LOFAR
System Overview

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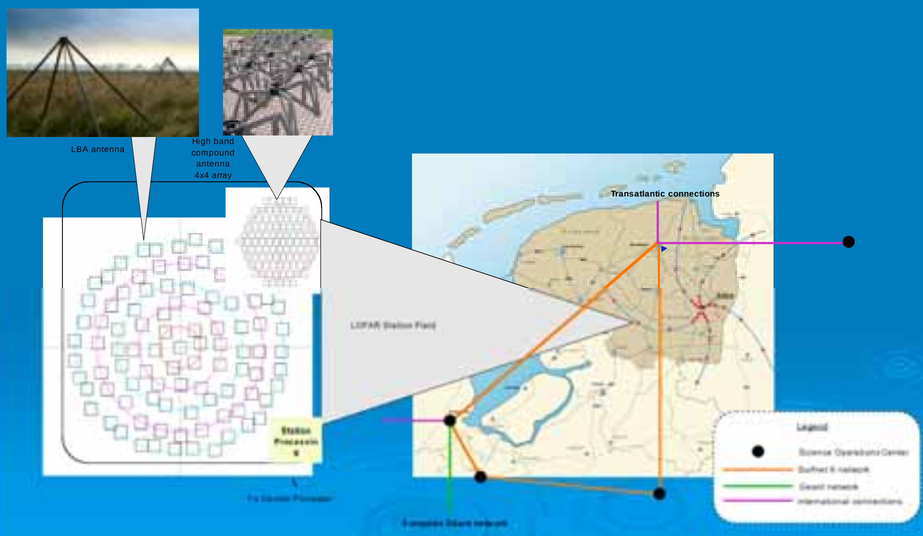
LOFAR Technical Concept

- LOFAR is a very large distributed radiotelescope:
  - 13,000 small antennas
  - in 77 stations
  - >20 Tbit/sec raw data
  - >40 Tflop supercomputer
  - innovative software systems
  - datamining and visualisation
- Full and exclusive control via the Internet
- Instantaneous view of the full sky, several simultaneous users.
- Pathfinder for the SKA in many respects

LOFAR: Top Level Architecture

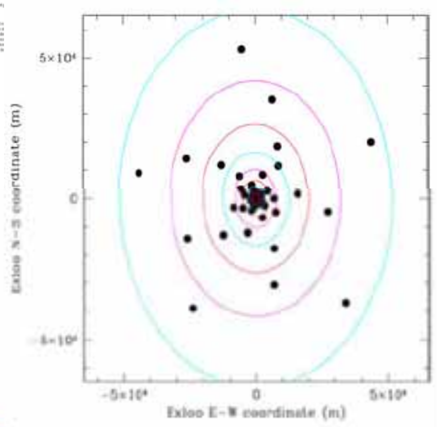


Geometry view

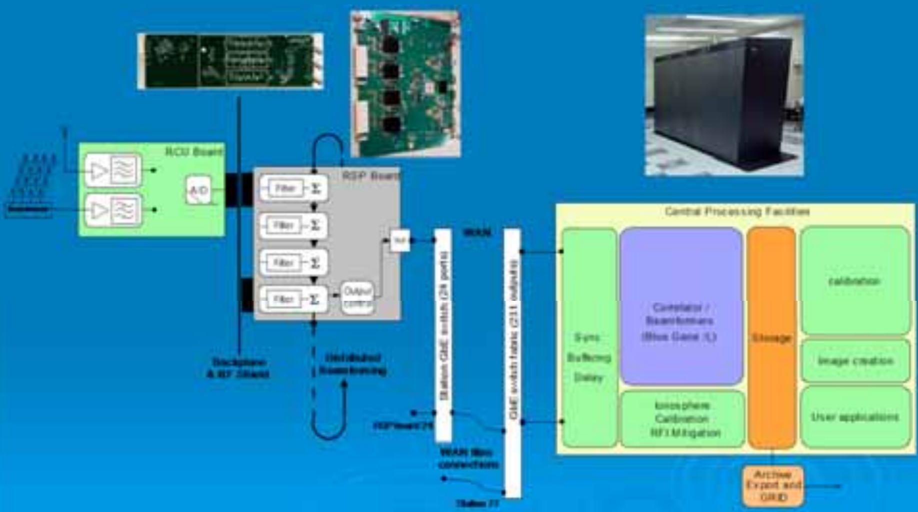
- 77 stations in the Netherlands
  - 32 in Compact Core
  - 45 Remote Stations
  - Logaritmic distribution
- Networks
  - 5 “arms” – maximum baselines: 100 km
  - Exloo – Groningen connection (max 800 Gbps)
  - GRID
    - SOCs on Surfnet6
    - Géant etc.
- Additional European stations on Géant network

Configuration

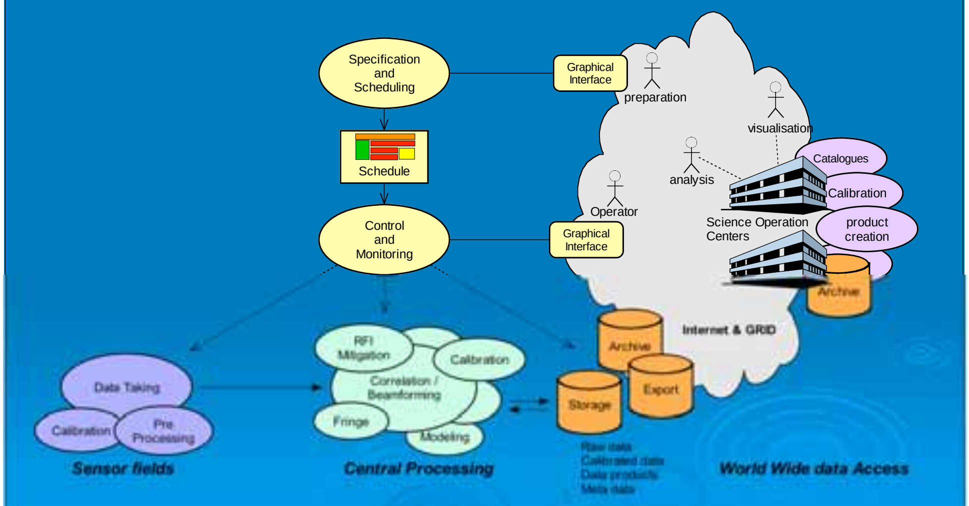
32 Core Stations
3x2 km



Dataflow View



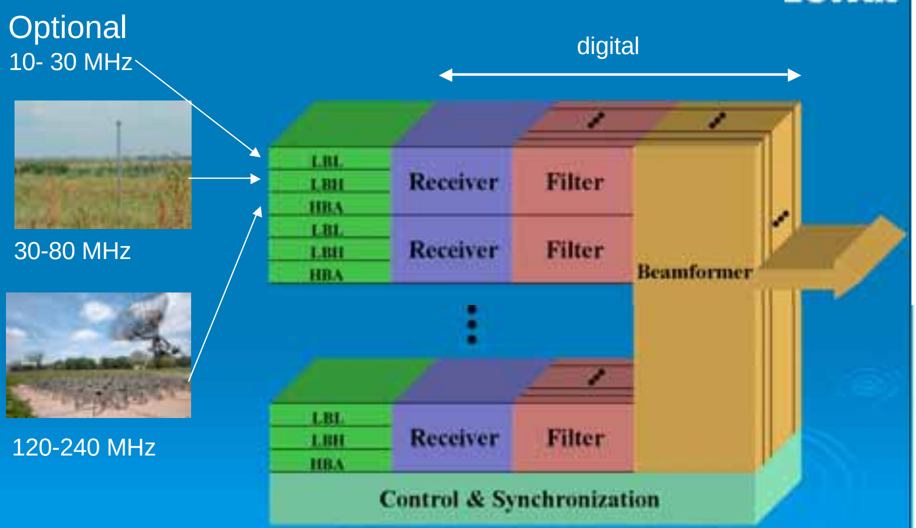
Operations View



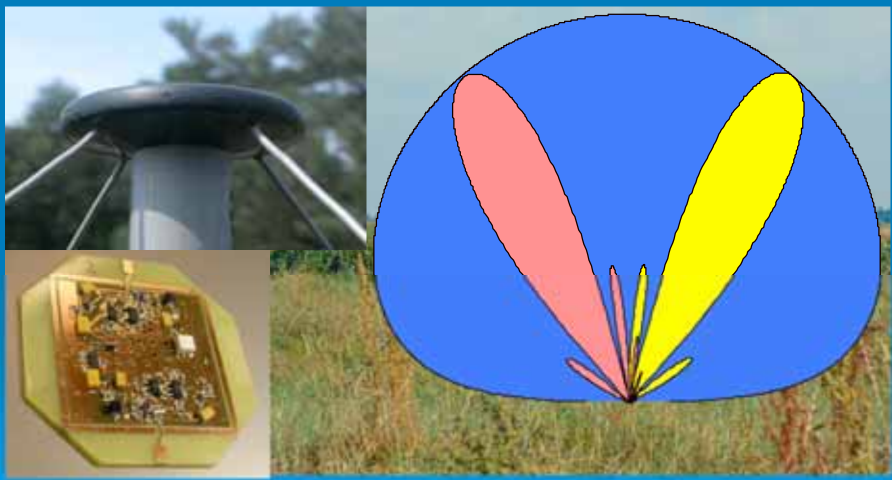
LOFAR System Overview

Stations

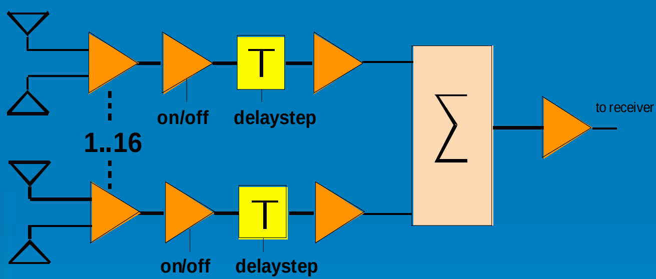
Remote Station Architecture



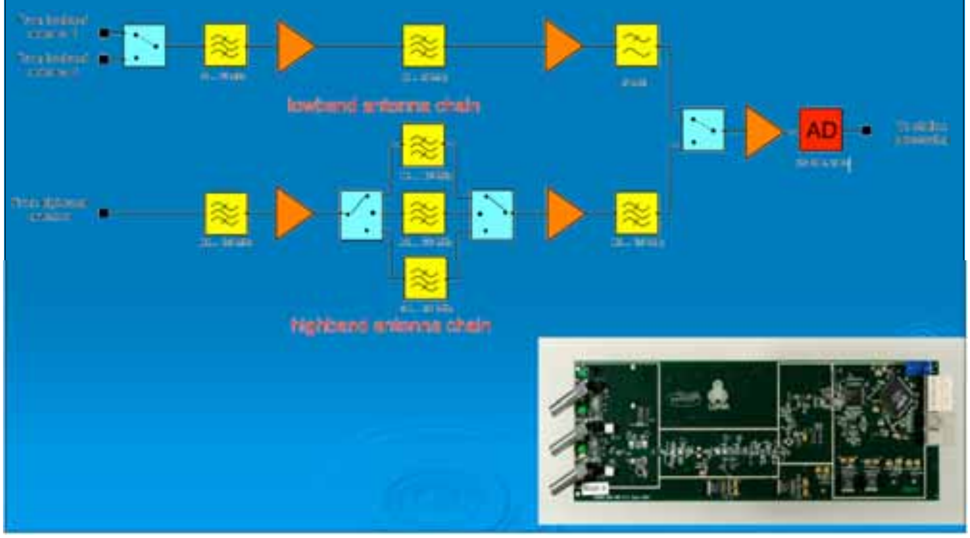
Low Band Antenna (30-80 MHz)



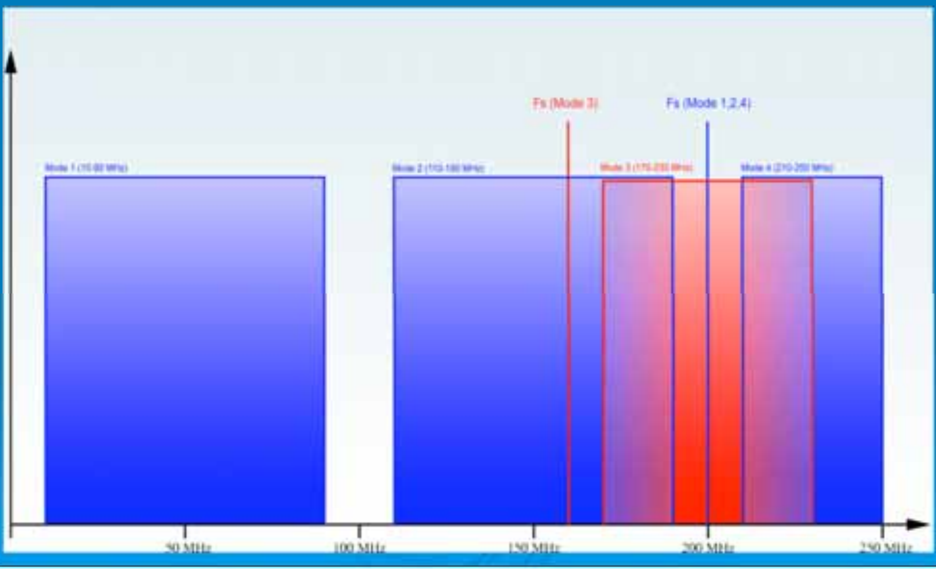
High Band Antenna (120-240 MHz)

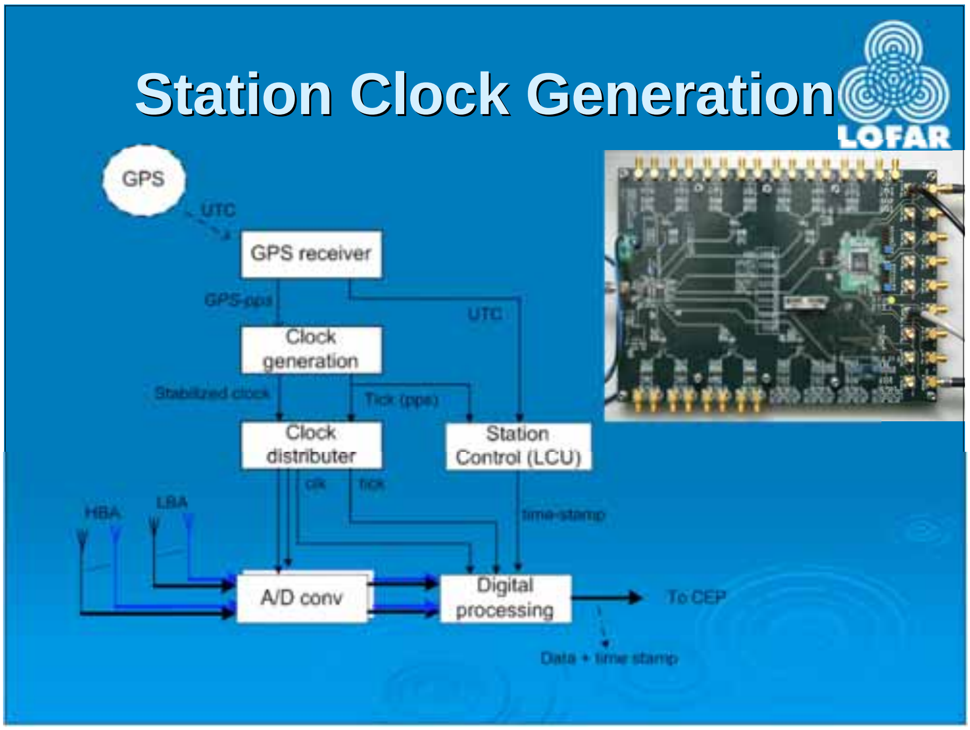


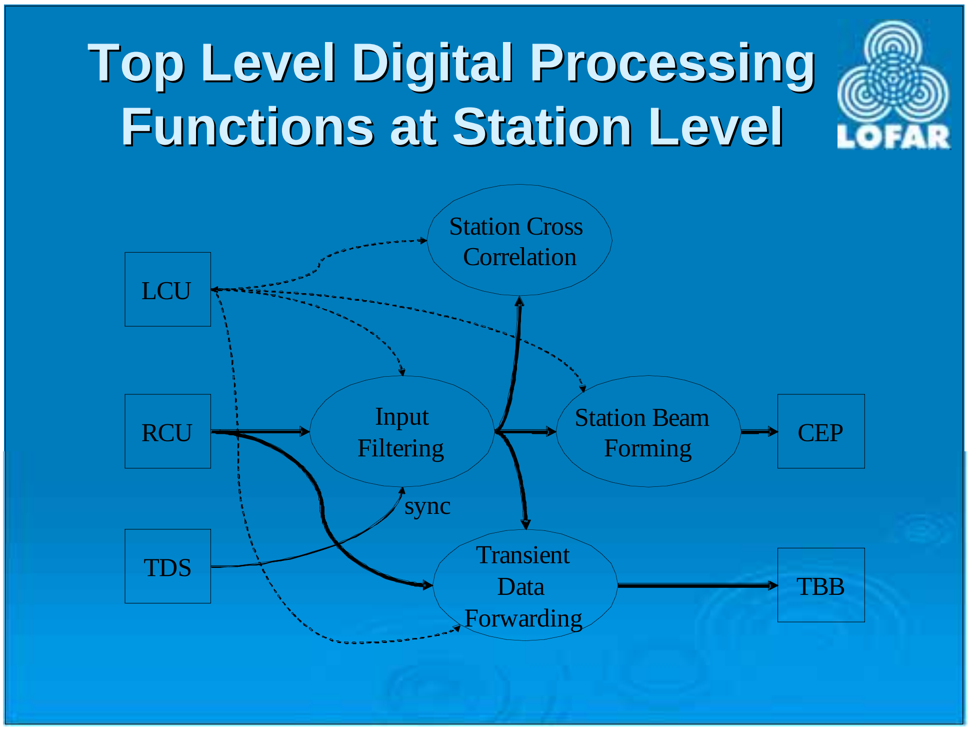
Receiver



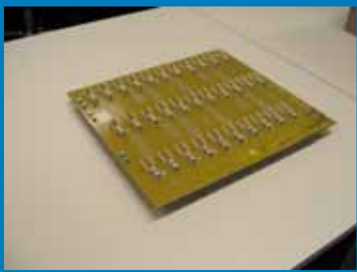
Receiver Bands




Station Clock Generation
LOFAR
GPS
UTC
GPS receiver
GPS-pps
UTC
Clock generation
Stabilized clock
Tick (pps)
Clock distributer
Station Control (LCU)
clk
tick
time-stamp
HBA
LBA
A/D conv
Digital processing
To CEP
Data + time stamp


Top Level Digital Processing Functions at Station Level
LOFAR
Station Cross Correlation
LCU
RCU
Input Filtering
Station Beam Forming
CEP
sync
TDS
Transient Data Forwarding
TBB

Remote Station Processing Board



- 90 nm technology
- 192, 18x18 multipliers
- 2.6 Mbit RAM
- 1020 "balls" on chip

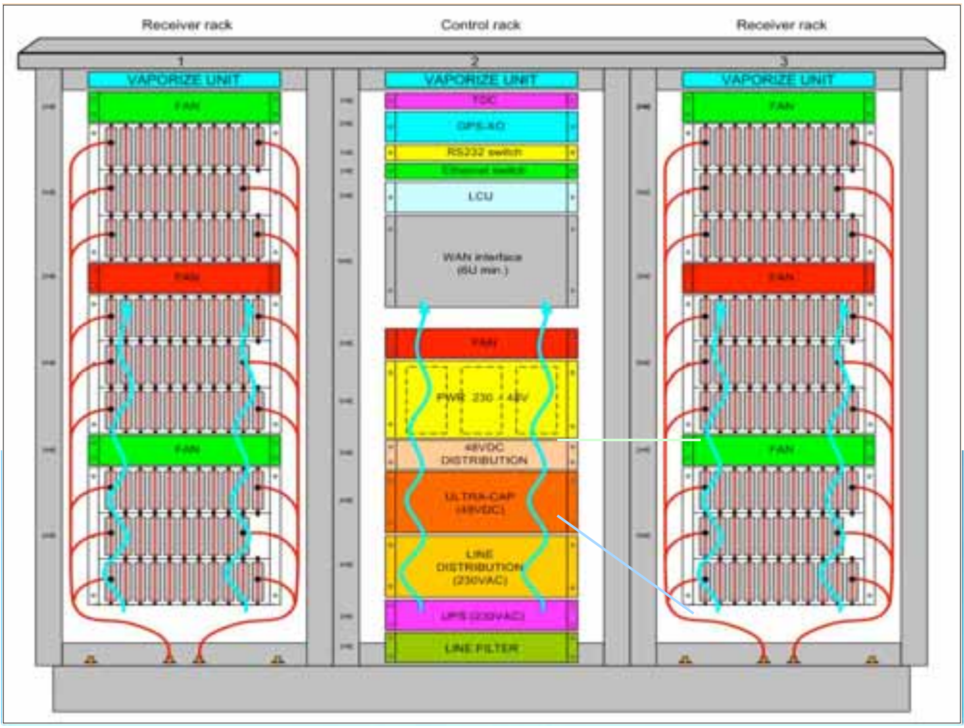
Remote Station Hardware Numbers

- 96 dual polarization low band antennas
- 96 dual polarization high band tiles
- 192 receiver boards
- 24 digital signal processing boards
- 12 transient buffer boards
- 6 backplanes
- 6 clock boards

Key Numbers

Description	Value	Unity
# subbands	512	
Max. number of beams (B = 4 MHz)	8	
Min. number of beams (B = 32 MHz)	1	
A/D converter resolution	12	bit
Sample frequency	200 / 160	MHz
Number of polarizations	2	
Output word width (complex)	16+16	bit
Aggregate output bandwidth	32	MHz
Output data rate	2048	Mbit/s
Transient buffer storage period	1	s

Description	Value for fs of		Unity
	160 MHz	200 MHz	
Subband width	156	195	kHz
Number of beamlets	206	165	

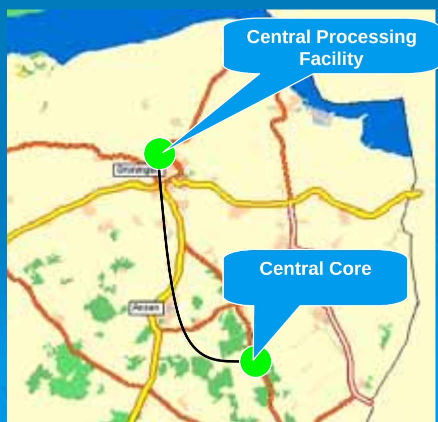


Pre-Production/Prototypes

Network & Central Processor

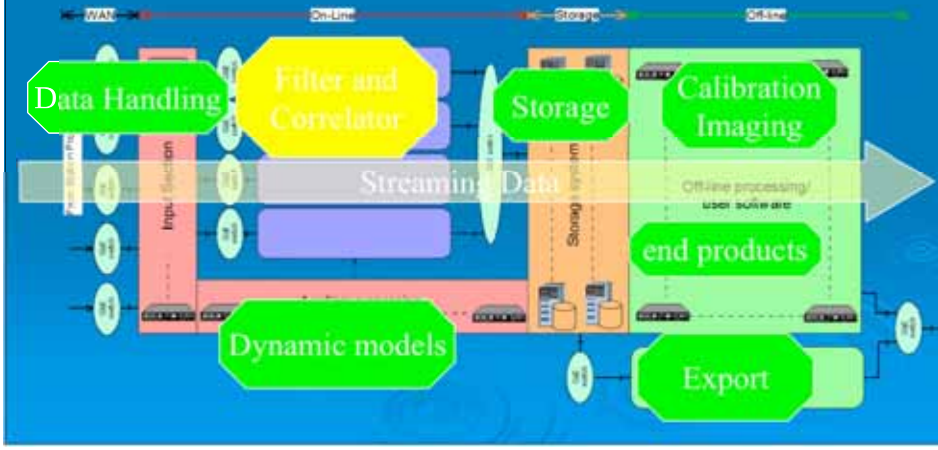
Wide Area Network

- Data transport from stations and central core to central processor facility
- Dedicated fiber connection between core and central processor
  - up to 800 Gbps bandwidth
  - 10 GbE CWDM
  - 8 channels
  - length ~70 km
- Remote station connections:
  - 10 GbE technology
  - data rate 2 Gbps from antennas + monitoring + other sensors



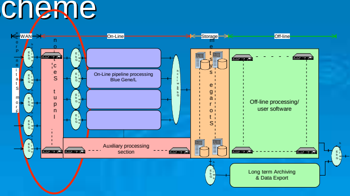
CEP Implementation Model

- Multiple sub-clusters with task-optimised hardware
- BlueGene inside



Input Section

- Receive data streams from remote stations
- Connections to WAN: raw 1 GbEthernet
- Input buffering and Synchronisation
- Embedded frequency separation filter
- Routing / Transpose
  - 320 Gbps All-to-All connection scheme
  - e.g. on Infiniband

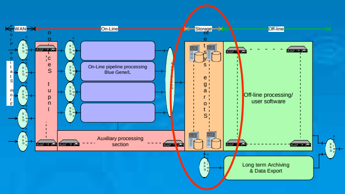


Auxiliary processing

- Control / tune processing pipelines
  - Fringe stopping
- Typical analysis applications
  - RFI detection & mitigation
  - Ionosphere calibration
- On-line modeling & analysis
  - e.g. Transient detection
- Resource pool, is scalable

Storage system

- Collect data streams into data sets
- Temporary storage of datasets (typically 2 days)
- Data input from
  - processing lines
  - off-line processing applications
- Data output to
  - off-line processing tasks
  - Data export & archiving

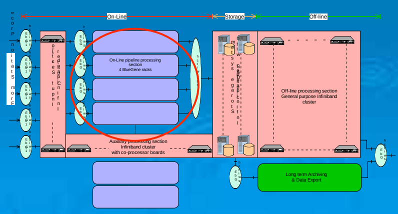


Off-line processing

- General purpose resources
- Typical tasks:
  - calibration
  - Imaging
  - interpretation
  - product generation
- Optimised resources for Selfcal and Imaging possible

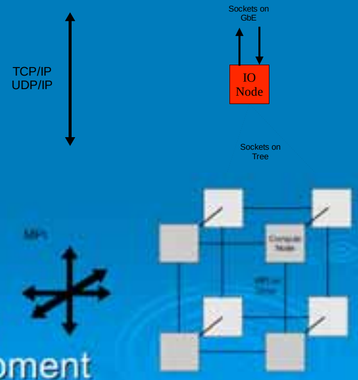
On-line pipeline processing

- Issues:
  - power/heat, volume, memory etc.
  - limited programming environment
- **Massive** processing power for
  - 8 bits complex multiplication and addition
- Simple applications scheme
  - pipes-and-filters style
  - operate in slave mode
- Simple data transformations
  - correlator
  - beamformer



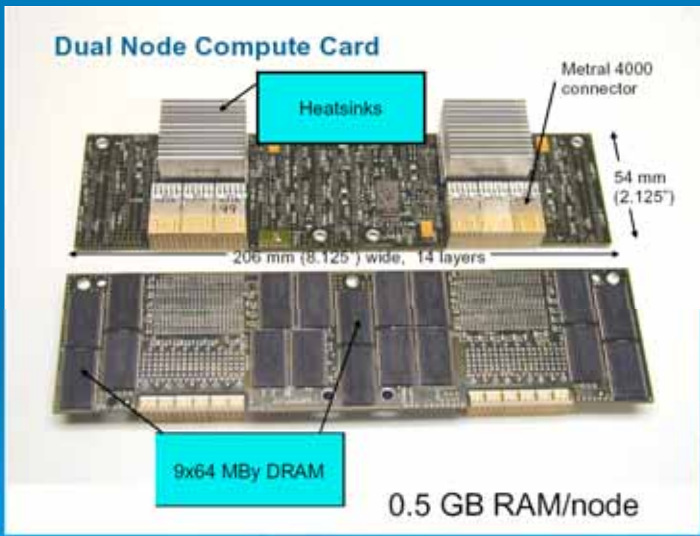
Subsystems: Blue Gene/L

- 6 racks
  - 128 IO nodes and 1024 compute nodes per rack
  - Internal Tree and Torus (175 MB/s * 6 directions)
  - Compute node
    - Dual core
    - 512 MB RAM
  - IO node
    - 1 GbE connection
    - Connected to 8 compute nodes
  - Diskless
- 1 Service Node (p650 + DB2)
- 8 Front-End nodes for development

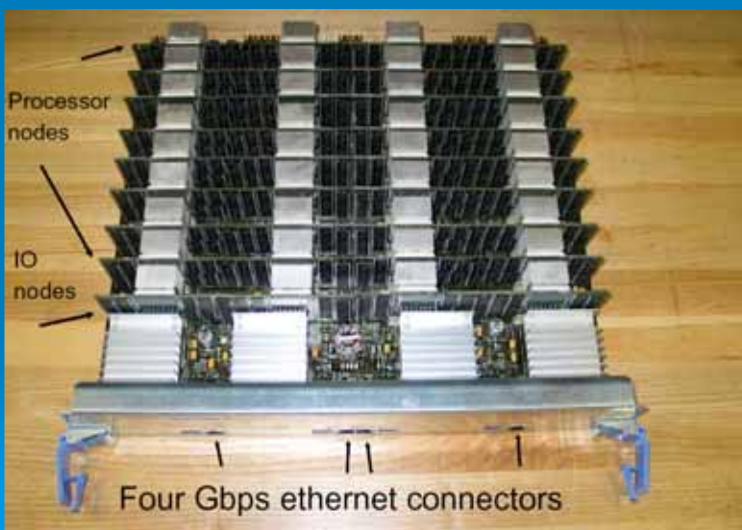


Blue Gene/L installation April 2005

Compute Card



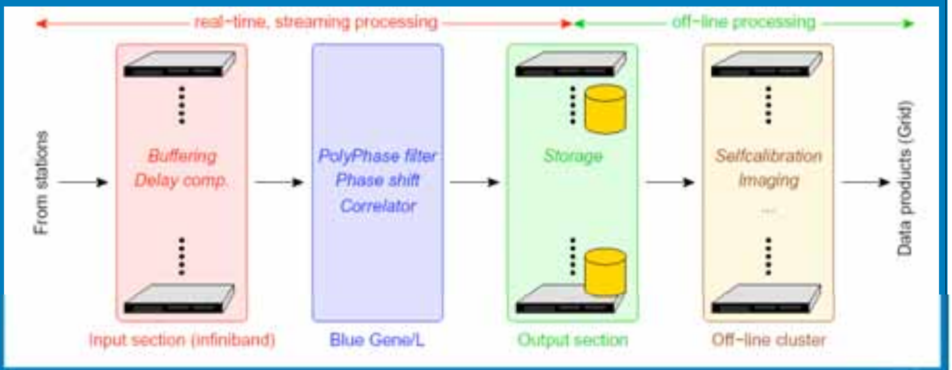
Node Board



BlueGene (half) Rack

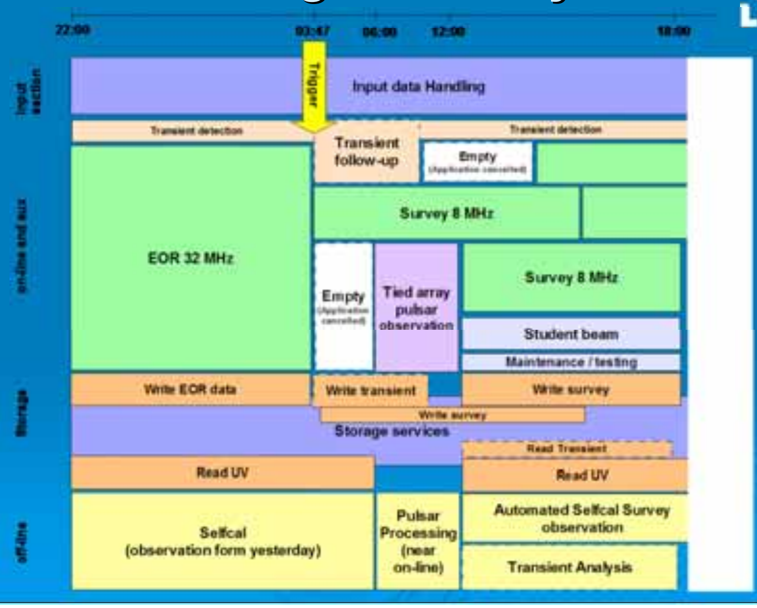
Software & Operations

Simplified processing steps

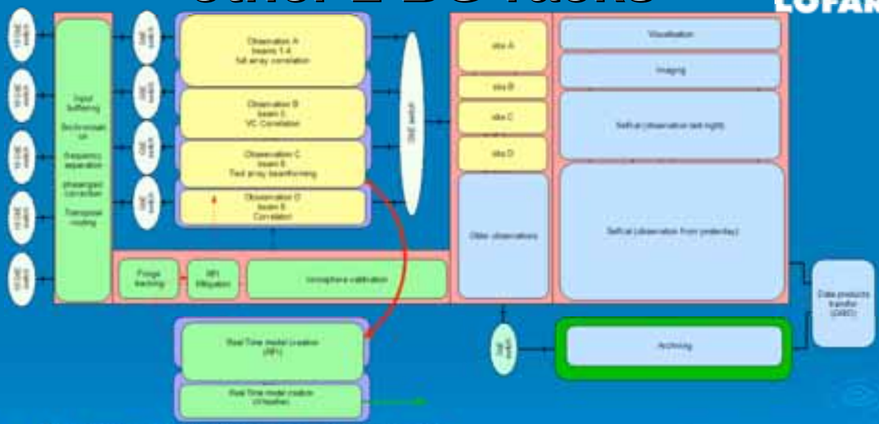


- Processing split in on-line and off-line
- Only main processing steps are shown

Scheduling on subsystems



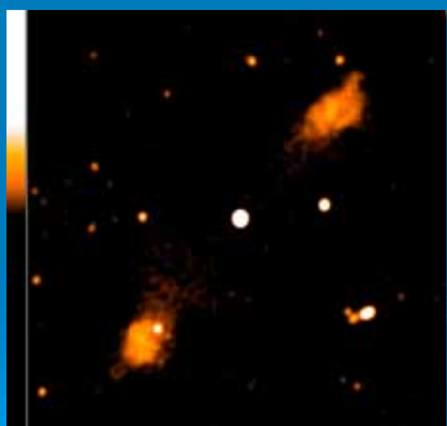
Model calculations on the other 2 BG racks



- Multiple observations run concurrently
- Applications have different lifetimes
  - service providers (green)
  - observation specific (yellow)
- On-line and Off-line applications scheduled independently

The Calibration Challenge

- 25 TByte of data
  - 10^{13} samples
- Models of
  - Instrument
  - Ionosphere
  - Sky sources
- Vary in time, freq., …
- ~100 000 parameters
- Correctly model physics
  - Image plane effects
  - Instrument behaviour etc.
- Complex minimalisation problem!



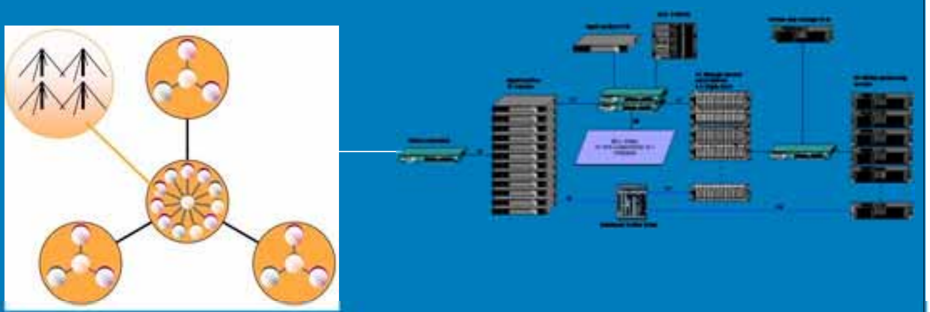
Major Observing Modes

LOFAR

- Synthesis Mode - imaging - data cubes
  - like Westerbork, VLA, GMRT
  - long baseline mode
  - core-only mode (EOR, All-sky monitor)
- Tied Array Mode - pulsars - time series
- Transient Modes
  - Raw time series - antenna data stream
  - Beamformed data - selected sub-bands

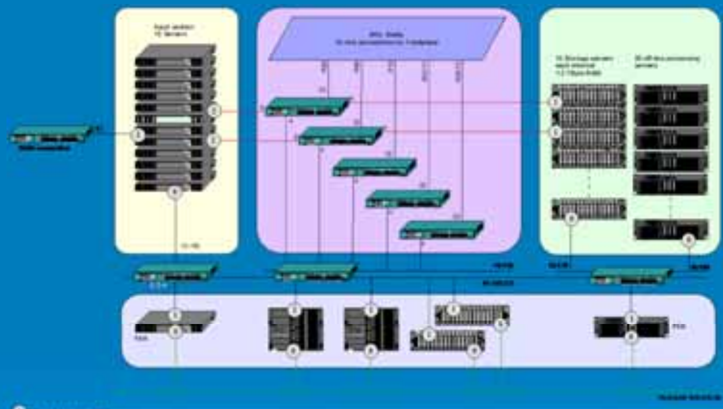
The next deliverable: CS1

LOFAR



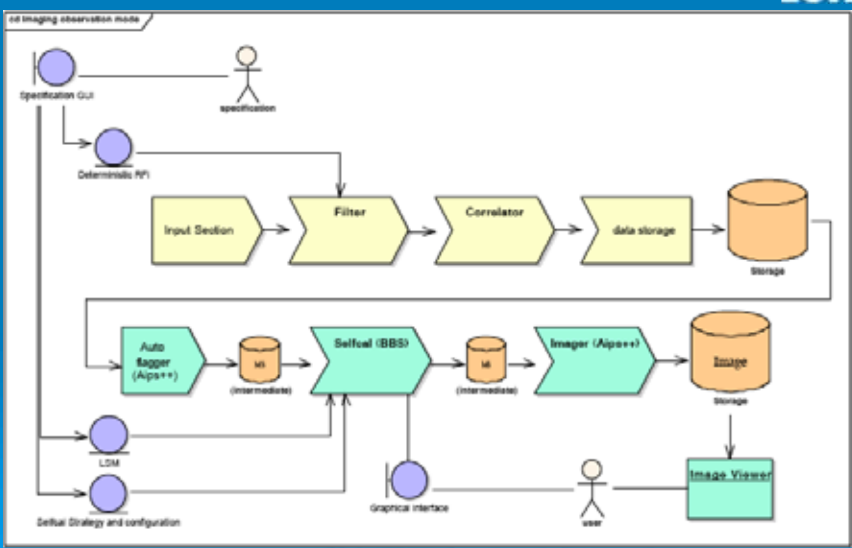
- Hardware of 1 station
- Distributed over 4 station locations
- 12 Gbps connection to Groningen
- Downscaled CEP installation

CS1 central processor



- 12 dual processor input nodes
- 1 BGL rack
- 15 TB storage cluster
- 20 nodes cluster for calibration and imaging

CS-1 Imaging Pipeline



Initial CS-1 Experiments

1. Correlate and integrate data with 1kHz, 10 sec resolution of all microstations (LBA) and store UV data
2. Create non-calibrated images on 10 sec time scales and copy them to an archive
3. Switch on On-line calibration pipeline on CEP
4. Copy UV data to a GRID

Timeline

- CS1 hardware: June 2006
- CS1 comissioning June-July 2006
- CS1 operation from June onwards

- CS1 software second release September
  - Increased usage of Stella system (up to 4 racks)

- Rollout of Core stations from end 2006 onwards
  - Stella usage grows to 4 rack steady; 6 racks

Project Schedule

- April 2006: CS-1 Roll-Out Review
  - Station infrastructure, EMC, Power, Cooling
- October 2006: System Critical Design Review
- Q1 2007: Completion of First Core Stations
- Mid 2008: Core Beamformer Upgrade
- Q1 2008: Completion of First Remote Stations
- Q4 2008: Roll-Out Completed