

KAIRA

Kilpisjärvi Atmospheric Imaging Receiver Array

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Sodankylä Geophysical Observatory, Finland

August 31, 2012

Why KAIRA?

- ▶ Two years ago we wrote a proposal for a LOFAR remote station.
- ▶ The main goal was to try out the hardware as a EISCAT3D pathfinder.
- ▶ Since then, many more science goals have been attached to the project.

What is LOFAR?



LEGO blocks for radio science





What is KAIRA?



- ▶ KAIRA is a dual array of wide band dipole VHF radio antennas
- ▶ A project of the Sodankylä Geophysical Observatory, principally funded by the University of Oulu in Finland.
- ▶ HBA: 30×50 m radio telescope for the 120-240 MHz
- ▶ LBA: 30 m diameter radio telescope for the 30-80 MHz
- ▶ Uses proven LOFAR antenna and digital signal-processing hardware. Black sheep of LOFAR.
- ▶ Primary purpose to receive EISCAT VHF transmissions
- ▶ Multiple uses in geophysical remote sensing and radio astronomy
- ▶ Prototype for EISCAT3D

DEEP SPACE

1 AU

1000 km

250 km

100 km

50 km

Radio astronomy



Interplanetary scintillation



Solar radio emission studies



Auroral kilometric radiation



Space debris



Relative electron content tomography



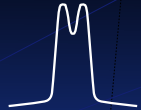
Field aligned irregularities



Ionospheric scintillation



Artificial field aligned irregularities



Incoherent scatter



Riometer imaging



Specular meteor trail echos



Tropospheric echos



Polar mesospheric winter/summer echos



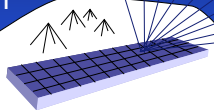
Artificial Electron heating



Meteor head echos



Meteor smoke particles



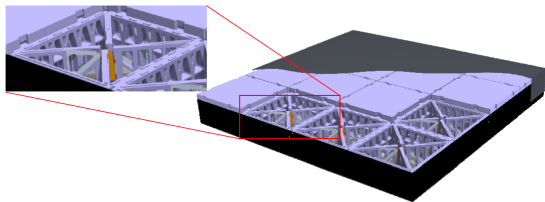
KAIRA

Kilpisjärvi Atmospheric Imaging Receiver Array

Nearby MST radars:
Esrange, Morro, MAARSY
Also: meteor radars,
DAB- and DTV transmitters

Tromsø ionospheric heater

Tromsø VHF



- ▶ Low Band Array 30 to 80 MHz.
- ▶ High Band Array 120 to 240 MHz.

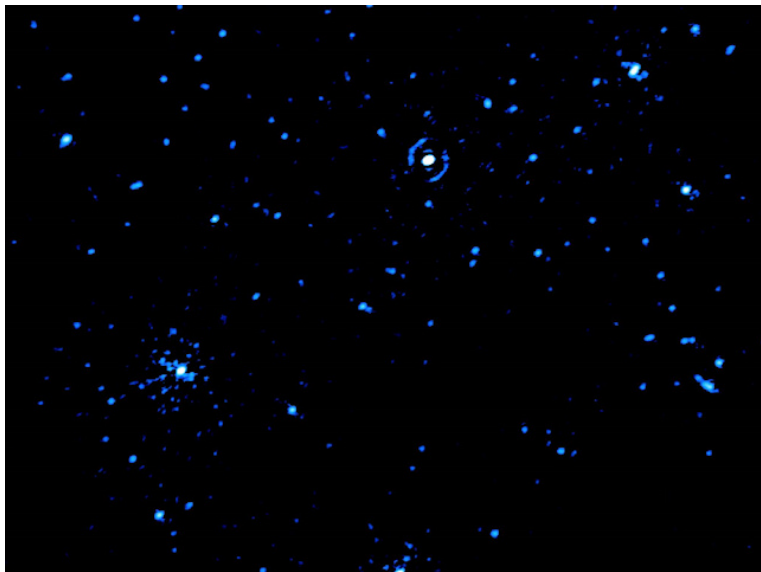
LOFAR Antennas



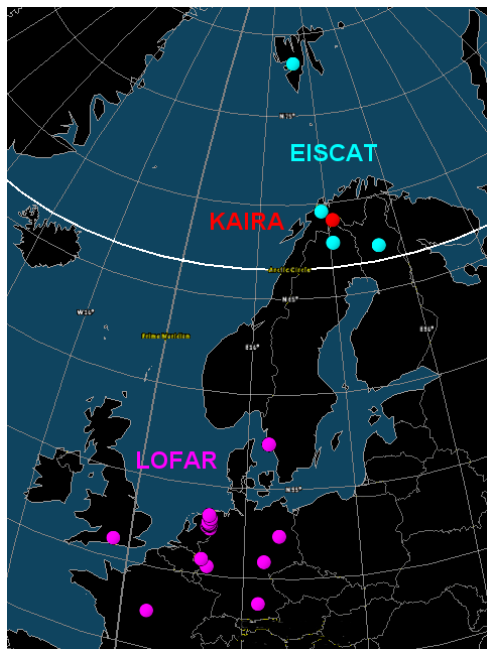
LOFAR Antennas



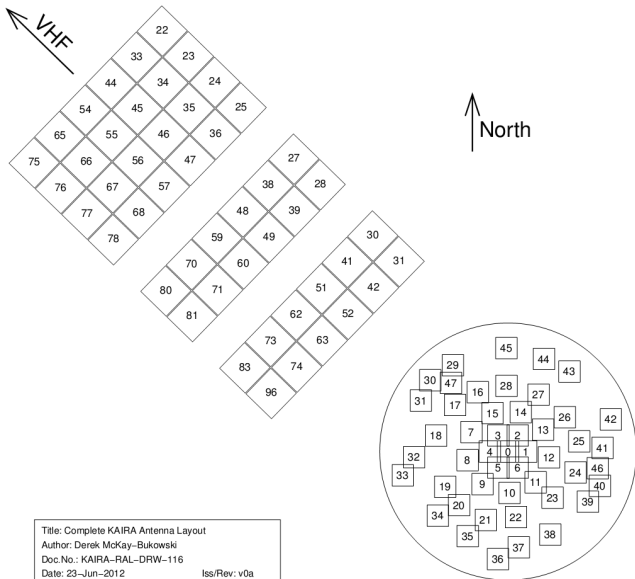
Interferometry



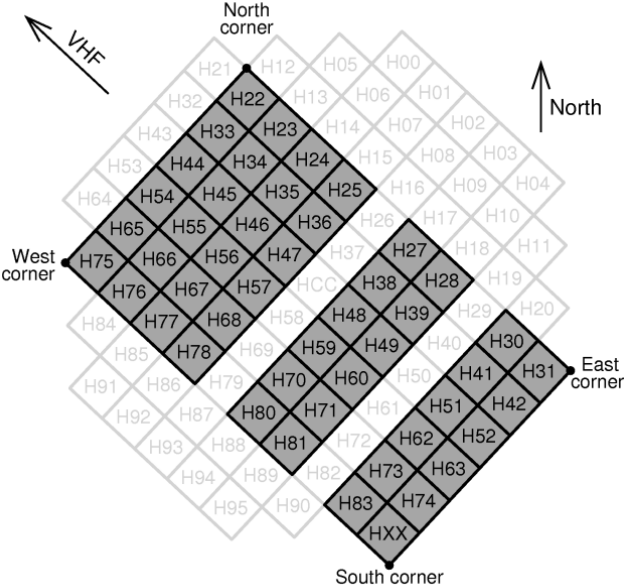
KAIRA Site layout



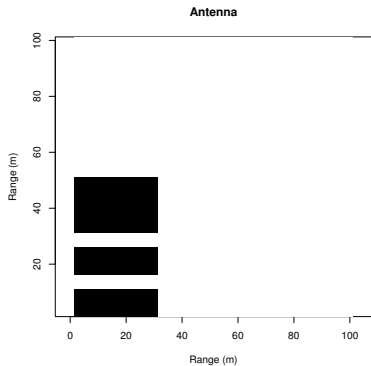
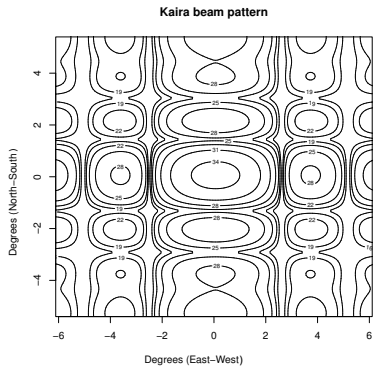
KAIRA Site layout



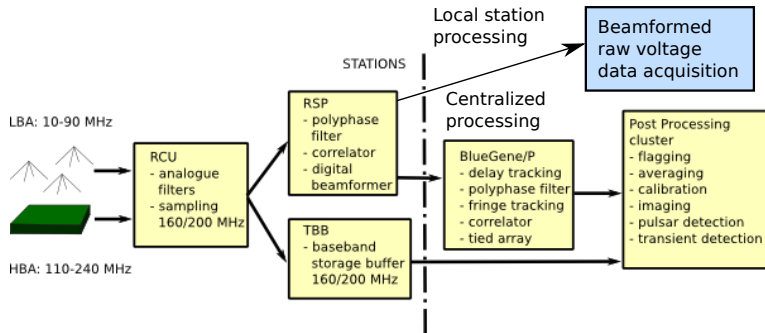
HBA Tile layout



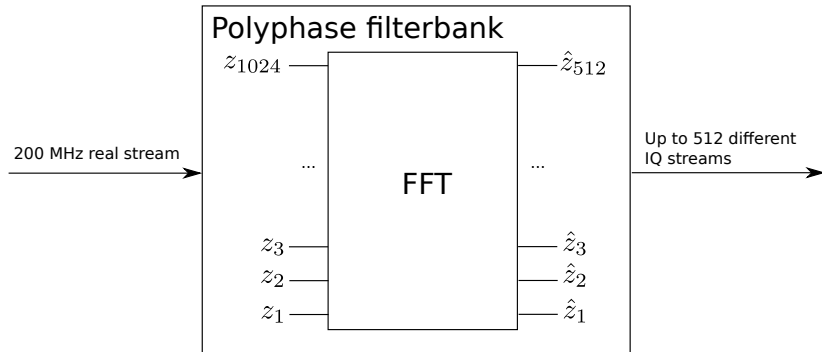
HBA Beam pattern



LOFAR Signal Processing



LOFAR Signal Processing



LOFAR Signal Processing

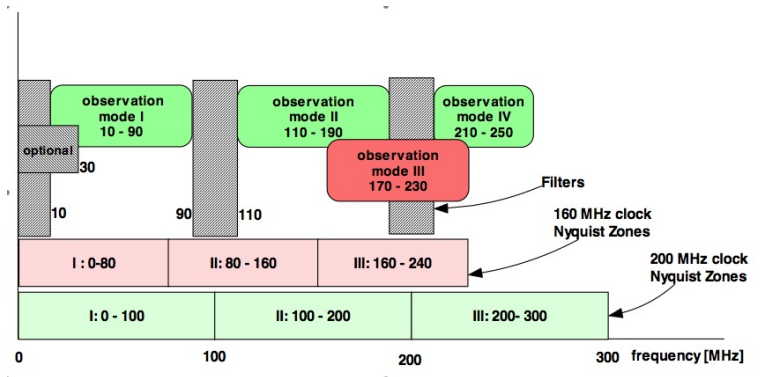
What is a digital downconverter?

$$z_t = \sum_{n=1}^{N_{\text{int}}} x_{n+tN_{\text{int}}} \exp(i\omega_c(n + tN_{\text{int}})) \quad (1)$$

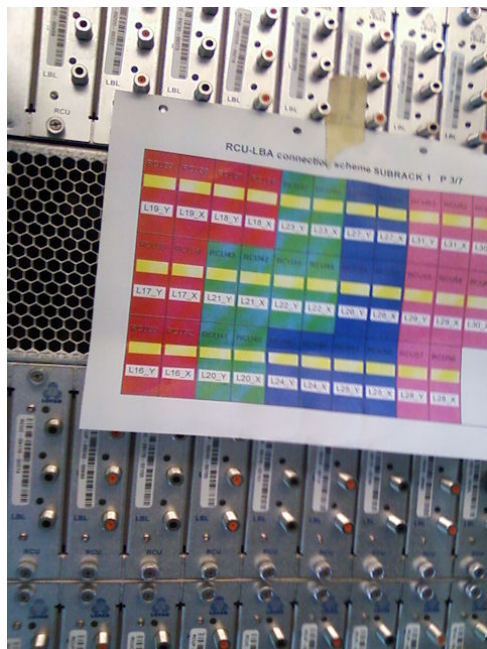
What does FFT do?

$$z_\omega = \sum_{n=1}^N x_n \exp(i\omega n) \quad (2)$$

LOFAR Signal Processing



LOFAR Signal Processing



Snow testing





Each load
between
500 and 1000kg

Measuring system
used to assess
applied load

Summit ~1.5m

7650kg total

0.6m high HBA tile

15t digger


1.0m frame

- Destructive testing
 - Snow impact, loading, lateral stresses, etc.

Snow testing continues...



Ilkka's visit to Astron

Author: I.I. Virtanen	Date of issue: 2012-Apr-13 Kind of issue: Public	Scope: Project Documentation Doc.nr.: LOFAR-ASTRON-MAN-064	
	Status: Draft Revision nr.: 1.0	File:	

Station Data Cookbook

Fast lag-profile inversion

- ▶ Lag-profile measurements are convolution measurements
- ▶ The transmission window in monostatic measurements prevents us from using frequency domain methods for deconvolution
- ▶ But bi-static observations have no transmission gaps and we can use FFT to dramatically speed up lag-profile inversion.

Lag-profile inversion

Consider the measurement equation for range and Doppler spread targets, but in this case using multiple different radar transmission envelopes indexed with c :

$$m_t^c = \sum_{r \in R} \epsilon_{t-r}^c \zeta_{r,t} + \xi_t. \quad (3)$$

If we now take conjugated self-products of these measurements with a lag τ . These can be organized as

$$m_t^c \overline{m_{t+\tau}^c} = \sum_{r \in R} \epsilon_{t-r}^c \overline{\epsilon_{t-r+\tau}^c} \sigma_r^\tau + \xi_t', \quad (4)$$

where $\sigma_r^\tau = \mathbb{E} \zeta_{r,t} \overline{\zeta_{r,t+\tau}}$, and ξ_t' is a zero-mean noise term, which is dominated by the receiver noise in the case of low signal to noise ratio measurements. In the case of high signal to noise ratio measurements, this will also have significant zero mean contributions from the incoherent scatter cross-products $\zeta_{r,t} \overline{\zeta_{r',t+\tau}}$, where $r \neq r'$.

Lag-profile inversion

In more concise form, the lag-product equations can be stated as

$$m_t^{c,\tau} = \sum_{r \in R} \epsilon_{t-r}^{c,\tau} \sigma_r^\tau + \xi_t', \quad (5)$$

which is equivalent to the measurement equation for coherent (stationary) range-spread radar targets. For each lag τ , the measurement equations are different, as the ambiguity functions $\epsilon_{t-r}^{c,\tau}$ depend on the lag (and also transmission envelope). The equation is linear, i.e., the relationship between the unknown σ_r^τ and the measurements $m_t^{c,\tau}$ can be represented in matrix

$$\mathbf{m}^{c,\tau} = \mathbf{W}^{c,\tau} \boldsymbol{\sigma}^\tau + \boldsymbol{\xi}', \quad (6)$$

where the measurement vector $\mathbf{m}^{c,\tau}$ spans over all time indices that contribute to the unknown $\boldsymbol{\sigma}^\tau$.

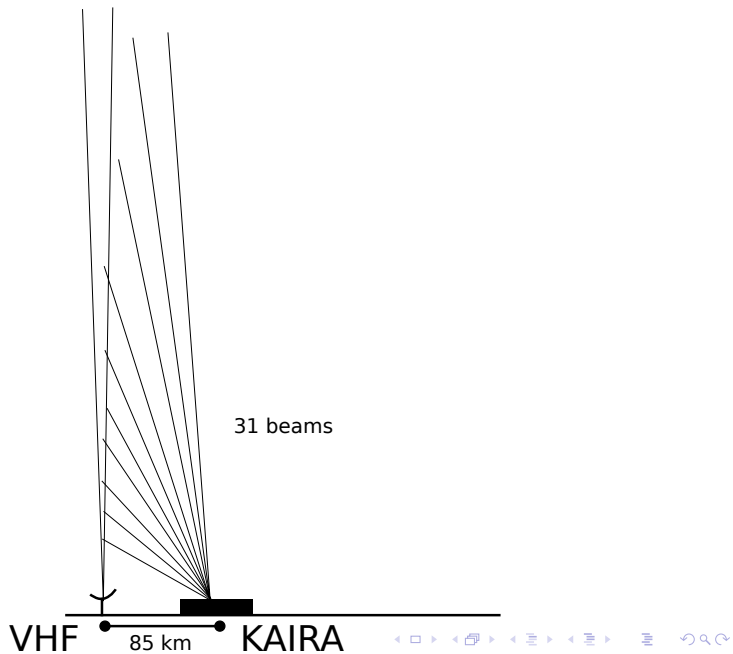
Fast lag-profile inversion

$$\mathbf{x}_{\text{ML}} = (\mathbf{A}^{\text{H}}\boldsymbol{\Sigma}^{-1}\mathbf{A})^{-1}\mathbf{A}^{\text{H}}\boldsymbol{\Sigma}^{-1}\mathbf{m} \quad (7)$$

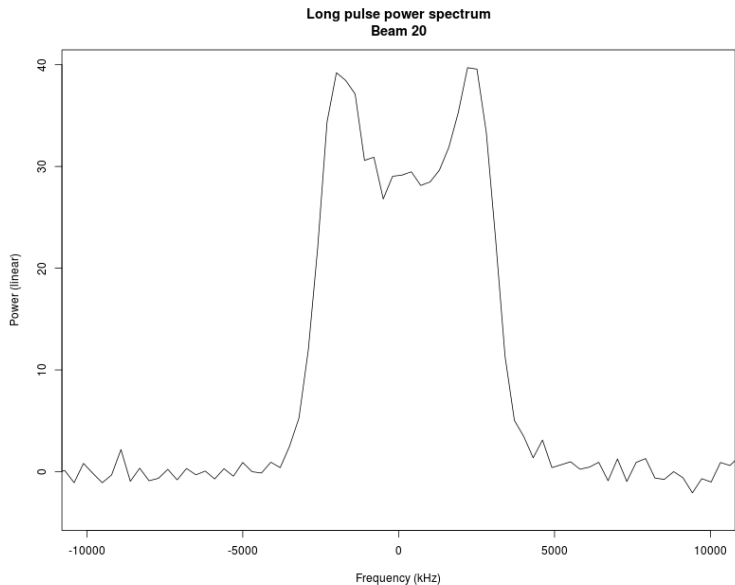
In frequency domain, the generalized linear least-squares for lag-profile inversion can be written as

$$\sigma_r^{\tau} = \mathcal{F}^{-1} \left\{ \frac{1}{\sum_{c=1}^{N_{\text{codes}}} |\epsilon_c^{\tau}(\omega)|^2} \sum_{c=1}^{N_{\text{codes}}} \overline{\epsilon_c^{\tau}(\omega)} m_c^{\tau}(\omega) \right\} \quad (8)$$

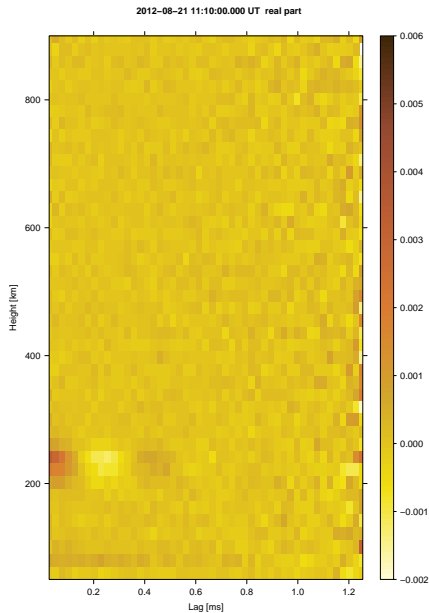
Bi-static configuration



First radar light 17.8.2012

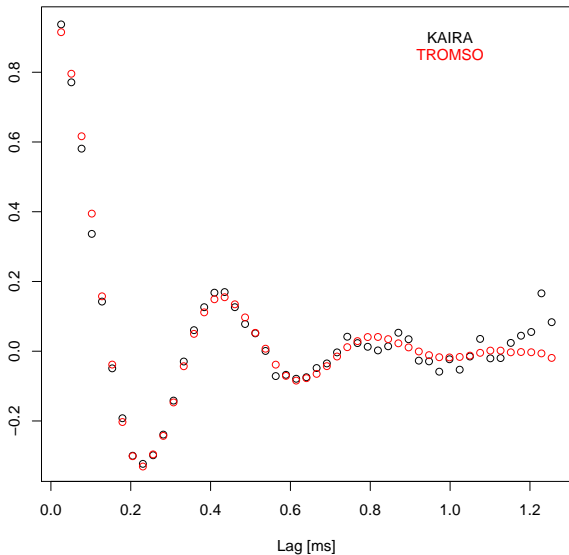


First coded pulse experiment 21.8.2012

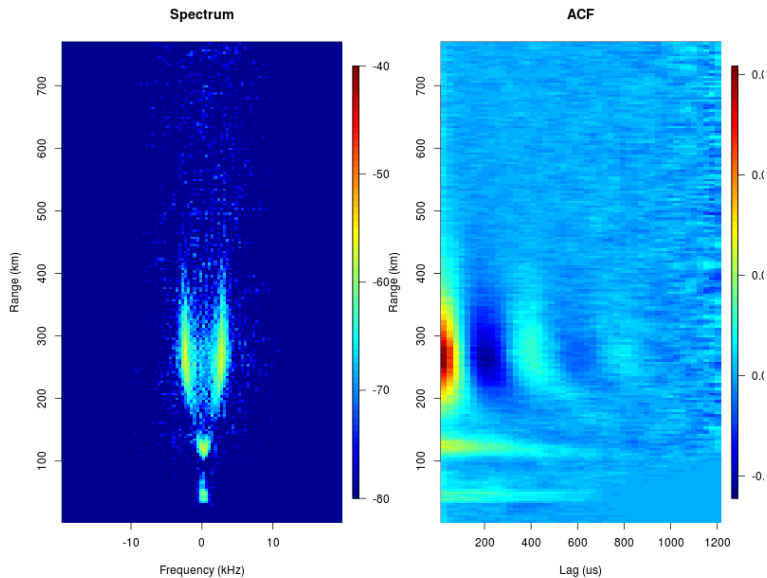


Comparison with Tromso

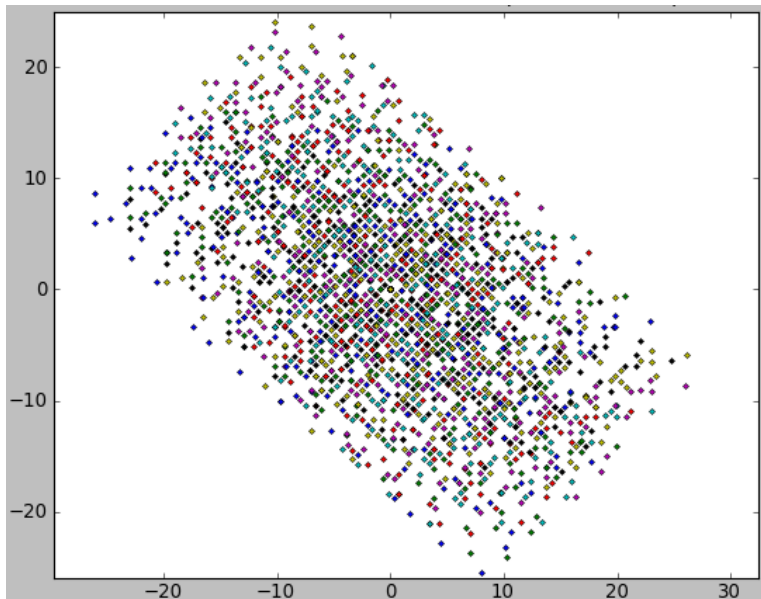
Re(ACF) at 240 km



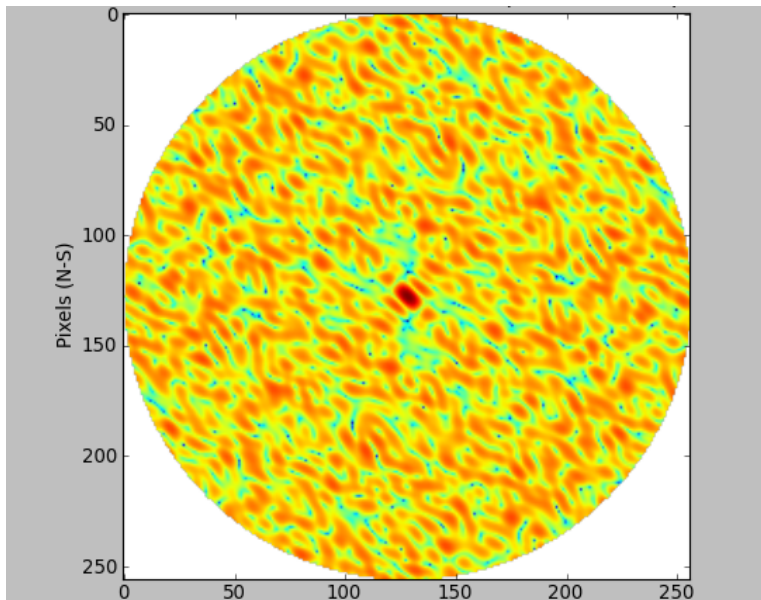
Fast LPI result from all beams



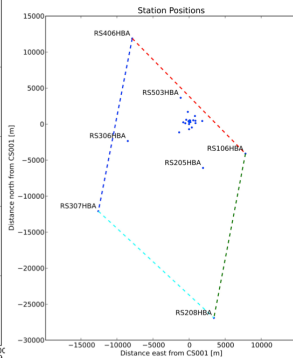
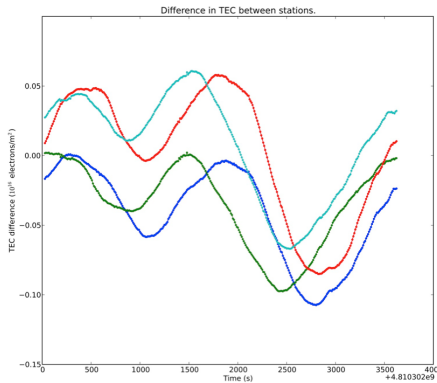
All-sky imaging



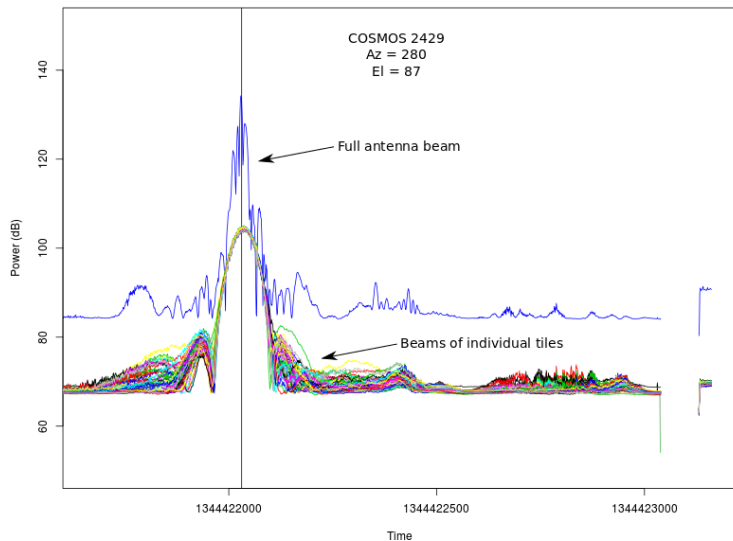
All-sky imaging



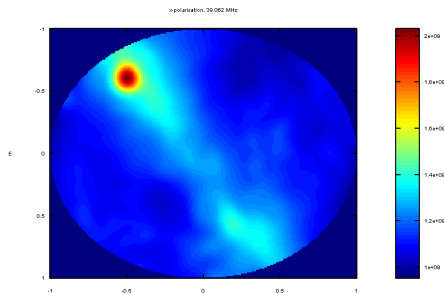
Relative total electron content



Beam shape using beacon satellites



Wideband Imaging Riometer



- ▶ All-sky imaging can be piggy-backed on all LOFAR stations operating with the LBA antenna. This is done by using the cross-correlated signals from all baselines that can be stored in parallel with other LOFAR operations.
- ▶ It is also possible to perform a dedicated riometer experiment with beams tracking radio sources in the sky.
- ▶ Wide frequency range (30-80 MHz)

Wideband Imaging Riometer

What can we do with this?

- ▶ More tolerant to interference
- ▶ Accurate quiet-day curve by tracking radio sources
- ▶ Inverting electron density profile from multi-frequency riometer absorption¹
- ▶ Inverting electron density and electron temperature from multi-frequency riometer absorption?

¹Lavergnat, J., and J. J. Berthelier (1973), An iterative mathematical technique for deriving electron-density profiles from multifrequency riometer data, *Radio Sci.*, 8(7),

What next?

- ▶ Do more VHF measurements
- ▶ Develop imaging riometer software
- ▶ Look at meteor head echos
- ▶ Look into IPS measurements



http://kaira.sgo.fi

The screenshot shows a web browser window displaying the KAIRA website. The browser's address bar shows 'kaira.sgo.fi'. The website header features the title 'KAIRA Kilpisjärvi Atmospheric Imaging Receiver Array' above a photograph of a snowy landscape with trees. Below the header, the date 'FRIDAY, 31 AUGUST 2012' is displayed. The main article is titled 'Fine tuning FFT LPI' and discusses the team's progress in calibrating and cross-validating ionospheric plasma parameter measurements. It mentions the use of fast Fourier transform lag-profile inversion and the ability to estimate ionospheric plasma incoherent scatter autocorrelation functions and spectra. A specific example of a 512 second integration is provided, showing results for altitudes up to 400 km. Two side-by-side plots are shown: 'Spectrum' and 'AOF'. The 'Spectrum' plot shows a vertical band of activity with a color scale from 0 to 10. The 'AOF' plot shows a horizontal band of activity with a color scale from 0 to 2. On the right side of the page, there is a 'SCIENCE' section with a diagram of the KAIRA system and a 'RELATED' section with links to 'EISCAT_3D blog' and 'LOFAR-UK'. The browser's download bar at the bottom shows a file named 'beacon.png' and a 'Show all downloads...' button.

Kilpisjärvi Atmospheric Im x

kaira.sgo.fi

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KAIRA

Kilpisjärvi Atmospheric Imaging Receiver Array

FRIDAY, 31 AUGUST 2012

Fine tuning FFT LPI

Going from initial first light to calibrated and cross validated ionospheric plasma parameter measurements is not an overnight step. However, the KAIRA team is making good progress. We have now managed to get fast Fourier transform lag-profile inversion working to some extent with real world signals contaminated with space debris and meteor head echoes. We can now estimate ionospheric plasma incoherent scatter autocorrelation functions and spectra with a fairly nice accuracy and computational speed.

Here is an example of a 512 second integration combined from all of the 30 beams intersecting the Tromsø VHF beam at different altitudes. With this experiment that has a 128 microsecond baud length, we can reach altitudes up to 400 km.

- Sodankylä Geophysical Observatory
- KAIRA / LOFAR Finland
- LOFAR France
- LOFAR Netherlands
- LOFAR Germany
- LOFAR Sweden
- LOFAR UK

SCIENCE

RELATED

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