LOFAR EoR data reduction: Analysis of SAGECal gain solutions

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LOFAR EoR Plenary Meeting

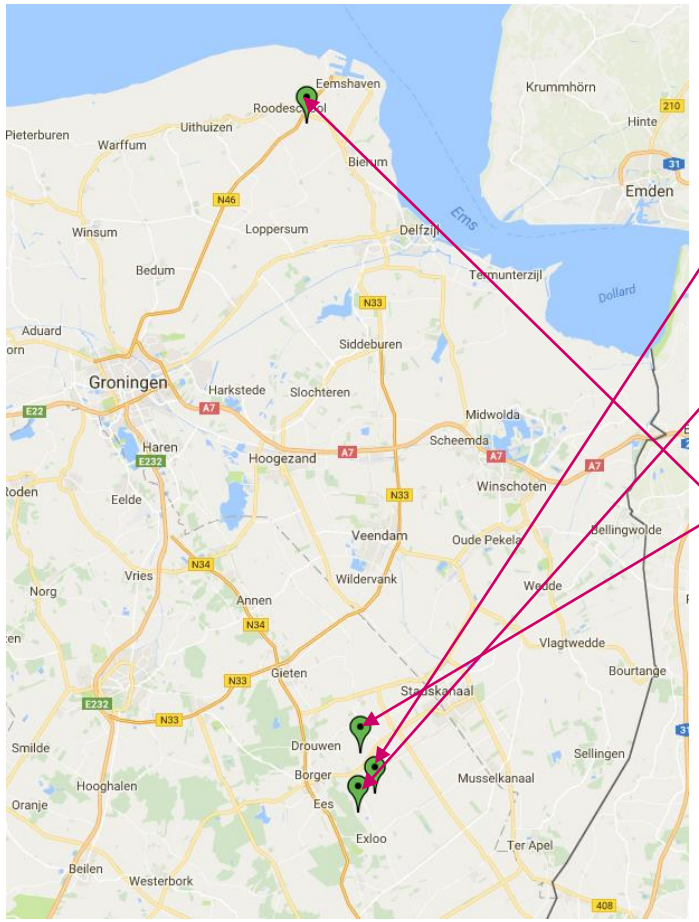
Groningen, The Netherlands

February 1, 2018

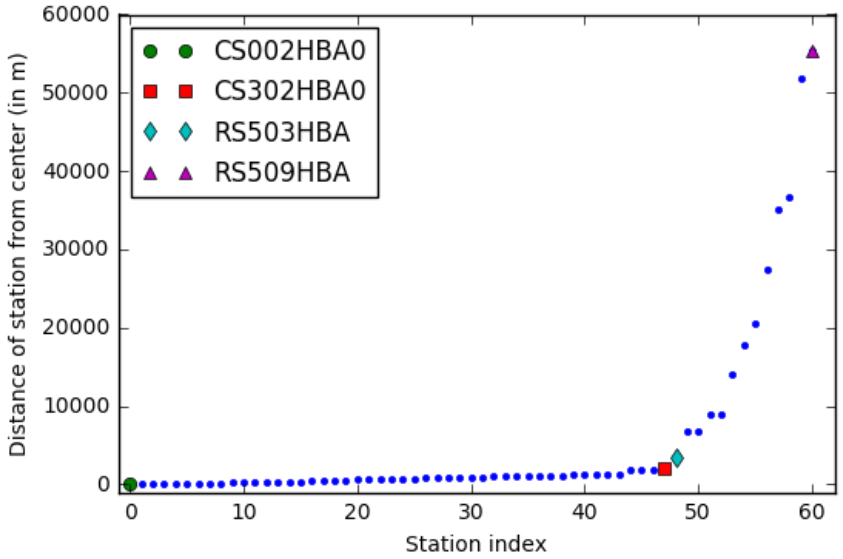
Data

- Field: NCP (RA=0, dec=+90°), observation code L90490 (Patil et al. 2017)
- Observation time : 13 hours
- Frequency range : 115 MHz – 175 MHz
- SAGECal solution interval : Nominal solution interval: 20 minutes
  - For certain clusters, more solutions per solution interval if SNR allows that
- Telescope configuration: All 61 Dutch LOFAR HBA stations
  - 48 core stations
  - 13 remote stations

Representative stations analyzed

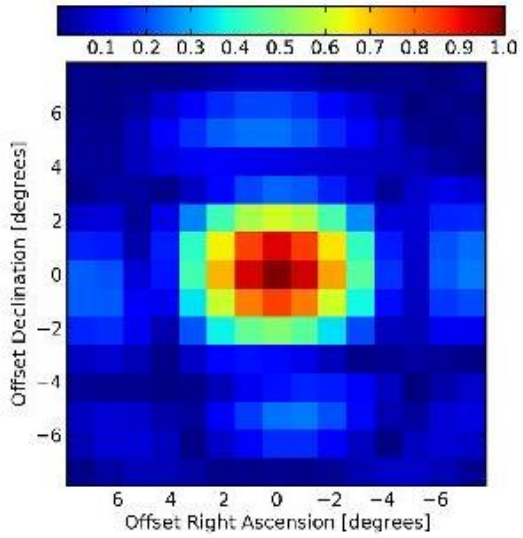


- CS002HBA0 : Central station : Core station in center of superterp
- CS302HBA0 : Core station furthest from central station
- RS503HBA : Remote station nearest to central station
- RS509HBA : Remote station furthest from central station

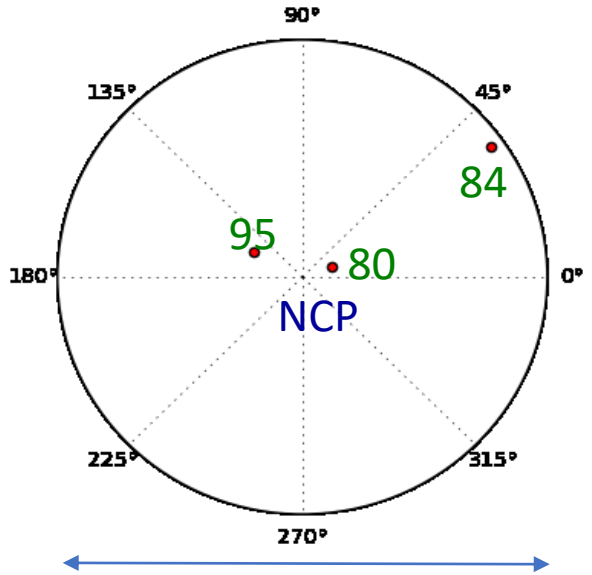


Directions/clusters analyzed

HBA core station beam (at 163 Mz)

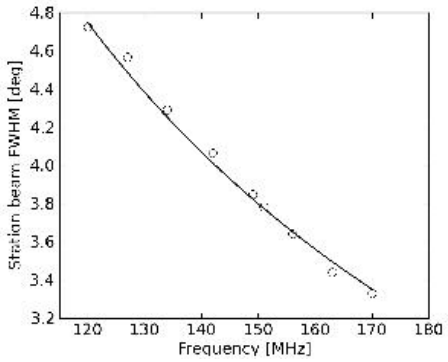


4°



8°

FWHM as a function of frequency

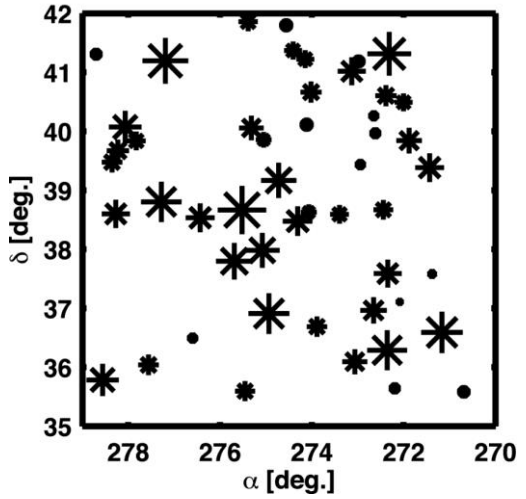


(Van Haarlem et al. 2013)

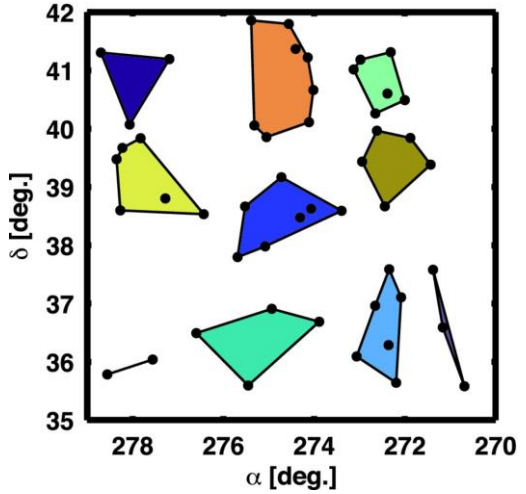
Cluster number	Distance from NCP	Number of solutions per solution interval
80	~ 0.5°	4
95	~ 0.75°	1
84	~ 3.75°	8

SAGECal

- Algorithm for computing direction-independent and direction-dependent gain solutions. Gain solutions are Jones matrices, J. (Kazemi et al. 2011)
- Metric used for for comparing gain solutions at different times, frequencies, in different directions, and at different stations: $\sqrt{\text{Trace}(JJ^H)}$
- Direction-dependent gain solutions: Divide the sky model into clusters, then compute direction-dependent gain solutions for each cluster. (Kazemi et al. 2013)



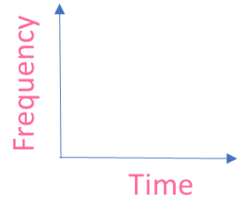
Sky model



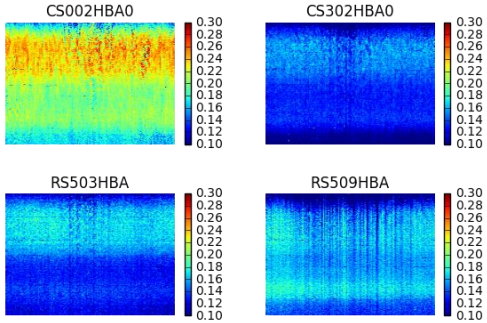
Clusters

(Kazemi et al. 2013)

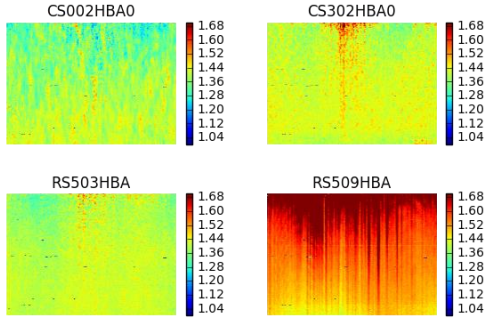
Dynamic spectrum of gain solutions



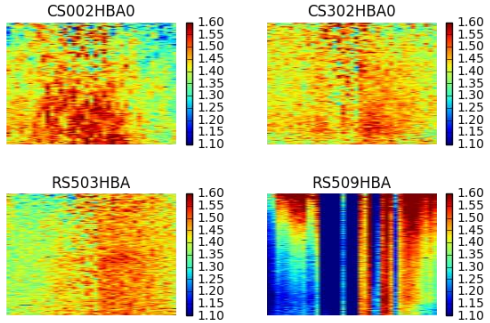
Direction independent



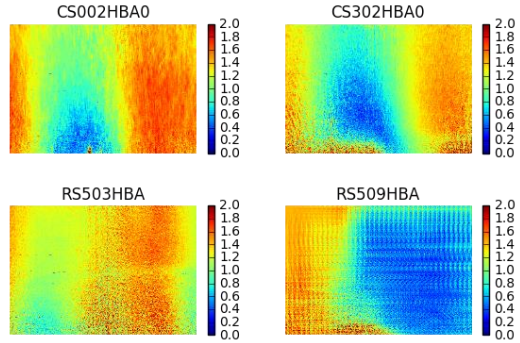
Cluster 80

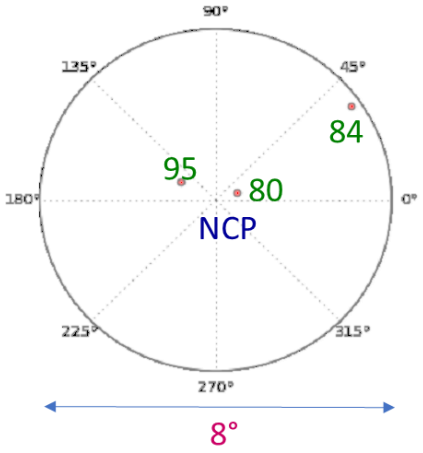


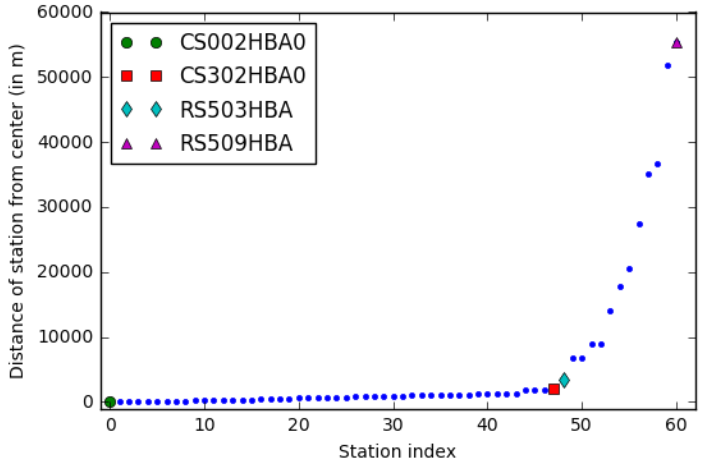
Cluster 95



Cluster 84







- Gain variation in both time and frequency increases with increasing distance from pointing center.
- Gain variation increases with increasing station distance from array center.
- Closest remote station behaves the same way as core stations.

Gain amplitude as a function of time

(at a particular frequency)

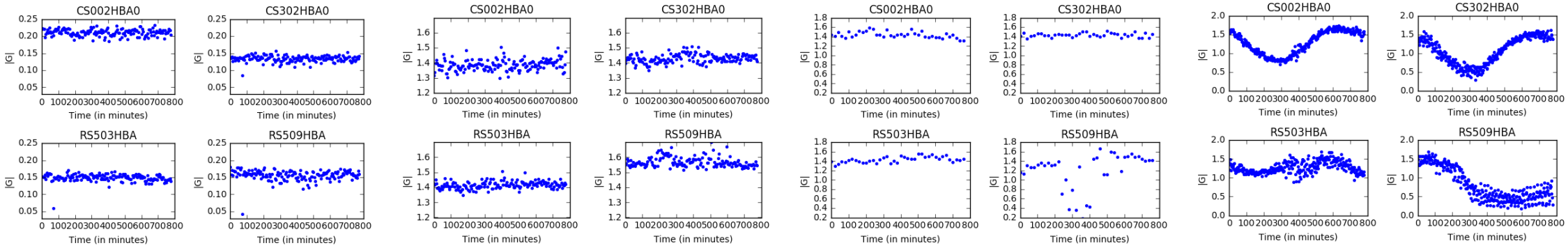
Frequency : 145 MHz
(mid-point of observing band)

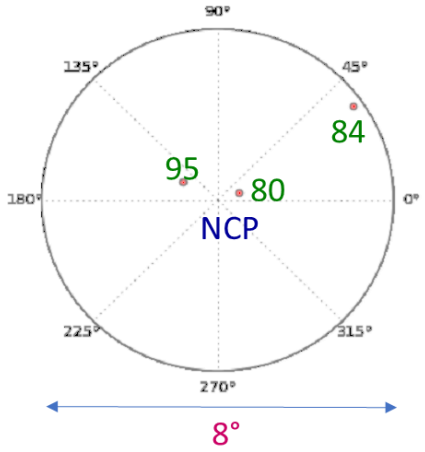
Direction independent

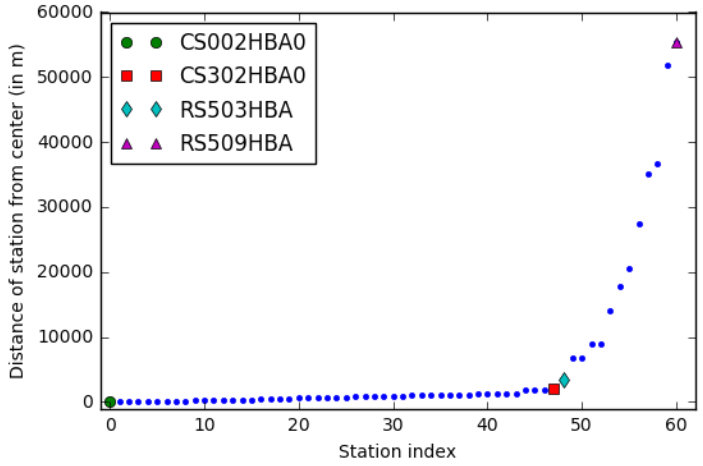
Cluster 80

Cluster 95

Cluster 84







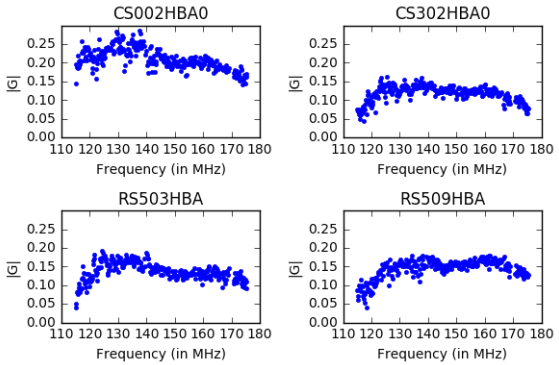
Gain variation with time due to changing beam gain as the beam rotates and as the beam shape changes with hour angle

Gain amplitude as a function of frequency

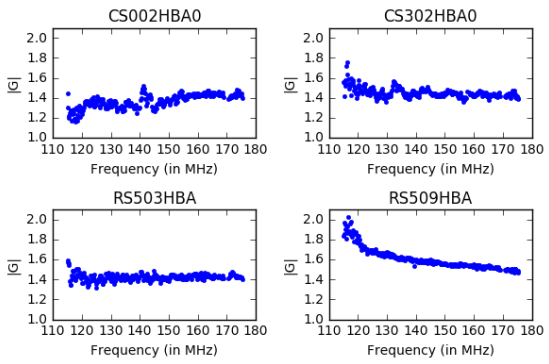
(at a particular time)

Time : 6.5 hours
(mid-point of observing time)

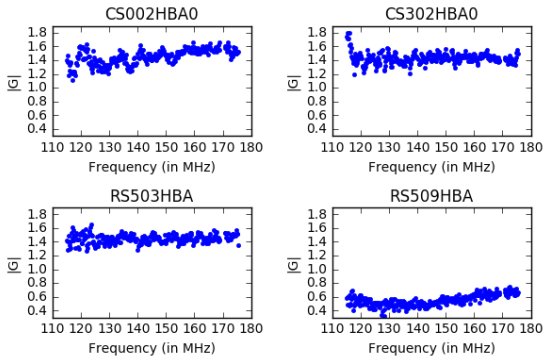
Direction independent



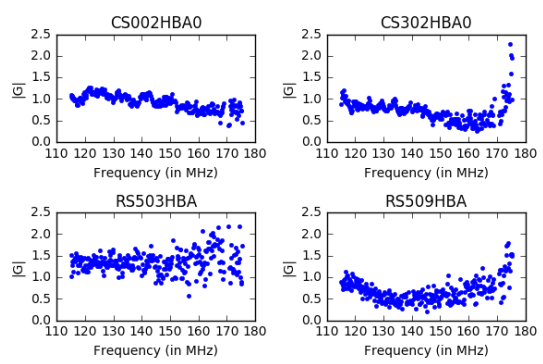
Cluster 80

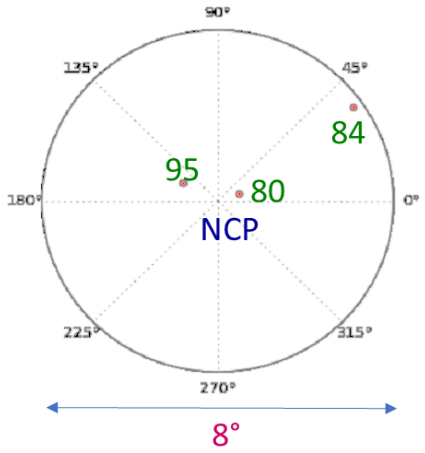


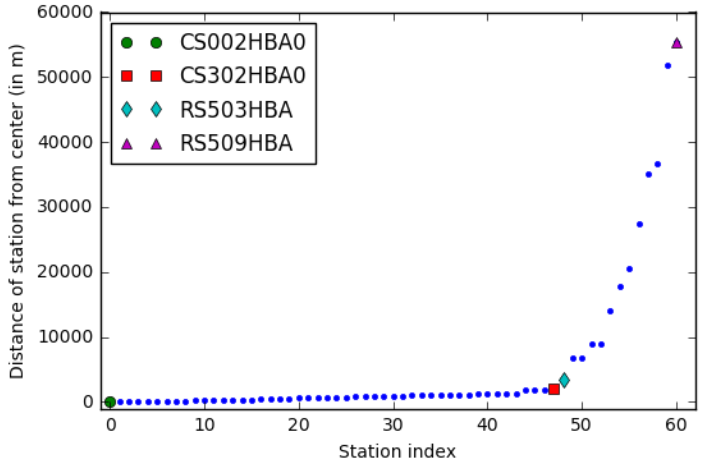
Cluster 95



Cluster 84







Gain variation with frequency due to frequency-dependence of beam shape and ionospheric effects

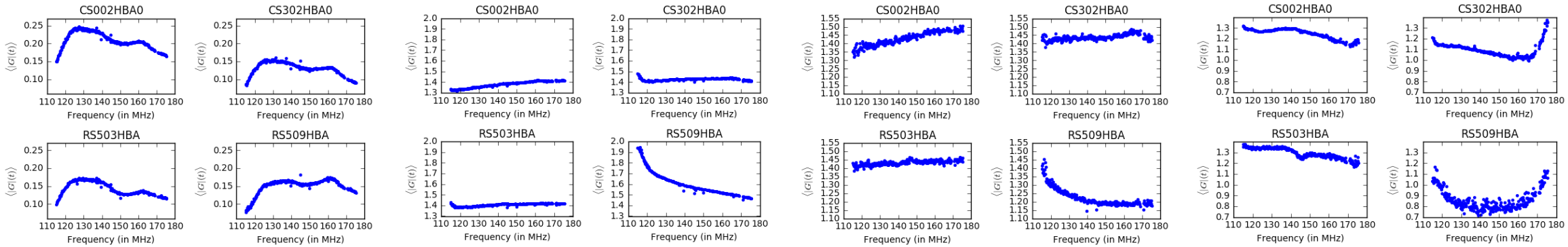
Time-averaged gain amplitude as a function of frequency

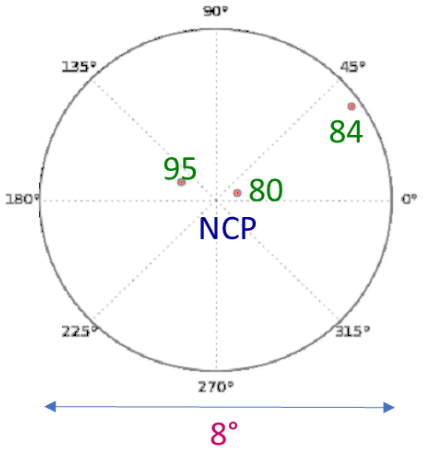
Direction independent

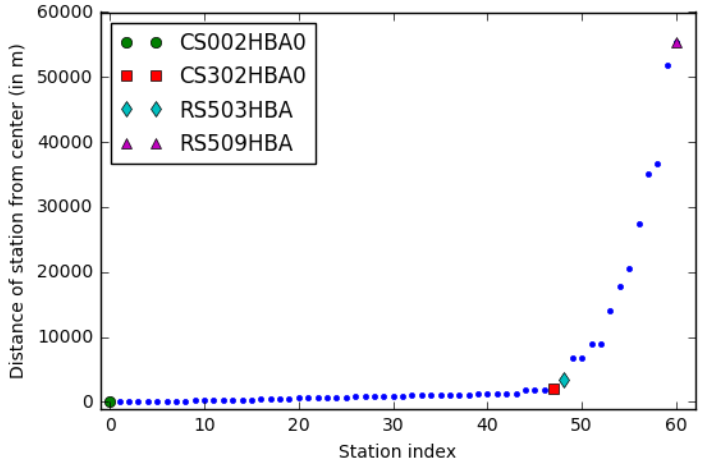
Cluster 80

Cluster 95

Cluster 84



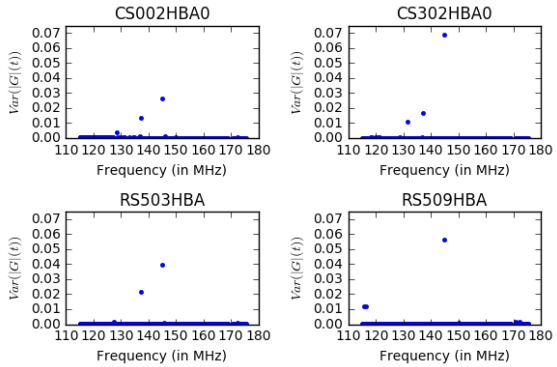




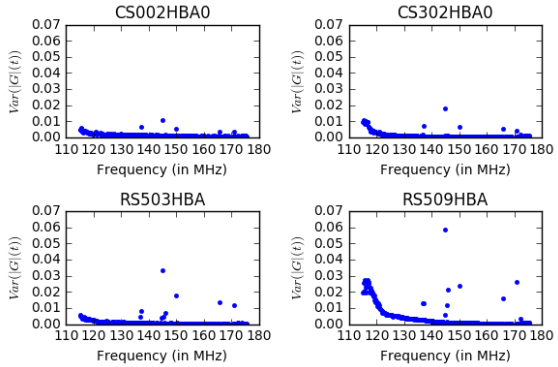
- Closest remote station shows same behavior as the core stations.
  → Difference in gain variation between core and remote stations due to longer baselines, not due to differences in station configuration/electronics.
- Gain variation at core stations: Due to beam effects?
- Gain variation at remotest station: Due to ionospheric effects?

Variance (over time) of gain amplitude as a function of frequency

Direction independent



Cluster 80



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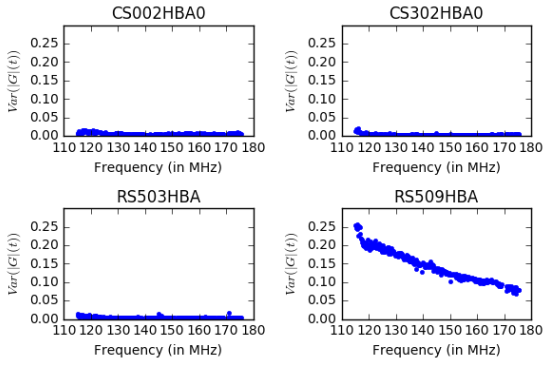
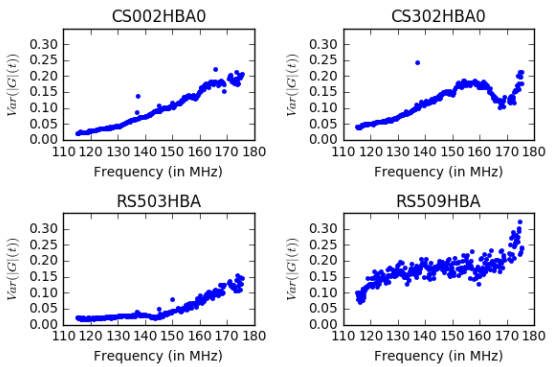
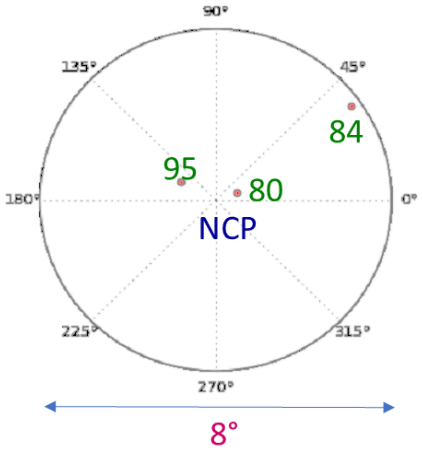
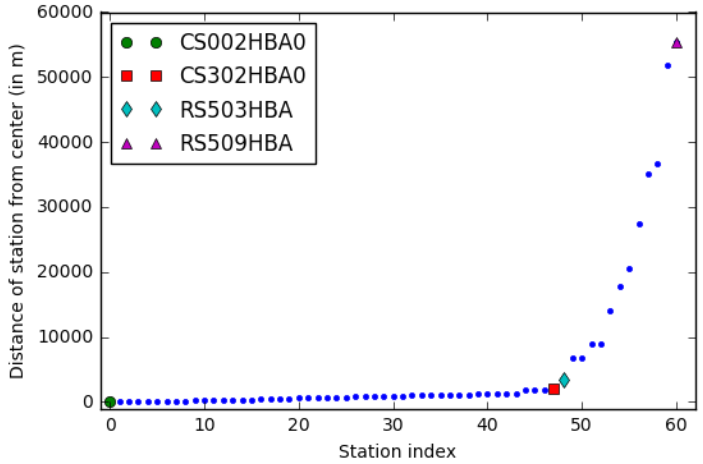


Cluster 84





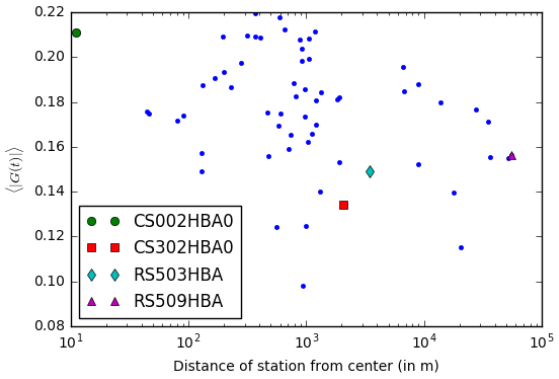


- Gain variance increases as one moves away
- from the pointing center.
- Gain variance is higher at remote stations
- than at core stations.
- U-shaped pattern likely due to bandpass.

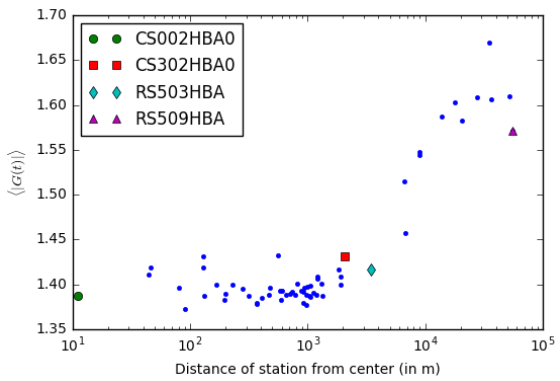
Time-averaged gain amplitude as a function of station distance

Frequency : 145 MHz
(mid-point of observing band)

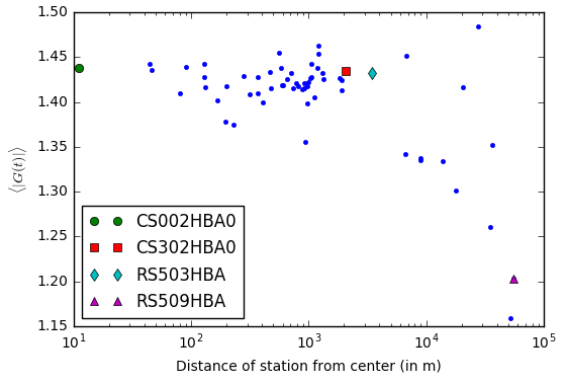
Direction independent



Cluster 80



Cluster 95



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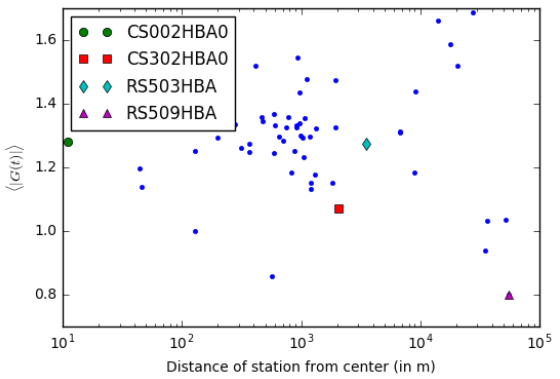
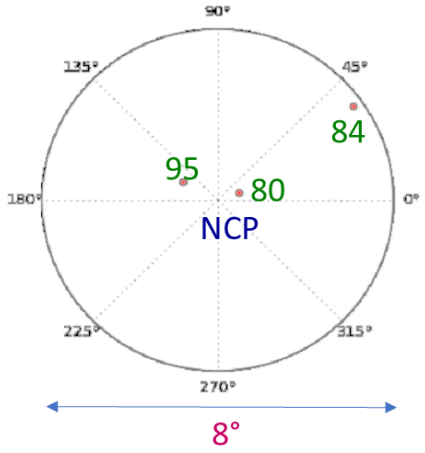
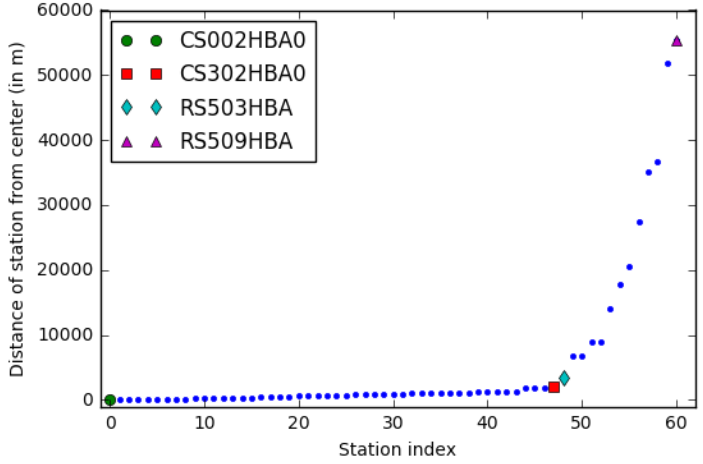




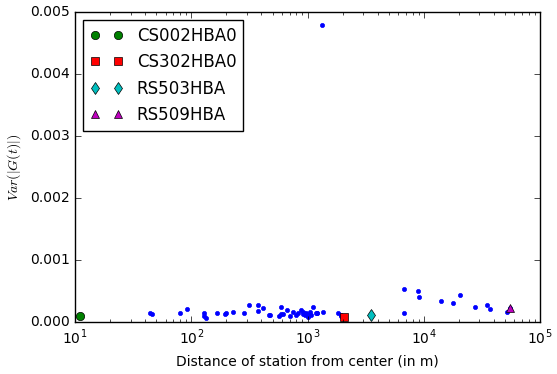


- Gain amplitude relatively constant at core stations. More scatter at remote stations.
- Scatter in gain amplitude increases with distance from pointing center.

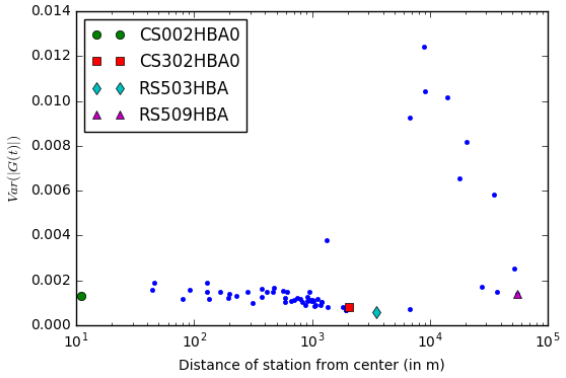
Variance (over time) of gain amplitude as a function of station distance

Frequency : 145 MHz
(mid-point of observing band)

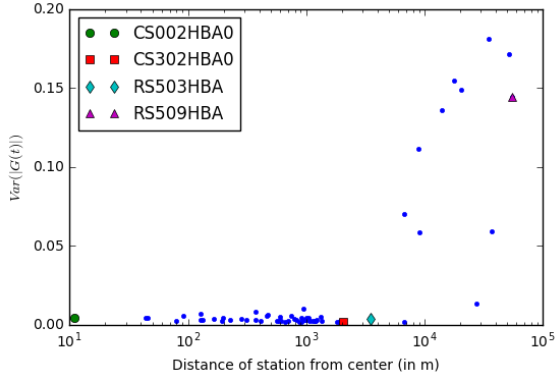
Direction independent



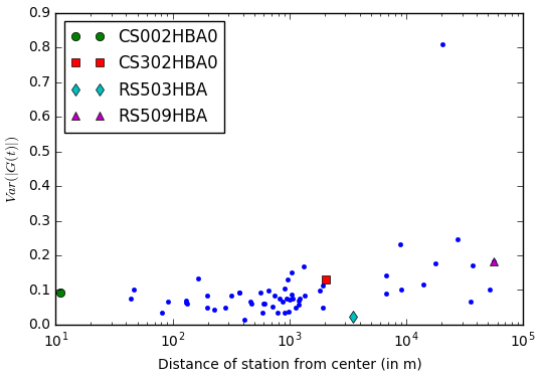
Cluster 80

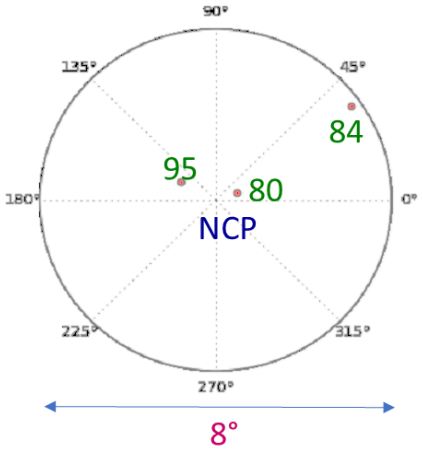


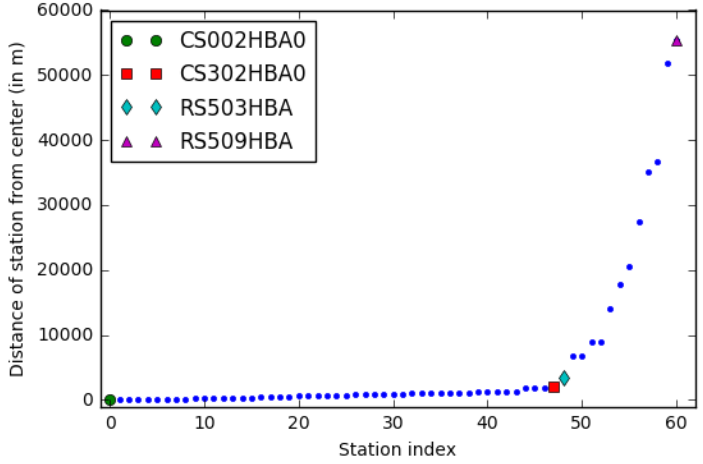
Cluster 95



Cluster 84





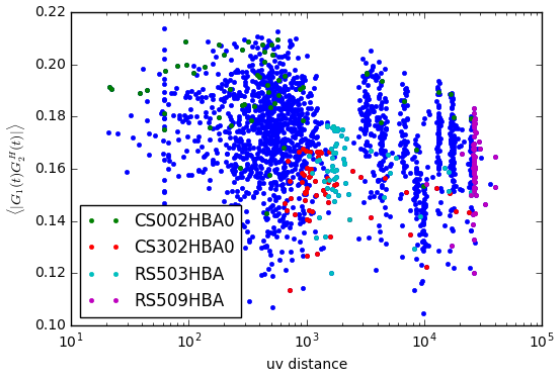


- Gain variance low and relatively constant at core stations, higher at remote stations.
- Variance in gain amplitude increases with increasing distance from pointing center.

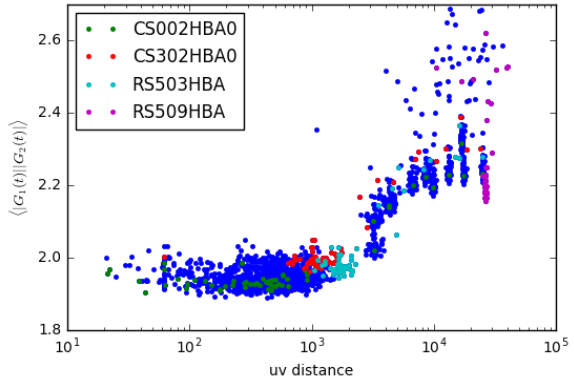
Time-averaged product of gain amplitudes as a function of *uv*-distance

Frequency : 145 MHz
(mid-point of observing band)

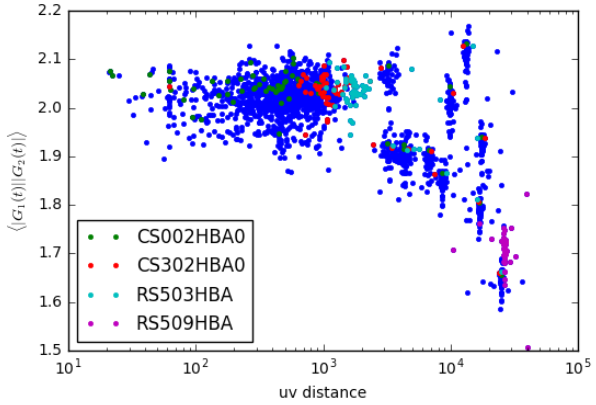
Direction independent



Cluster 80



Cluster 95



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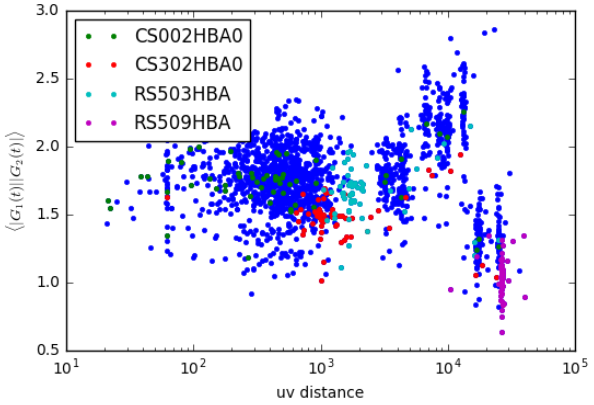
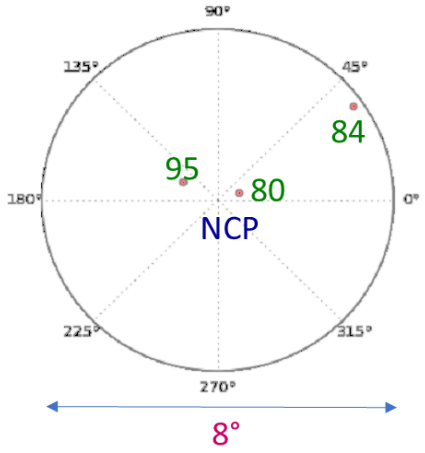
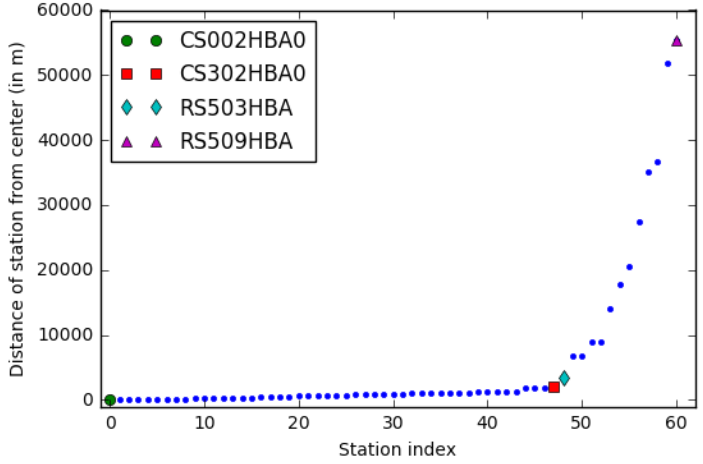




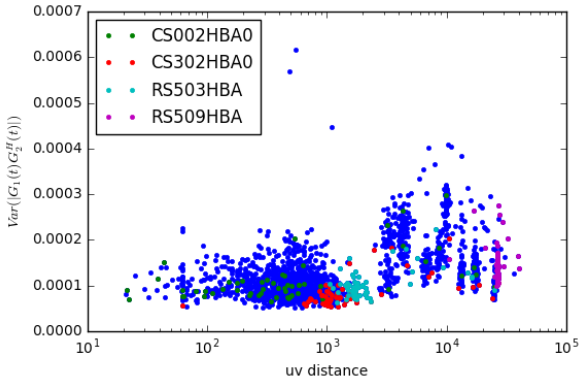


- Relatively constant on short baselines. More scatter on longer baselines.
- Scatter increases with increasing distance from pointing center.

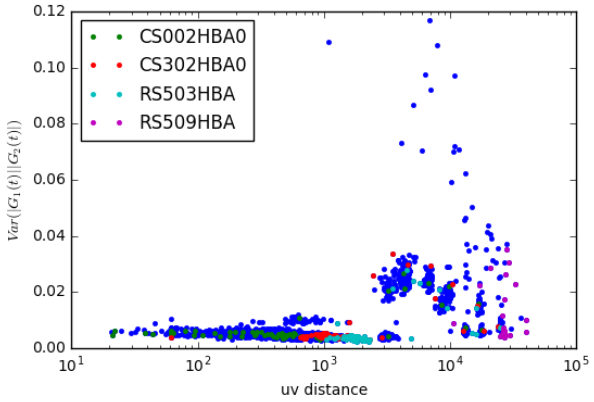
Variance (over time) of product of gain amplitudes as a function of *uv*-distance

Frequency : 145 MHz
(mid-point of observing band)

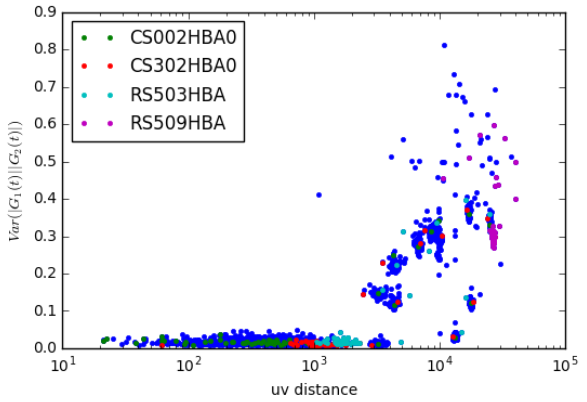
Direction independent



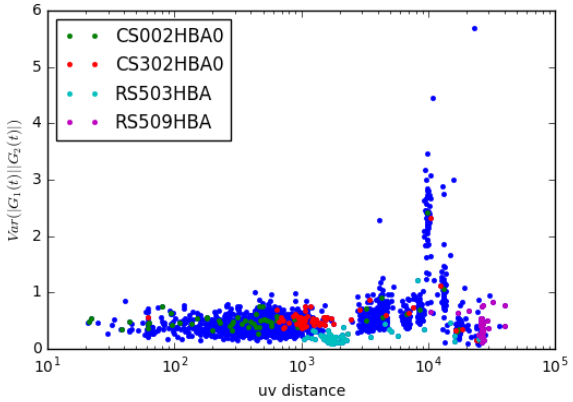
Cluster 80

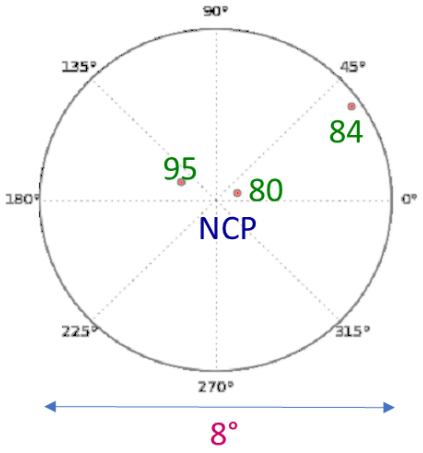


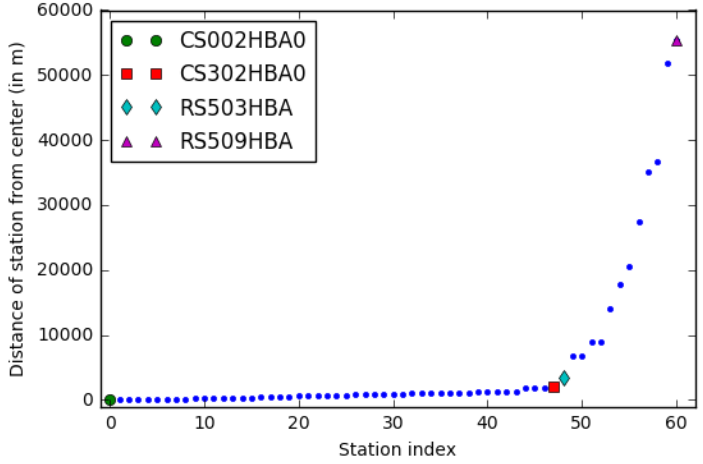
Cluster 95



Cluster 84



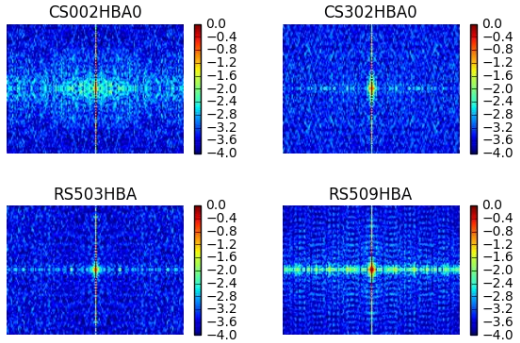




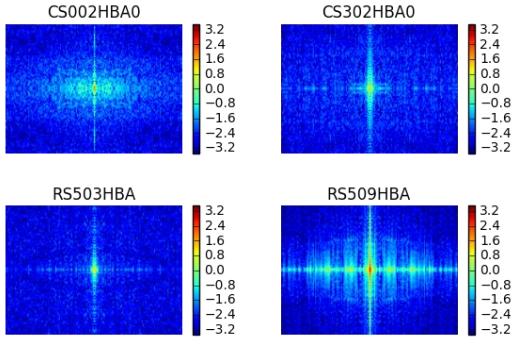
- Variance low and relatively constant on short baselines, higher on long baselines.
- Variance increases with increasing distance from pointing center.

Power spectrum of gain solutions

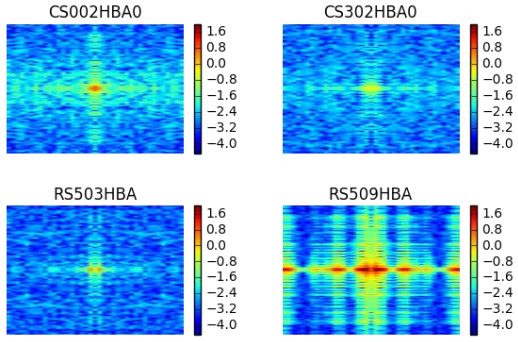
Direction independent



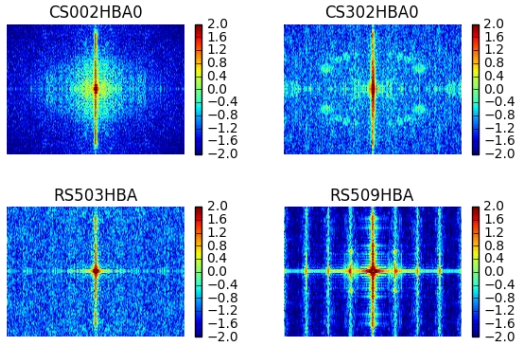
Cluster 80

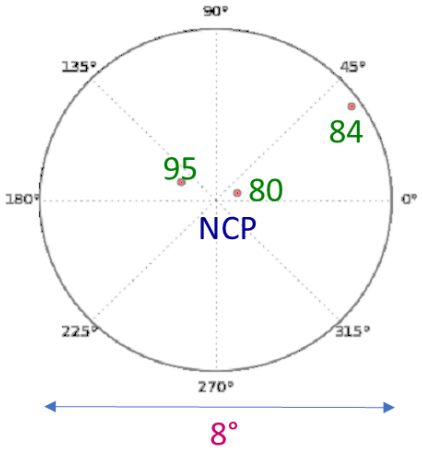


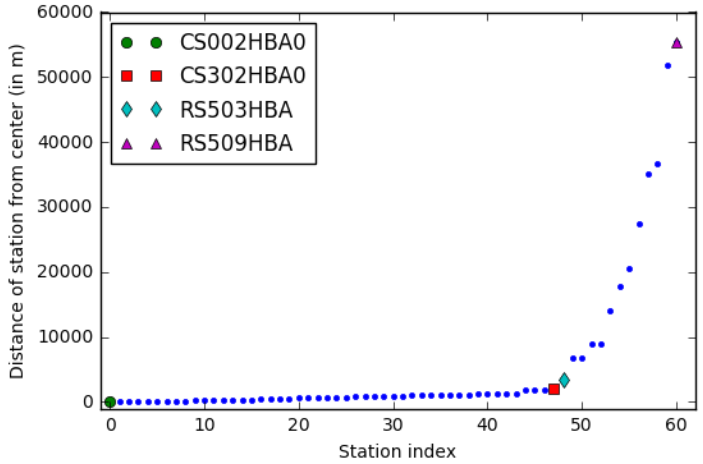
Cluster 95



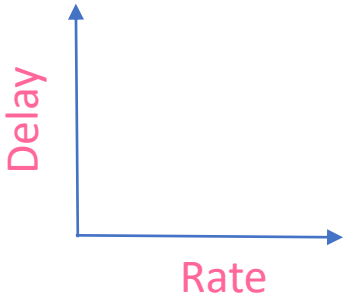
Cluster 84







Cluster number	Number of solutions per solution interval	Effective solution interval (in min)
80	4	5
95	1	20
84	8	2.5



Summary and conclusions

- Gain amplitude dominated by beam gain at core stations, ionospheric effects at remote stations.
- At a given frequency, time-averaged gain amplitude relatively constant at core stations. More scatter at remote stations. Scatter increases with increasing distance from pointing center.
- At a given frequency, gain amplitude variance (over time) low and relatively constant at core stations. Higher at remote stations. Variance increases with increasing distance from pointing center.
- Difference in gain amplitudes and variance between core and remote stations due to longer baselines, not because of the difference in geometry/electronics between core and remote stations.