processing

CEP4

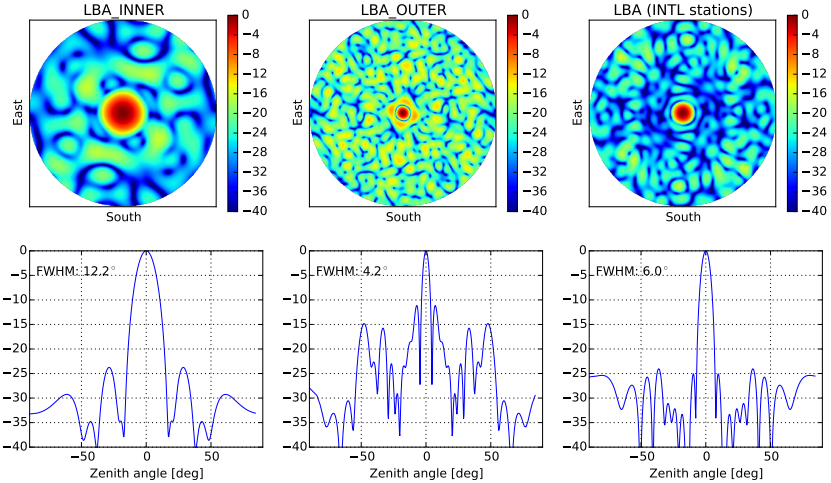
- Data *REDUCTION* (tens of TB to a few TB)
- Batch processing only (Slurm)
- No user access
- Send data off to Long Term Archive (LTA)

CEP3

- user processing for limited time ($\sim$ 4 weeks)
- all LOFAR software pre-installed
- 24 Dell PowerEdge R720 servers
- 128GB memory
- 20 Cores (2 ten-core Intel Xeon e5 2660v2 processors)
- Dell PERC H710P RAID controller 8 x 4TB disks in RAID6 setup, 22TB net diskspace, XFS filesystem

Outline

LBA beams at 50 MHz



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HBA tile

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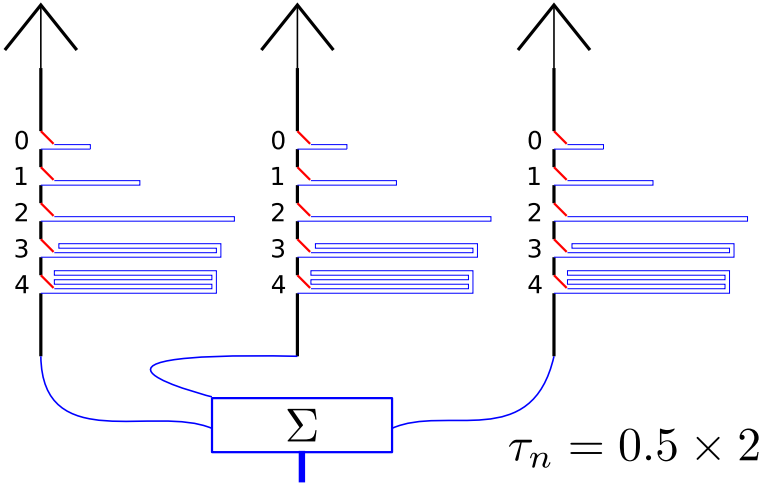
Analogue beam forming



$$\tau_n = 0.5 \times 2^n \mathrm{ns}$$

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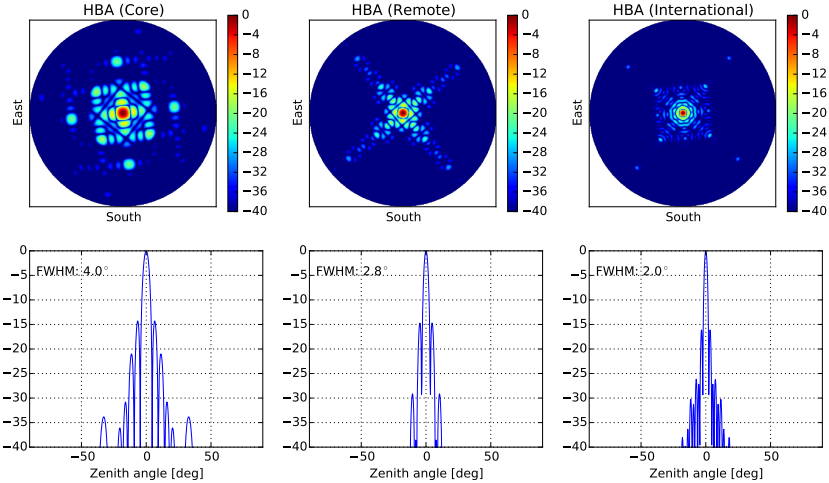
HBA beams at 150 MHz



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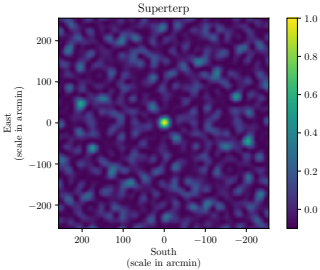
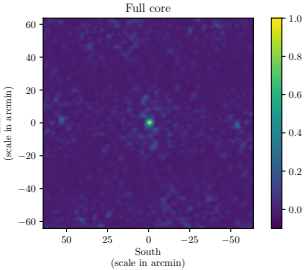
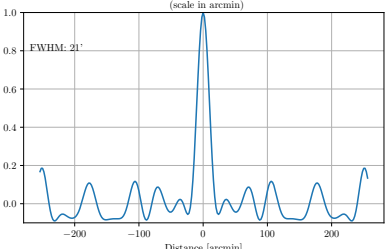
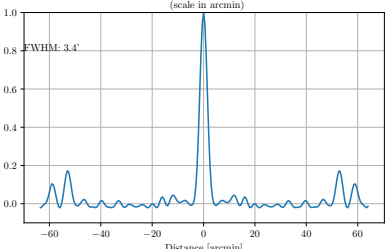
Coherent sum of stations at 150 MHz









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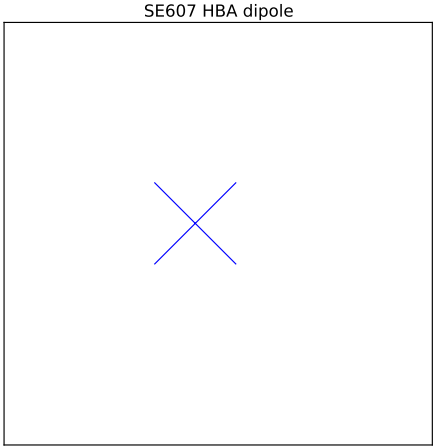
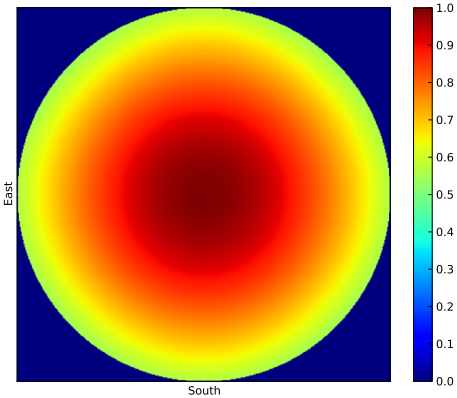
Outline

HBA element beam 150 MHz





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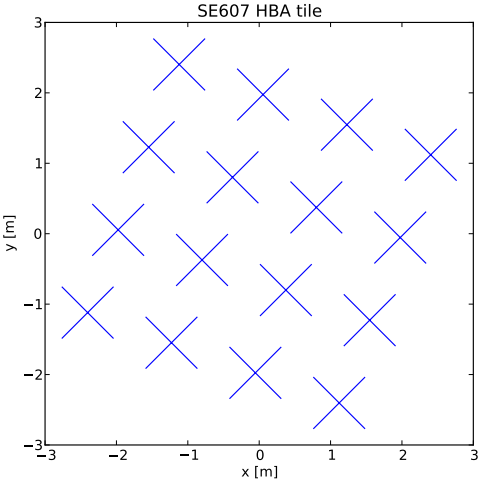
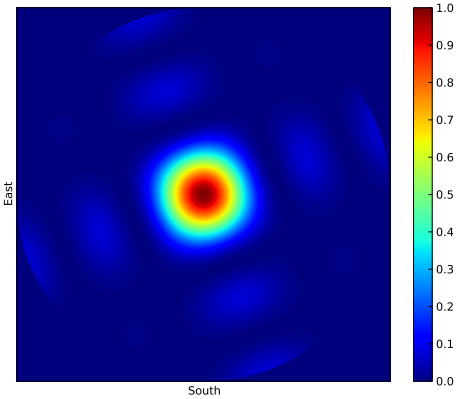
HBA analogue tile beam 150 MHz





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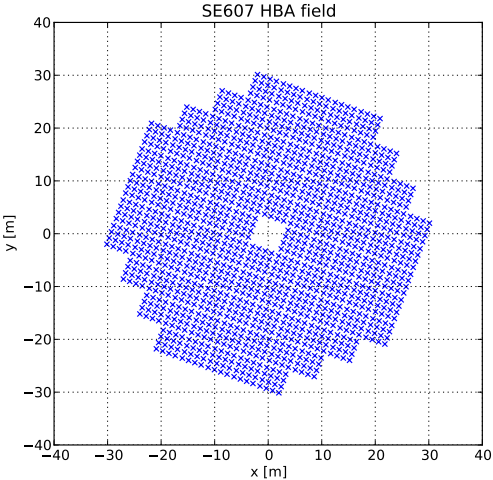
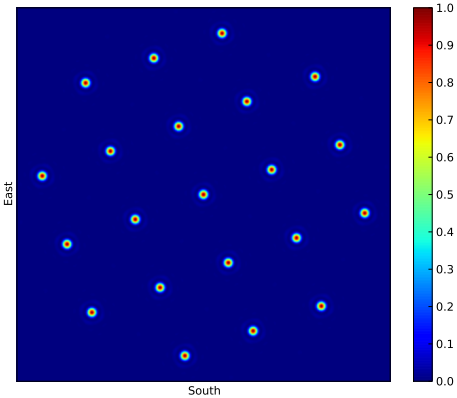
HBA digital beam 150 MHz





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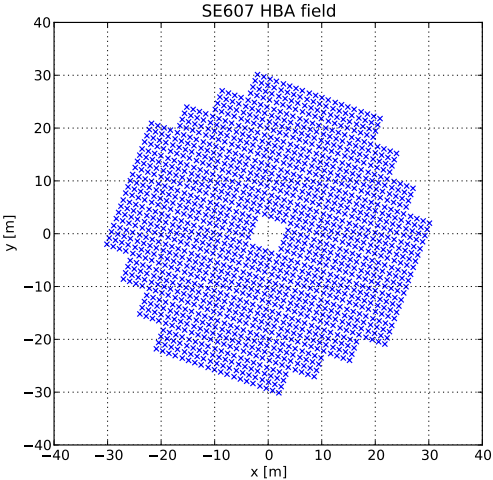
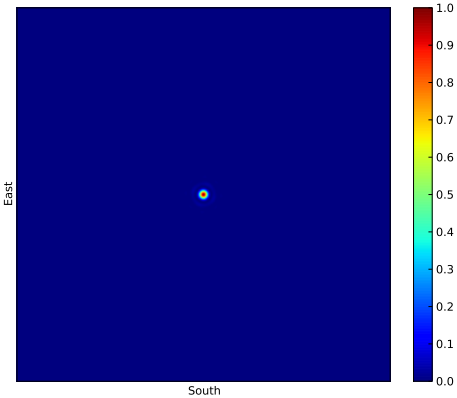
HBA station beam 150 MHz





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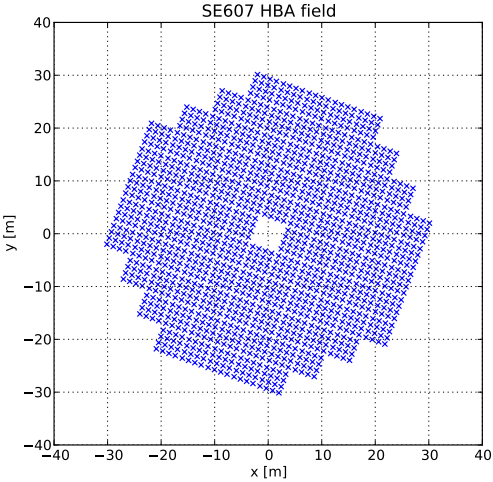
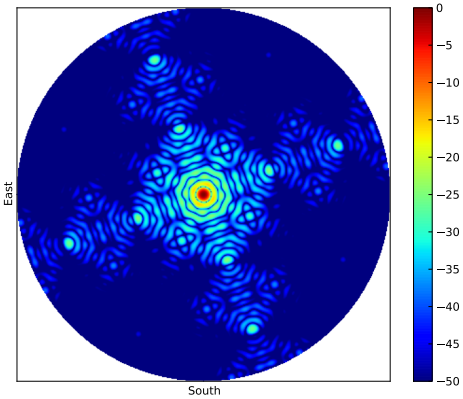
HBA station beam 150 MHz (dB)





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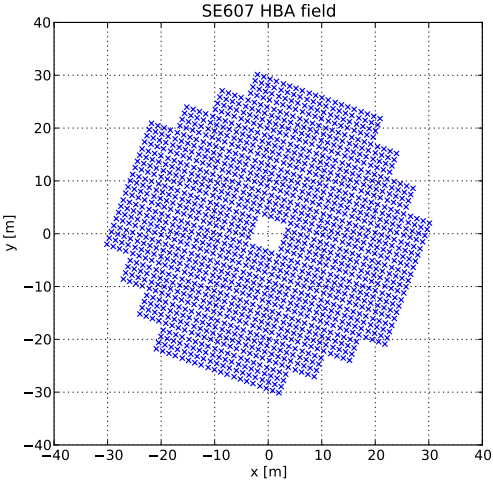
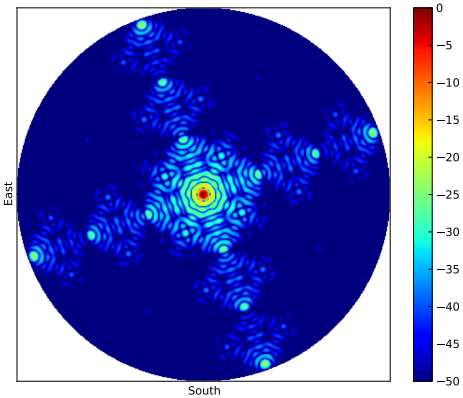
HBA station beam 180 MHz (dB)





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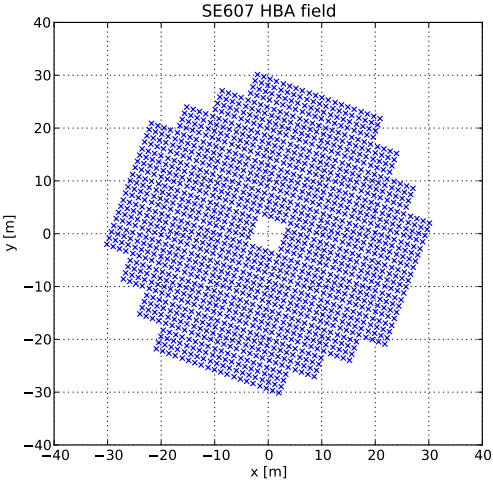
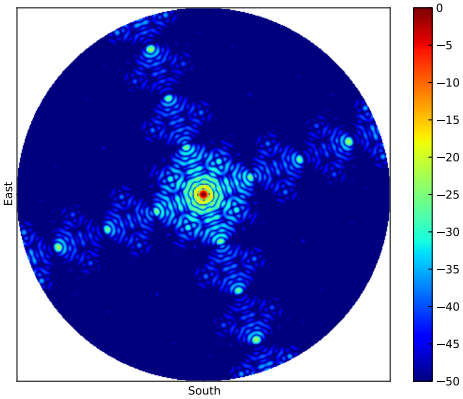
HBA station beam 210 MHz (dB)





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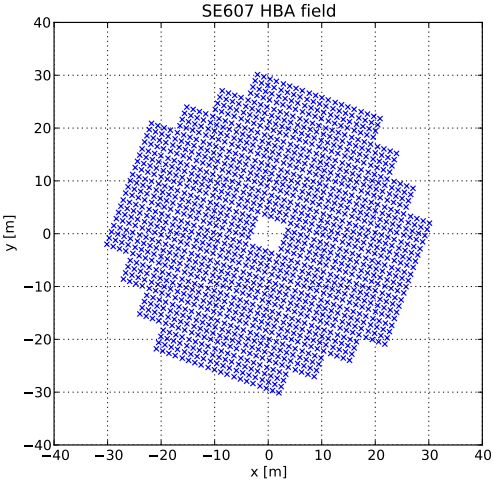
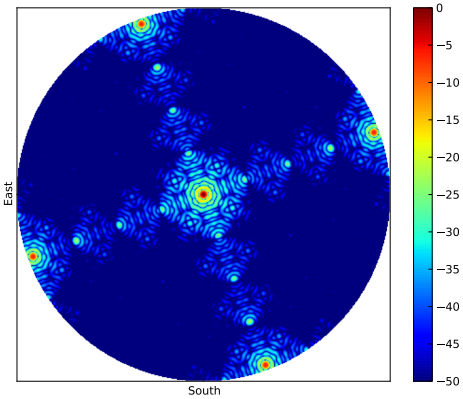
HBA station beam 240 MHz (dB)





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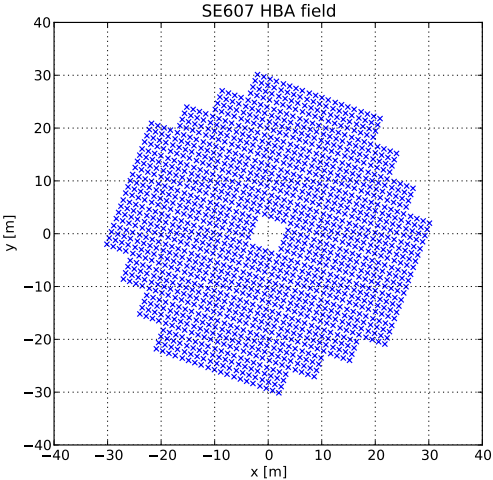
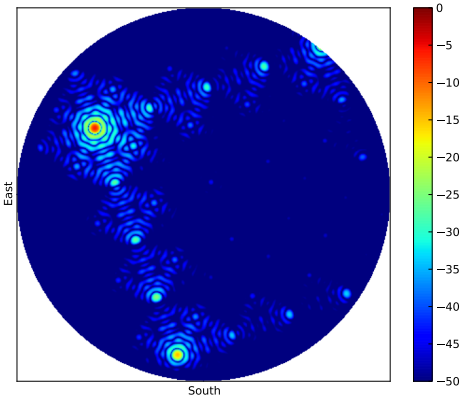
HBA station beam tracking 180 MHz (dB)





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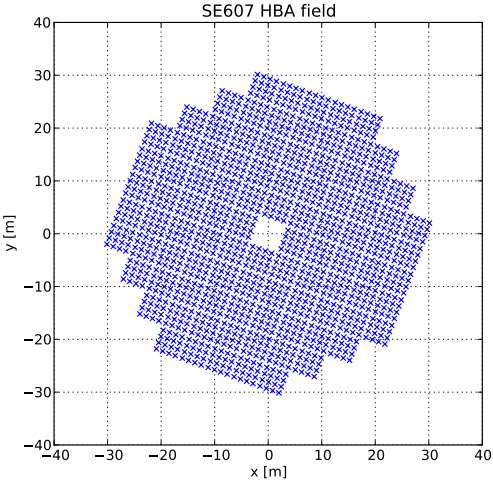
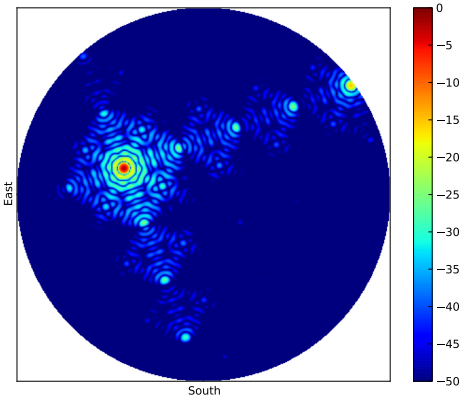
HBA station beam tracking 180 MHz (dB)





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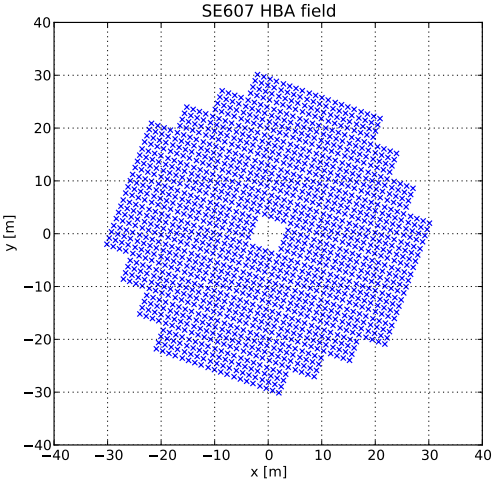
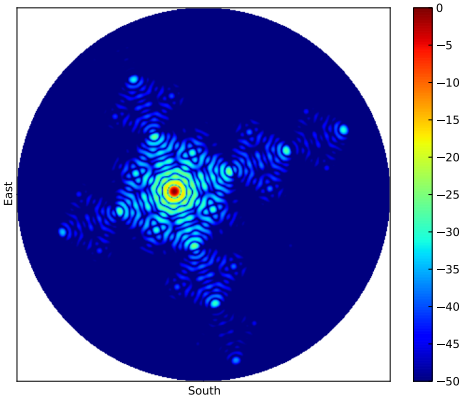
HBA station beam tracking 180 MHz (dB)





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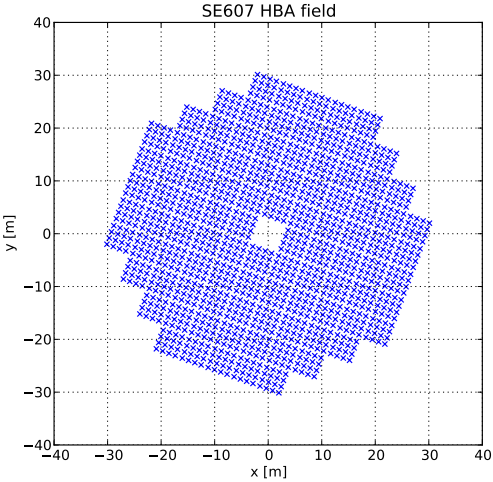
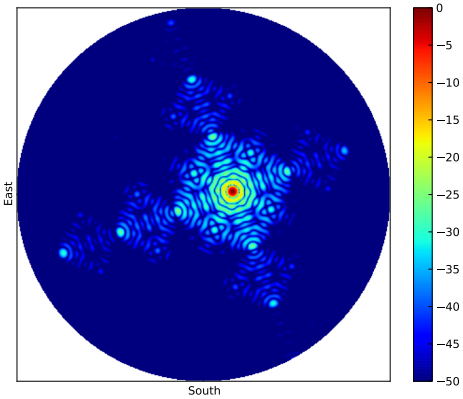
HBA station beam tracking 180 MHz (dB)





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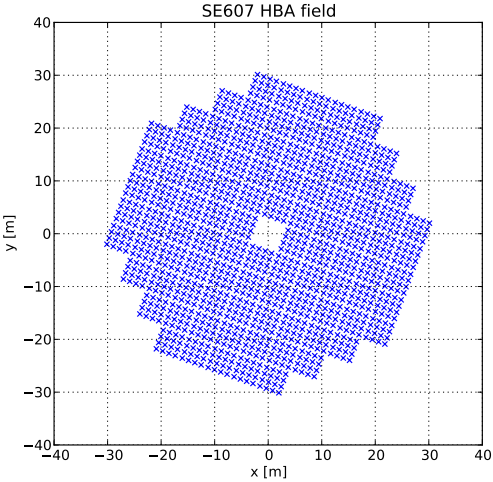
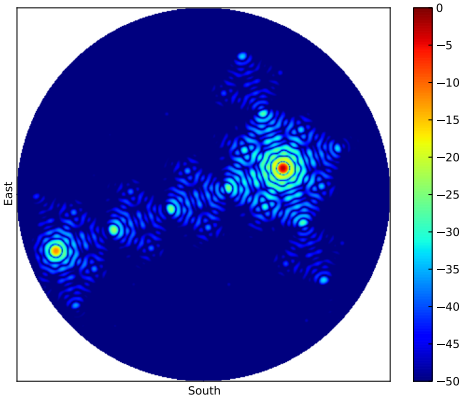
HBA station beam tracking 180 MHz (dB)





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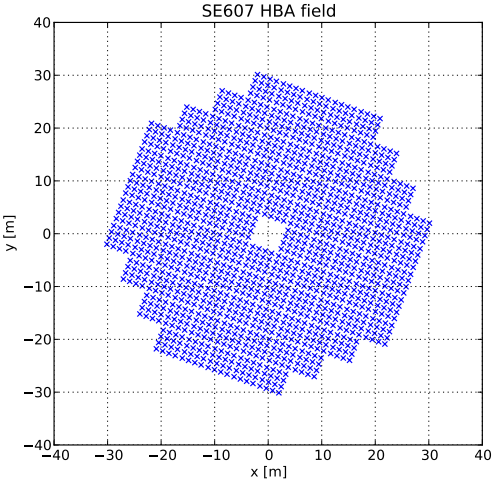
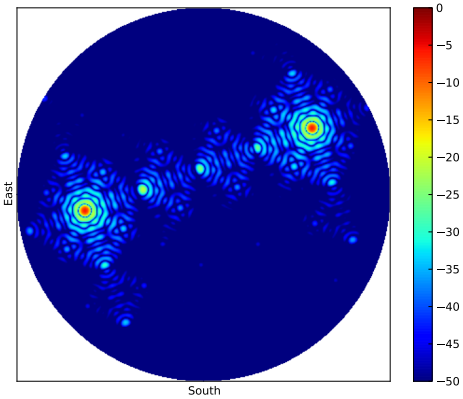
HBA station beam tracking 180 MHz (dB)





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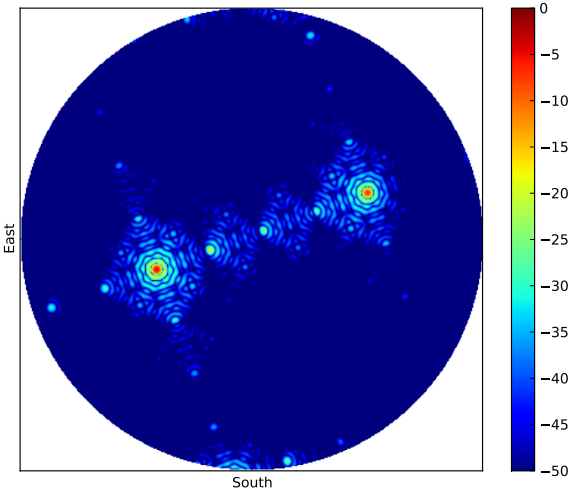
Break-out assignment

- Discuss among your group members how one can figure out where the station is pointing.
- Assign one person to be your “representative”
- This person will type the answer.
- You have 5 minutes

SE607 beam 240 MHz (dB)



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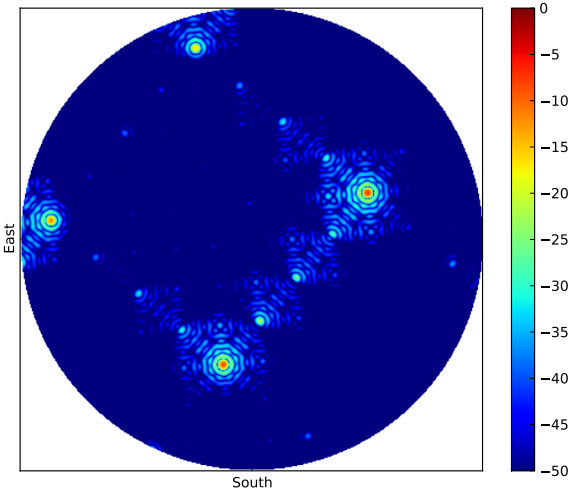
UK608 beam 240 MHz (dB)



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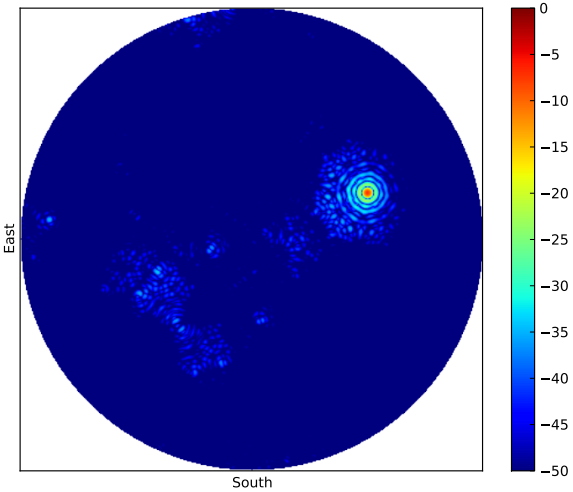
SE607-UK608 beam 240 MHz (dB)



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Outline

End of this week?

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