# LOFAR Technical Status

*LOFAR Surveys Meeting*
*17 June 2009*

**Michael Wise**
*(on behalf of the entire LOFAR team)*

# LOFAR Technical Status

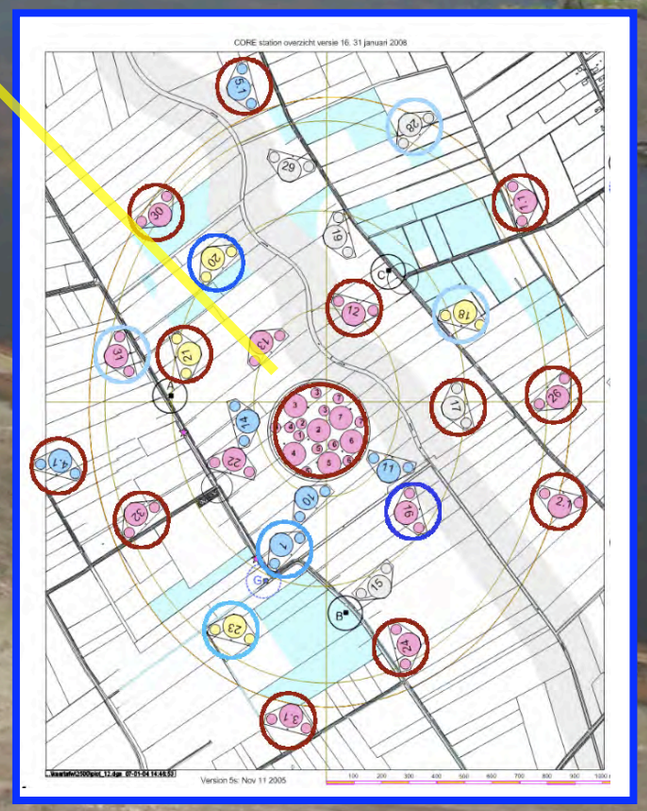
## Outline

- System Overview
- Recent Improvements
- Pipeline Development
- Timelines

# System Overview

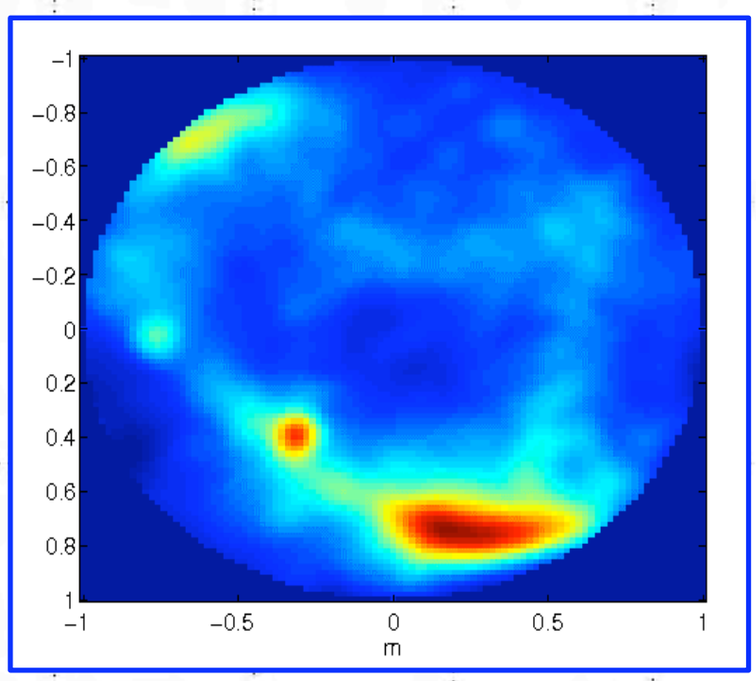
- Station Hardware
- Central Processing (CEP)
- Control System (MAC/SAS)

# LOFAR “Superterp”



# Station CS302

d:\LOFAR\dataCS302\\20090516_123406_sst_rcu094.dat time=2



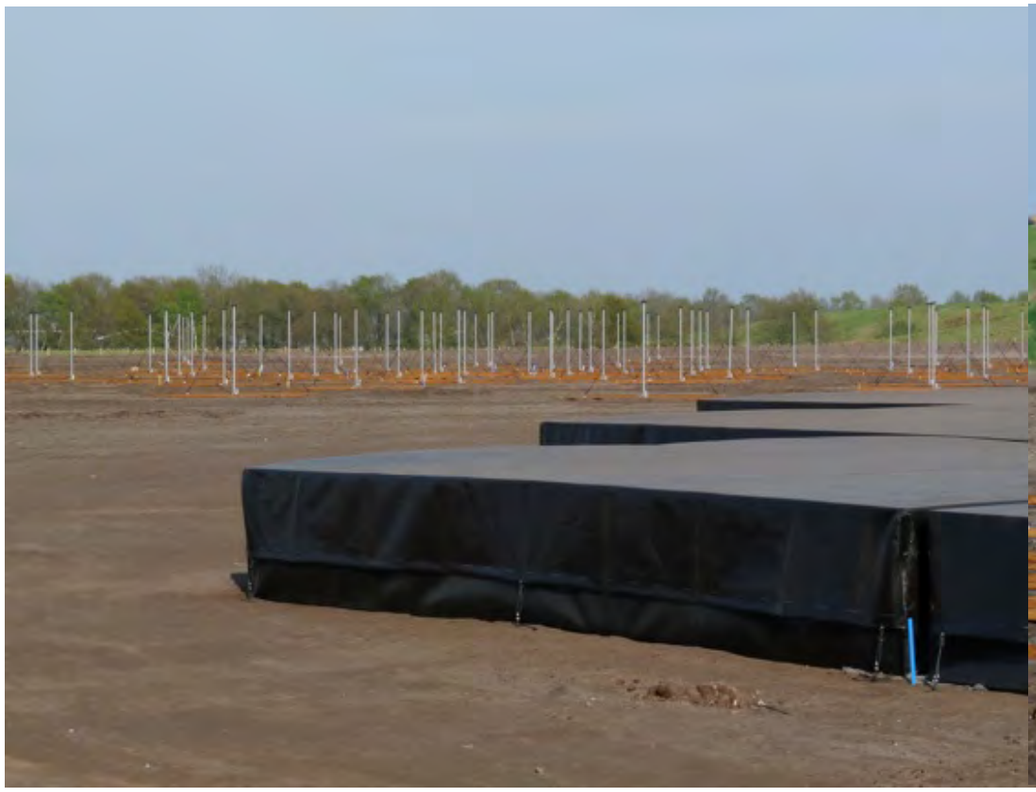

Power (dB)

-50
-60
-70
-80
-90
-100
-110

0
10
20
30
40
50
60
70
80
90
100

Frequency (MHz)

# Station and CEP Hardware

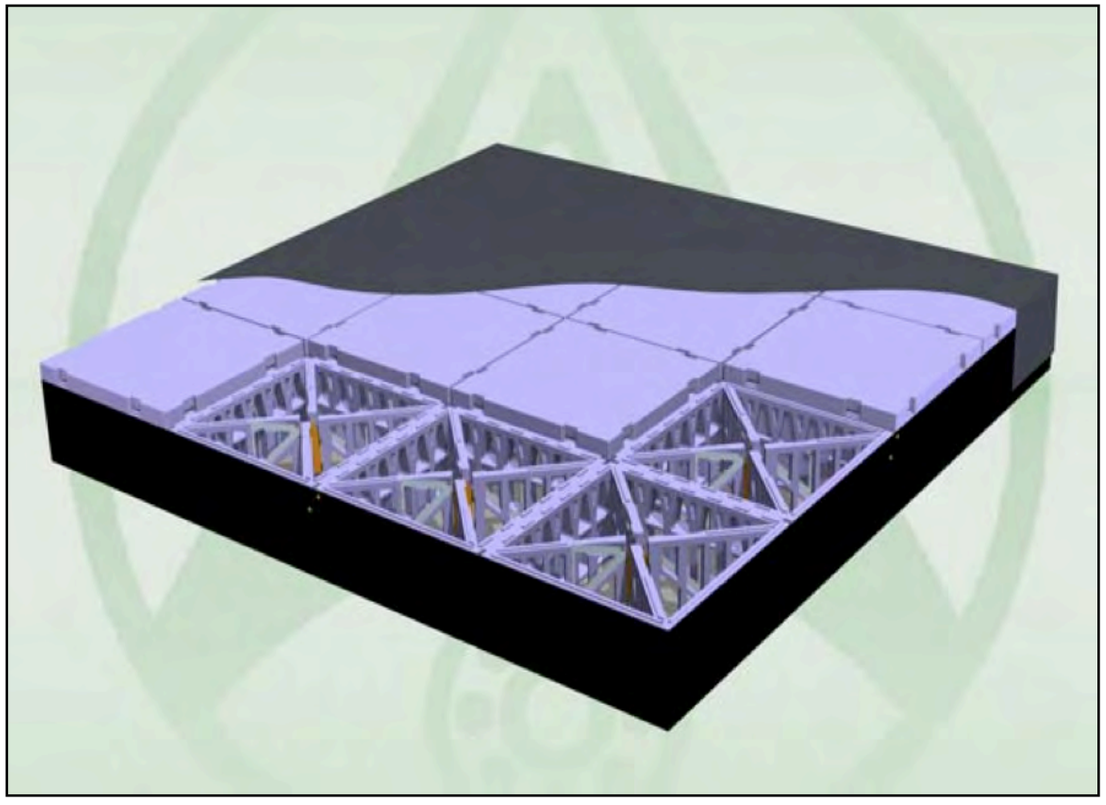


- Station 302 complete and almost done with verification
- Station 307 complete modulo some connectivity issues
- Station 503 LBA installed, HBA complete next week
- Two teams working in core (106, 208, 301, ...)
- First batch of offline cluster hardware has arrived
- Installation and testing underway

# LOFAR Antennas

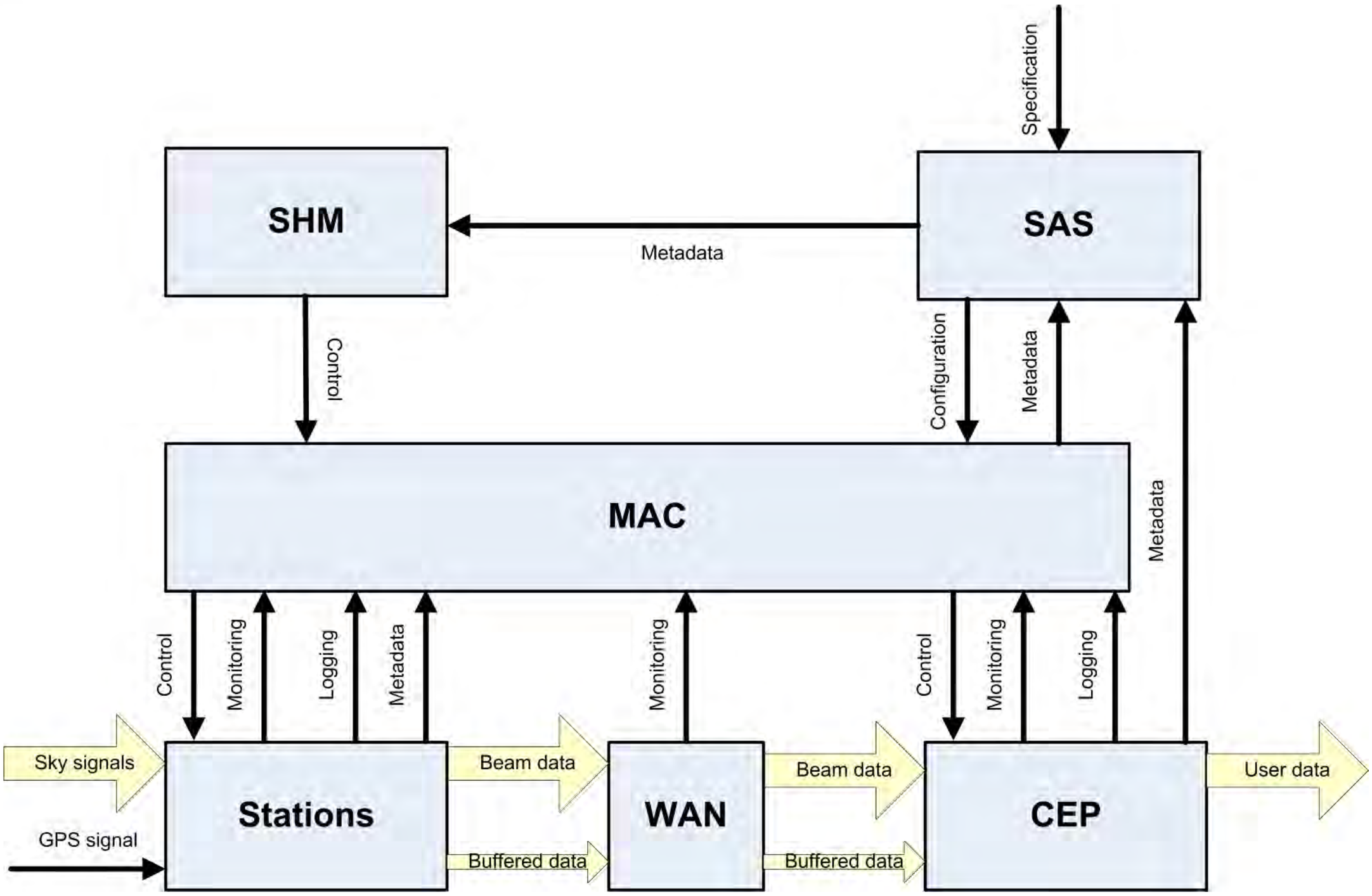
Low band antenna: 30 – 80 MHz
48/96 antennas per station

High band tiles:120 – 240 MHz
96 tiles/station, 4x4 antennas/tile

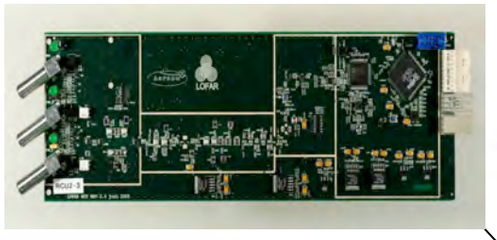


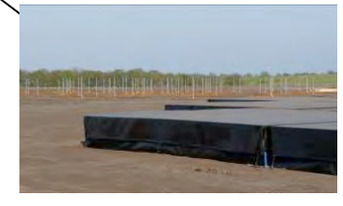
- 36 NL + 8 EU stations of dipoles
- Replace big dishes by many cheap dipoles
- No moving parts: electronic beam steering
- Flexible digital beam forming

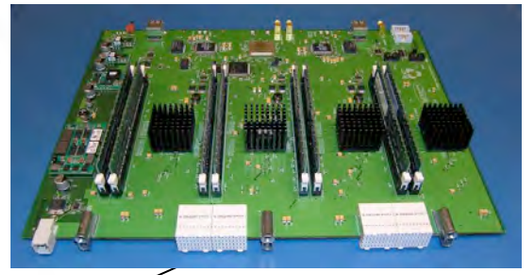
# Top Level Architecture



# Station Architecture







GPS

MAC

Control

Monitoring

Metadata

Logging

Sync

Sync

Time

Local Control

Sync

Clock

Clock

Control

Monitoring

Metadata

Sky Signal

LBL

Antenna Signal

Sky Signal

LBH

Antenna Signal

Sky Signal

HBA

Antenna Signal

Control

Receiver

Control

Antenna Data

Antenna Data

Digital Processing

Beam Data

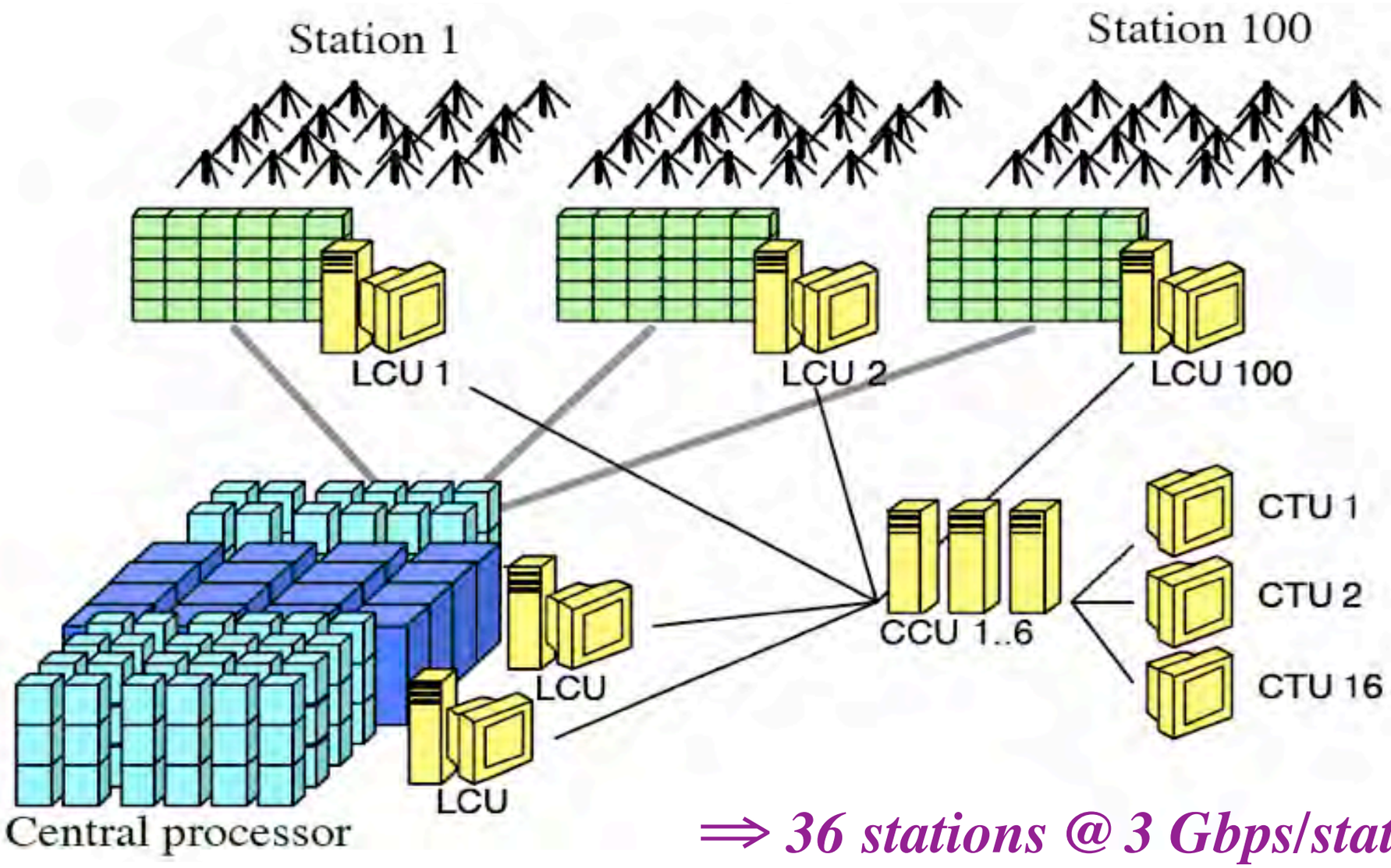
WAN

Buffer Data

WAN

# Data Flow

- Station level processing *Amplification, digitization, filtering, beam-forming, transient ram buffers (TBB)*
  - Central processing *Delay compensation, correlation, calibration, data reduction pipelines (BG/P, storage, offline cluster)*




⇒ ***36 stations @ 3 Gbps/station***

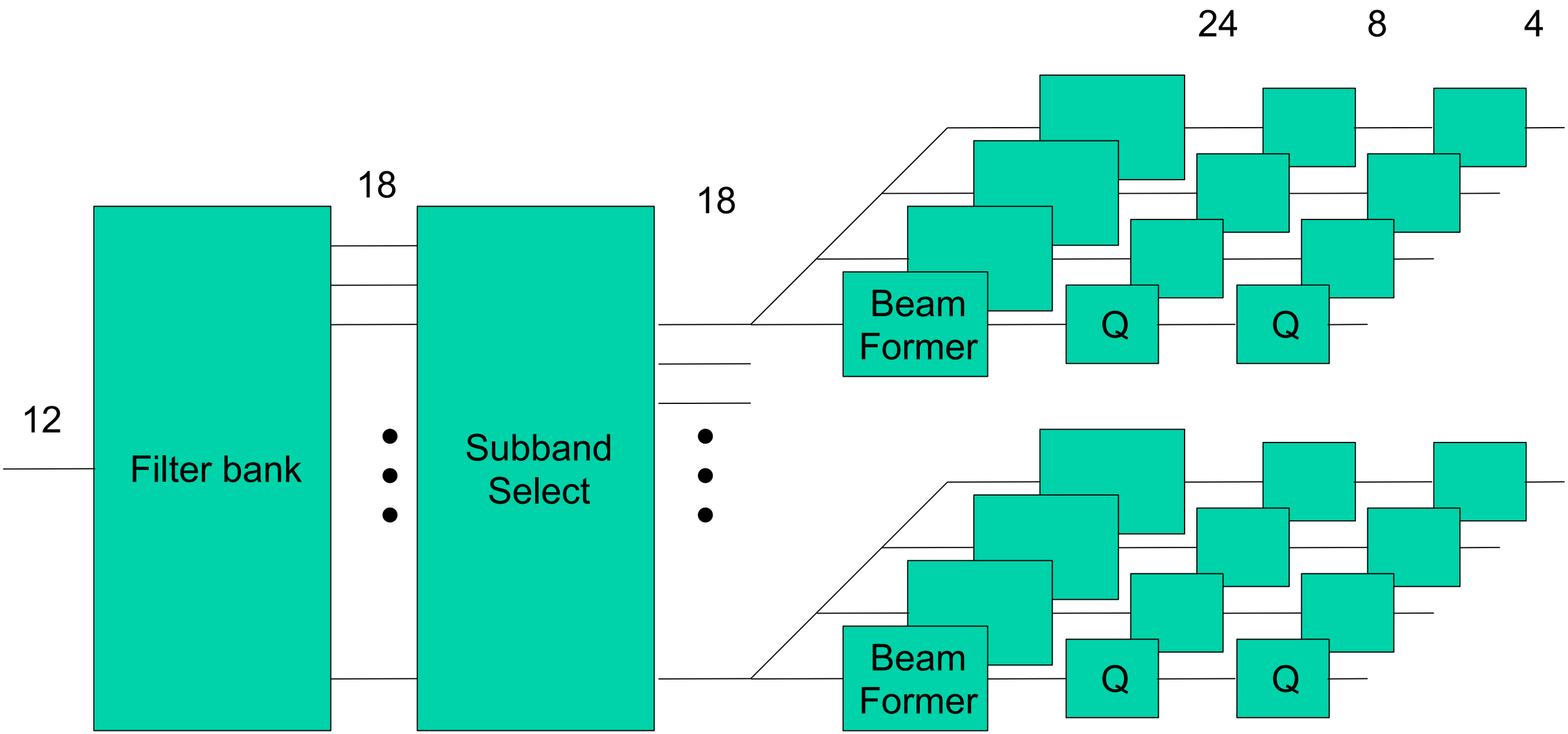
# Bandwidth Improvement

| Clock frequency | 160 | 200 | MHz |
|---|---|---|---|
| Sub-band width | 156.25 | 195.3 | kHz |
| # sub-bands / RSP | 62 | 62 | |
| Total # sub-bands | 248 | 248 | |
| **Bandwidth** | **38.75** | **48.44** | **MHz** |
| Data rate / RSP | 620 | 775 | Mb/s |
| Total data rate | 2.48 | 3.1 | Gb/s |

Expected availability: ~~June 2009~~

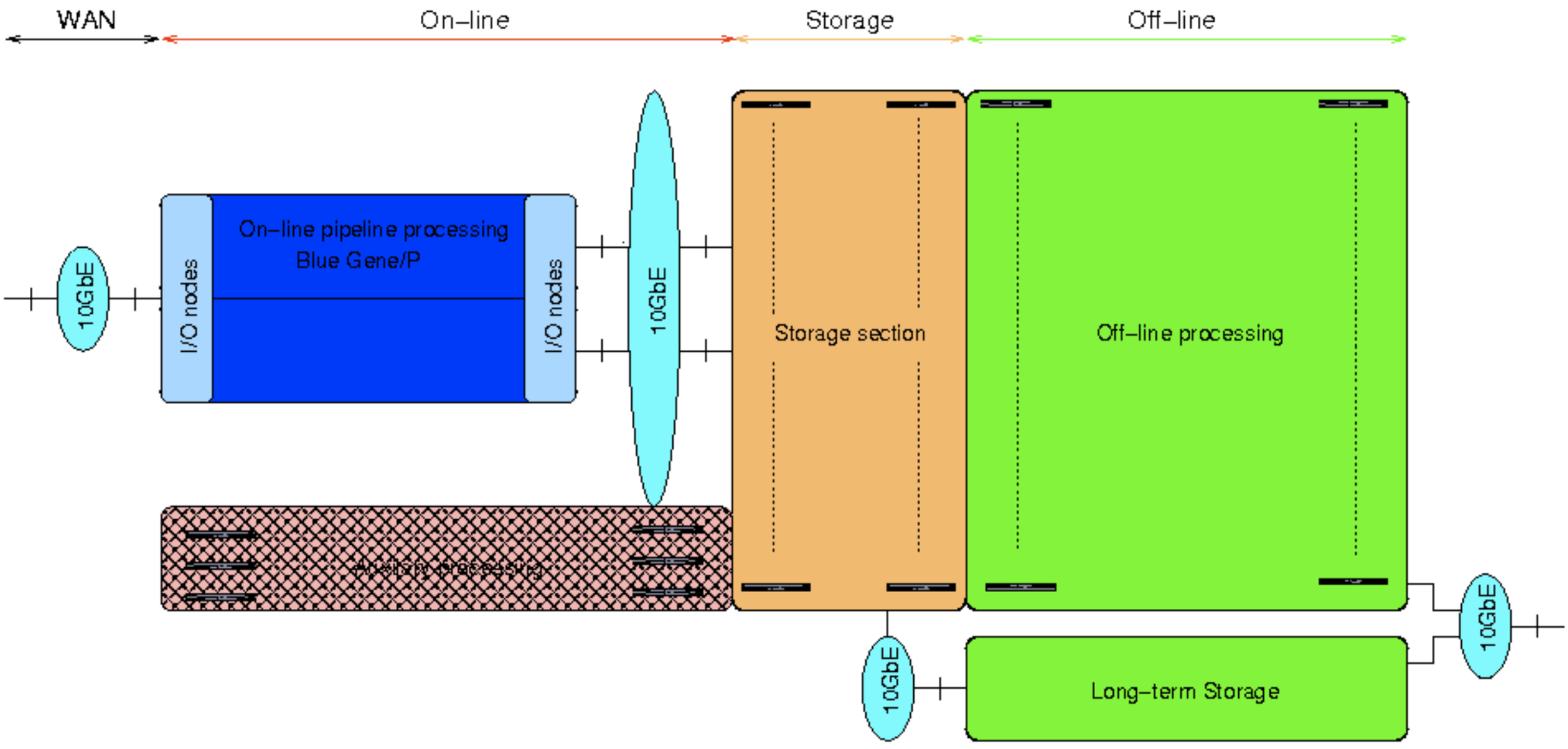
***Now!***

# 4-bit Mode



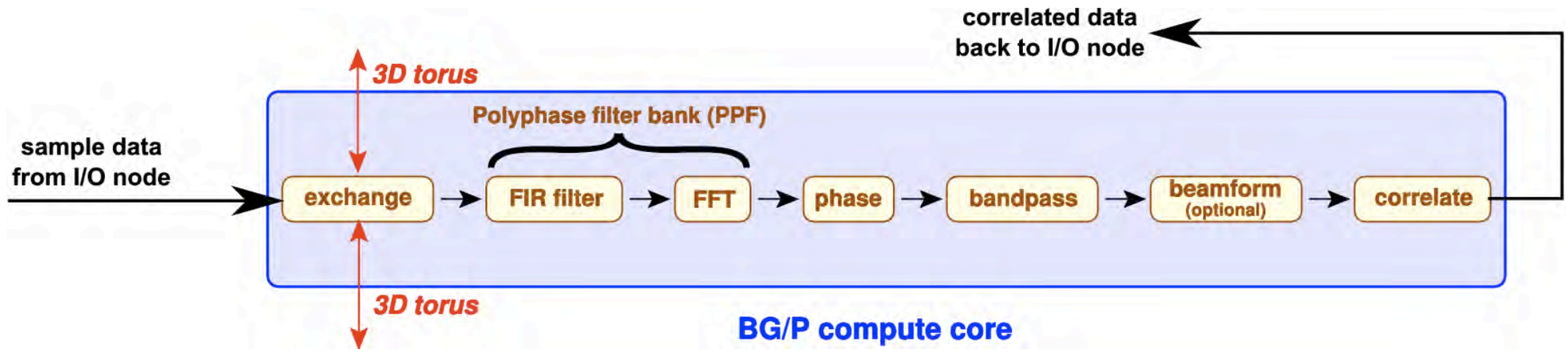

*Expected availability: late 2009/early 2010*

# Central Processing




- BG/P *Data reception, transpose, correlation, beam-forming, 41. 8 TFLOPS, 6TB memory*
  - Storage system *Short term storage of data, ~2 PByte, 50-100 Gbps I/O*
    - Offline cluster *Calibration, data products, off-line analysis, ~5 TFLOPS*

# Performance Tests




| observation mode | A | B | C |
|---|---|---|---|
| #stations | 64 | 64 | 48 |
| #subbands | 248 | 496 | 992 |
| #bits/sample | 16 | 8 | 4 |
| obs. bandwidth (MHz * #beams) | 48.4 | 96.9 | 194 |
| input bandwidth (Gb/s) | 64 * 3.1 | 64 * 3.1 | 48 * 3.1 |
| output bandwidth (Gb/s) | 62 * 0.58 | 62 * 1.2 | 62 * 1.3 |
| CPU load compute nodes | 35% | 70% | 85% |
| CPU load I/O nodes | 67% | 81% | 80% |
| data loss | ~ .0001% | ~ 0.01% | ~ 0.01% |

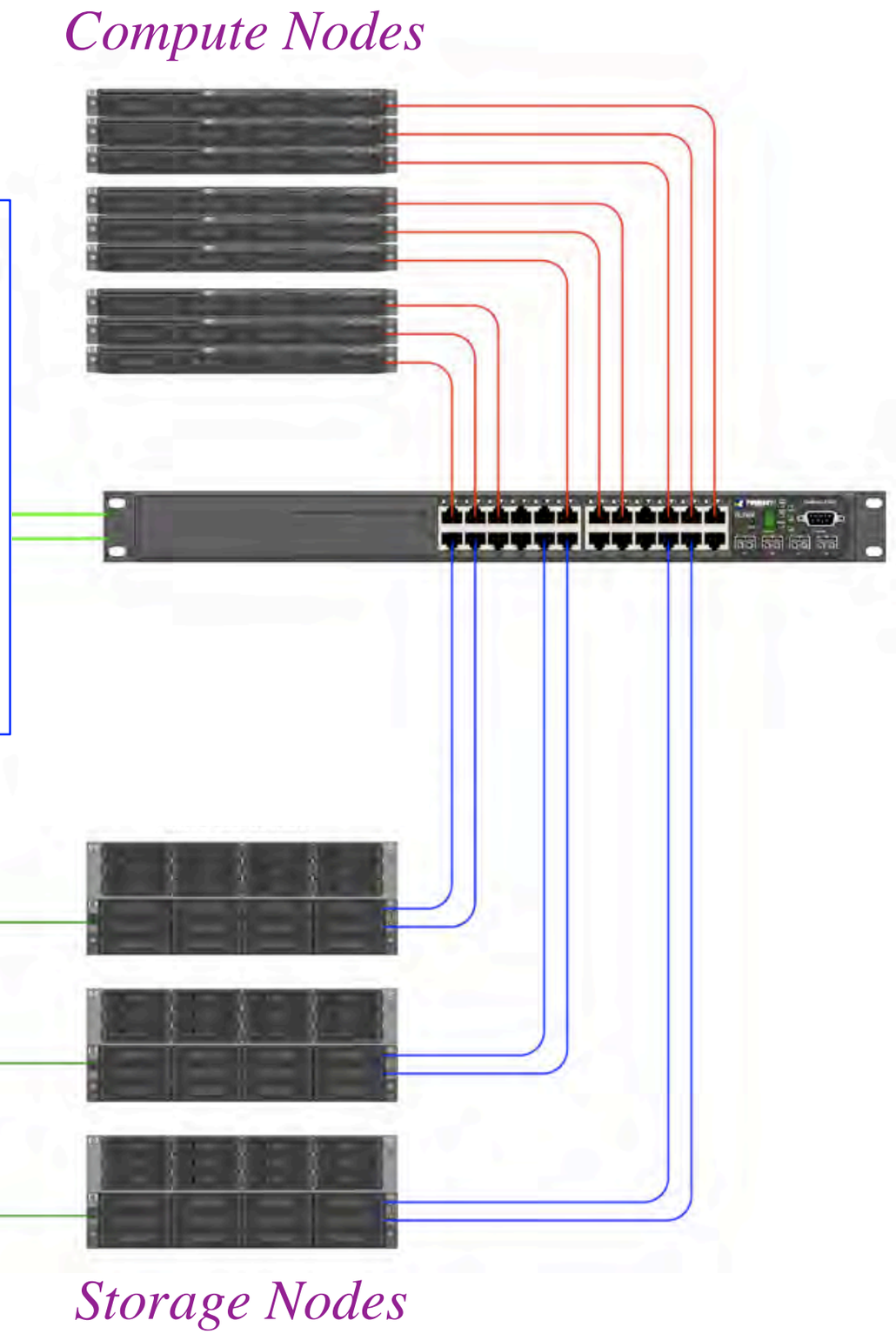
- 1 rack = Simulates data (64 stations @ 3.1 Gbits/s)
- 1 rack = Correlator
- 1/2 rack = Dumps visibilities

# Phase 1 Offline Cluster

***Currently being installed***

8 24 port switches with 2 10 GbE uplinks each
24 Storage nodes, each with ~24 TB disks
72 Computational nodes

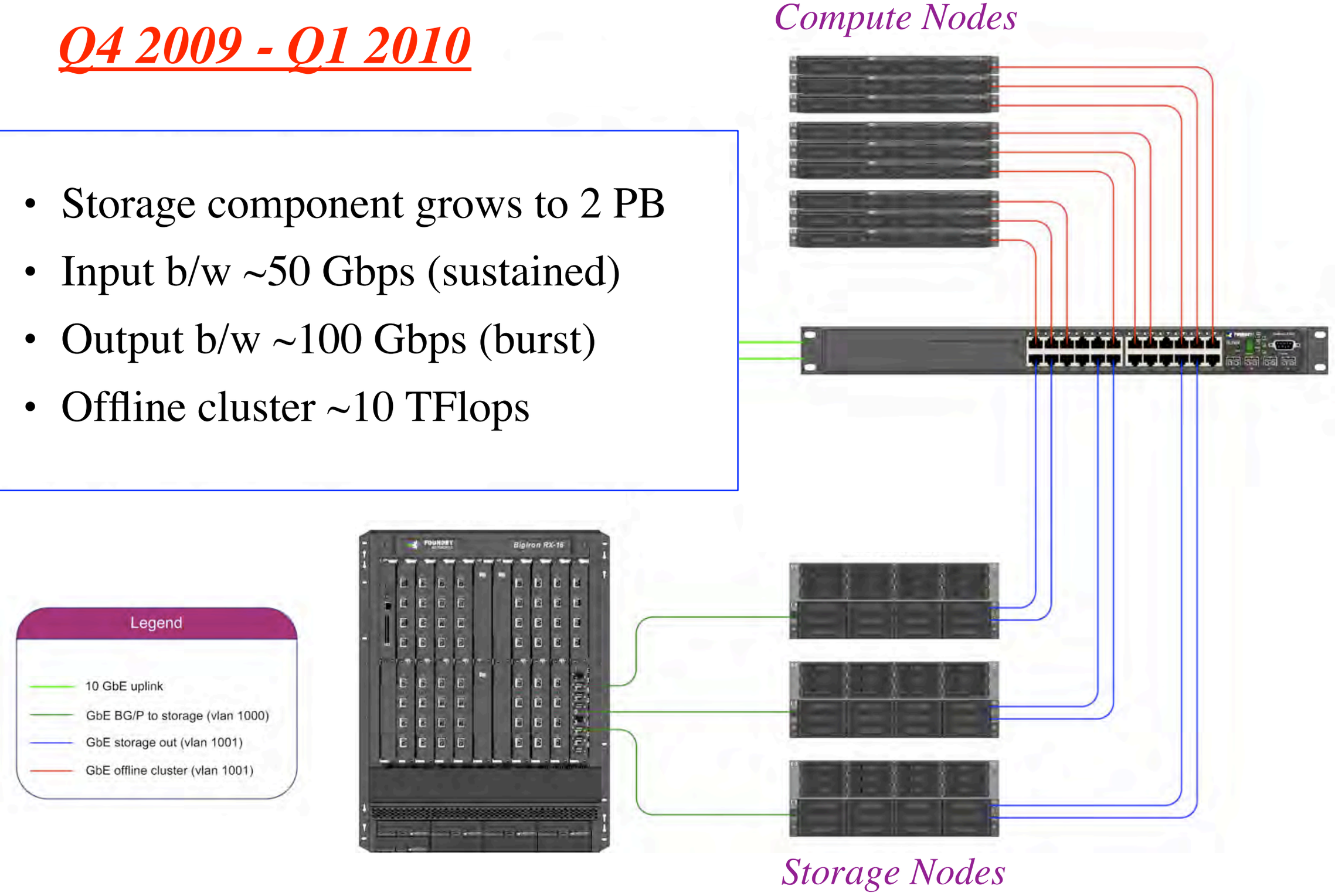
| | |
|---|---|
| Total storage capacity: | ~480 TB |
| Total input bandwidth: | ~24 Gbps |
| Total output bandwidth: | ~48 Gbps |



# Phase 2 Offline Cluster

***Q4 2009 - Q1 2010***

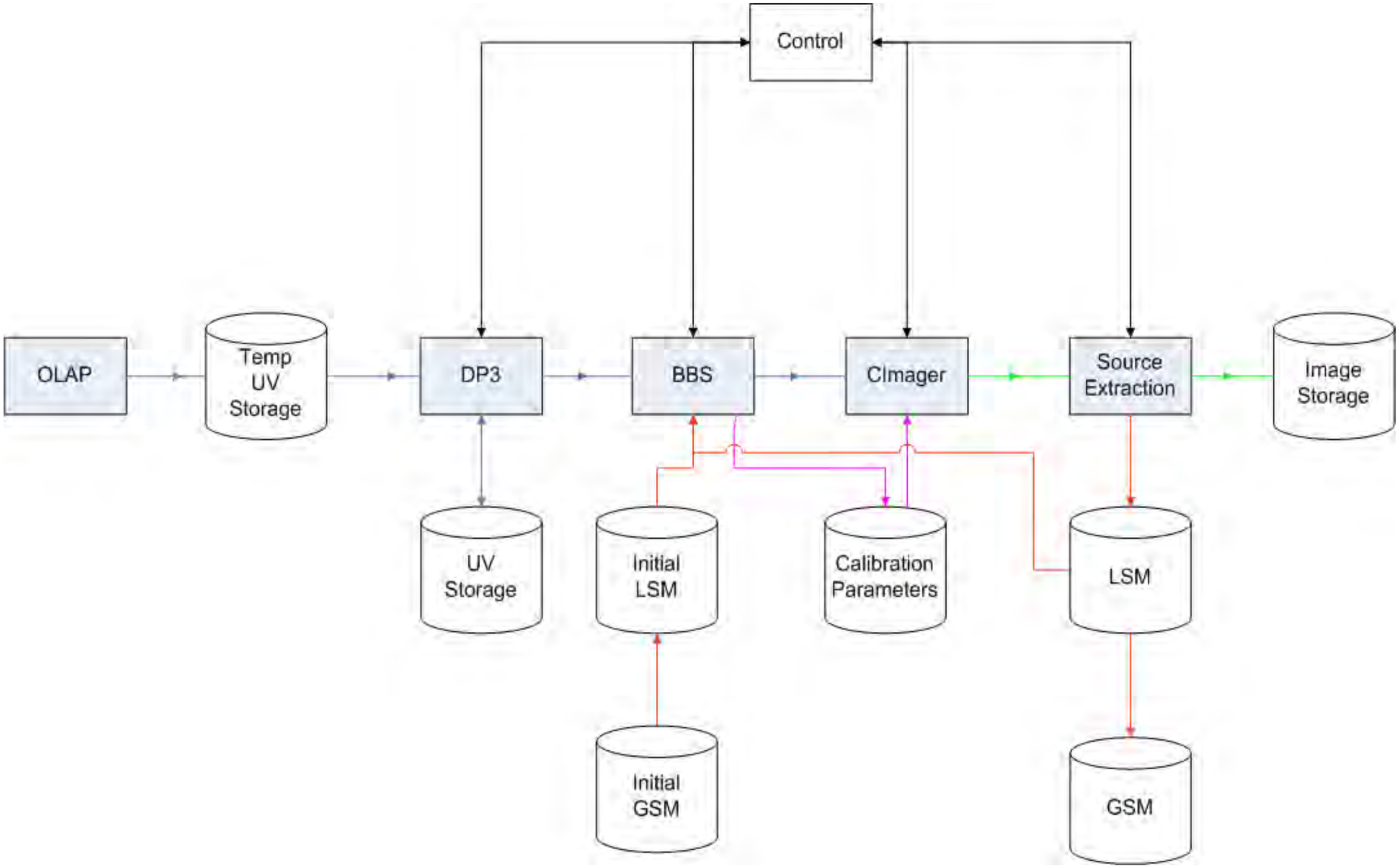
- Storage component grows to 2 PB
- Input b/w ~50 Gbps (sustained)
- Output b/w ~100 Gbps (burst)
- Offline cluster ~10 TFlops



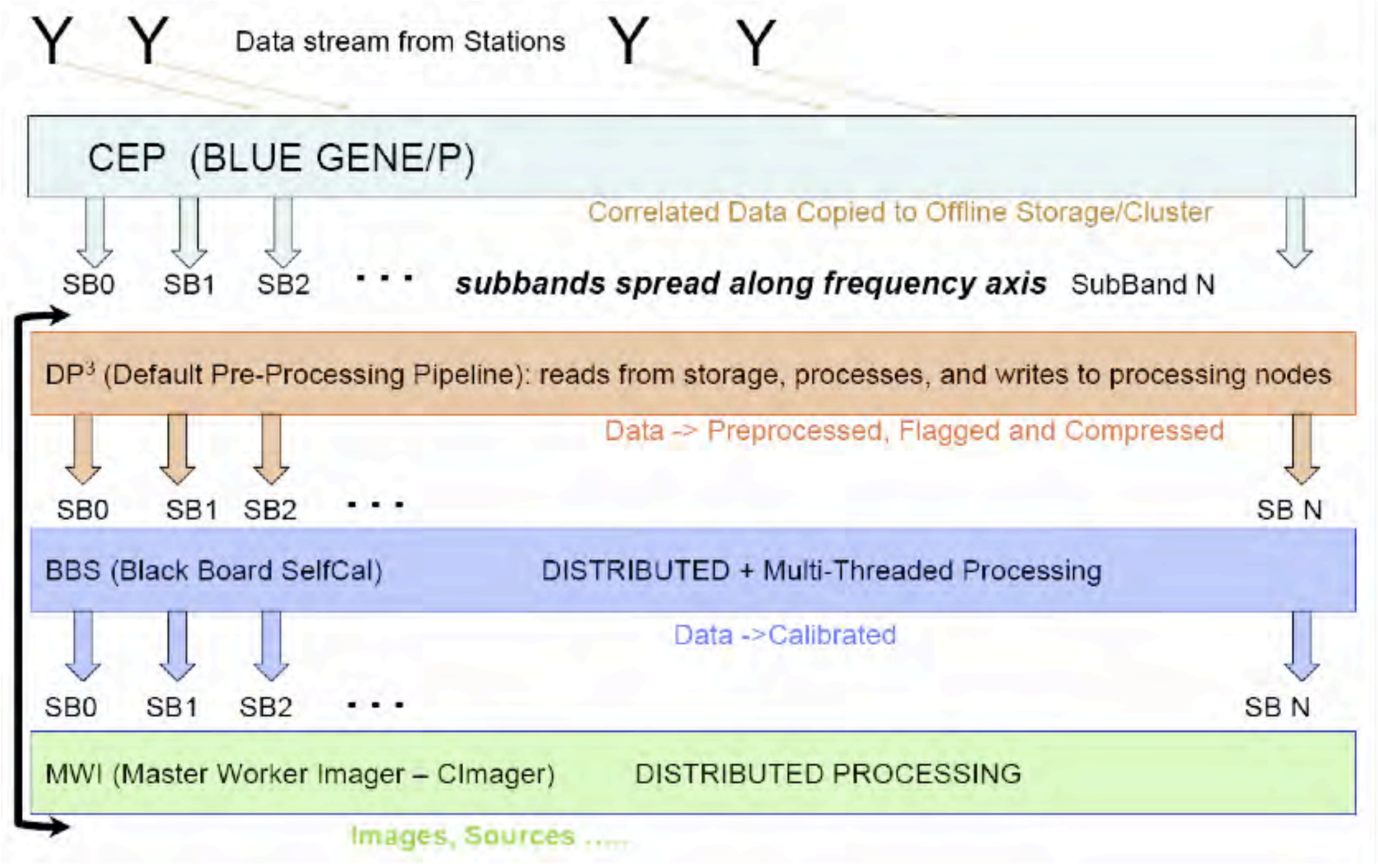
# Pipeline Development

- Standard Imaging Pipeline
- Pulsar Pipeline
- VHE Cosmic Ray Pipeline
- *RM Synthesis Imaging*
- *Solar Spectrometer Mode*

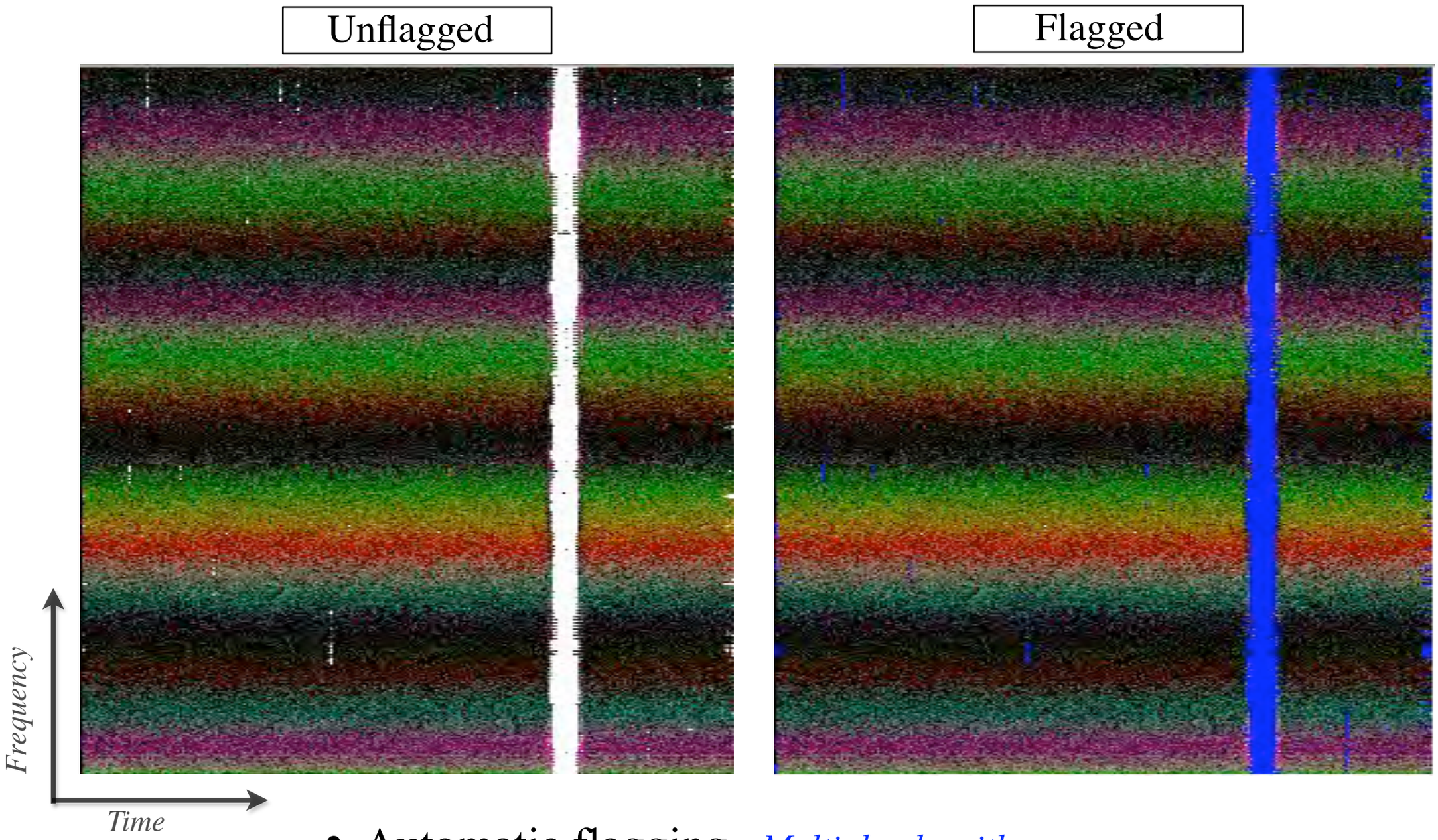
# Standard Imaging Pipeline



# Distributed Processing



# Default Pre-Processing Pipeline (DPPP)



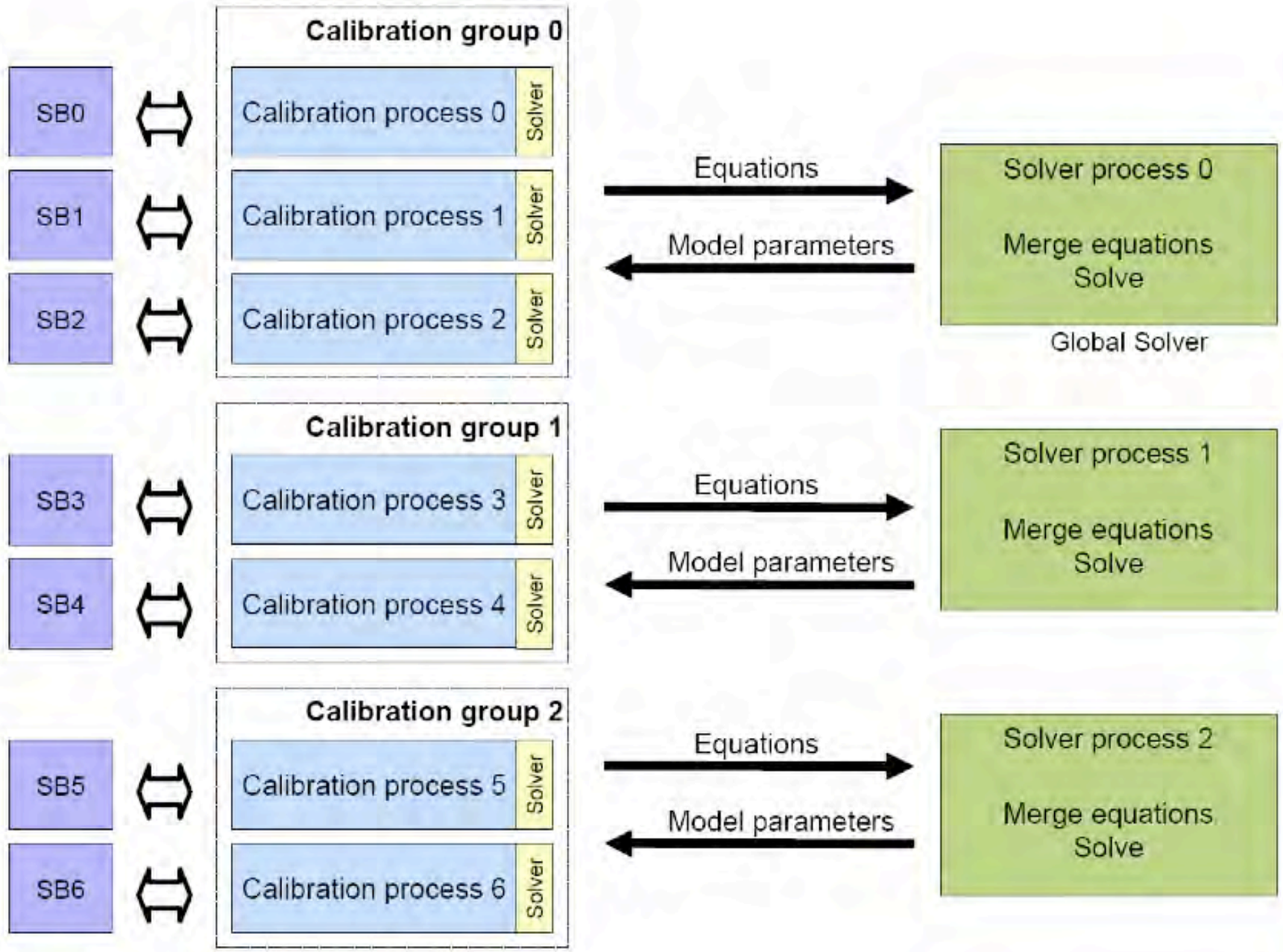

- Automatic flagging *Multiple algorithms*
- Data compression *Time and frequency averaging*
- Simple cal. corrections *Clock phases, A-team subtraction*

# DPPP Status

| Functionality | Status |
|---|---|
| • Flagging | |
| – *Frequency Flagger* | |
| – *Complex Median Flagger* | |
| – *Modified Complex Median Flagger* | |
| – *Binning Flagger* | |
| – *MAD Flagger* | |
| • Application of global bandpass correction | *To be implemented* |
| • Correction for clock drifts | *To be implemented* |
| • Solve for and subtract the A-Team | *To be implemented* |
| • Compression of data | Ready |
| – *Time* | |
| – *Frequency* | |
| • Combining of Subbands / MSs | Ready |

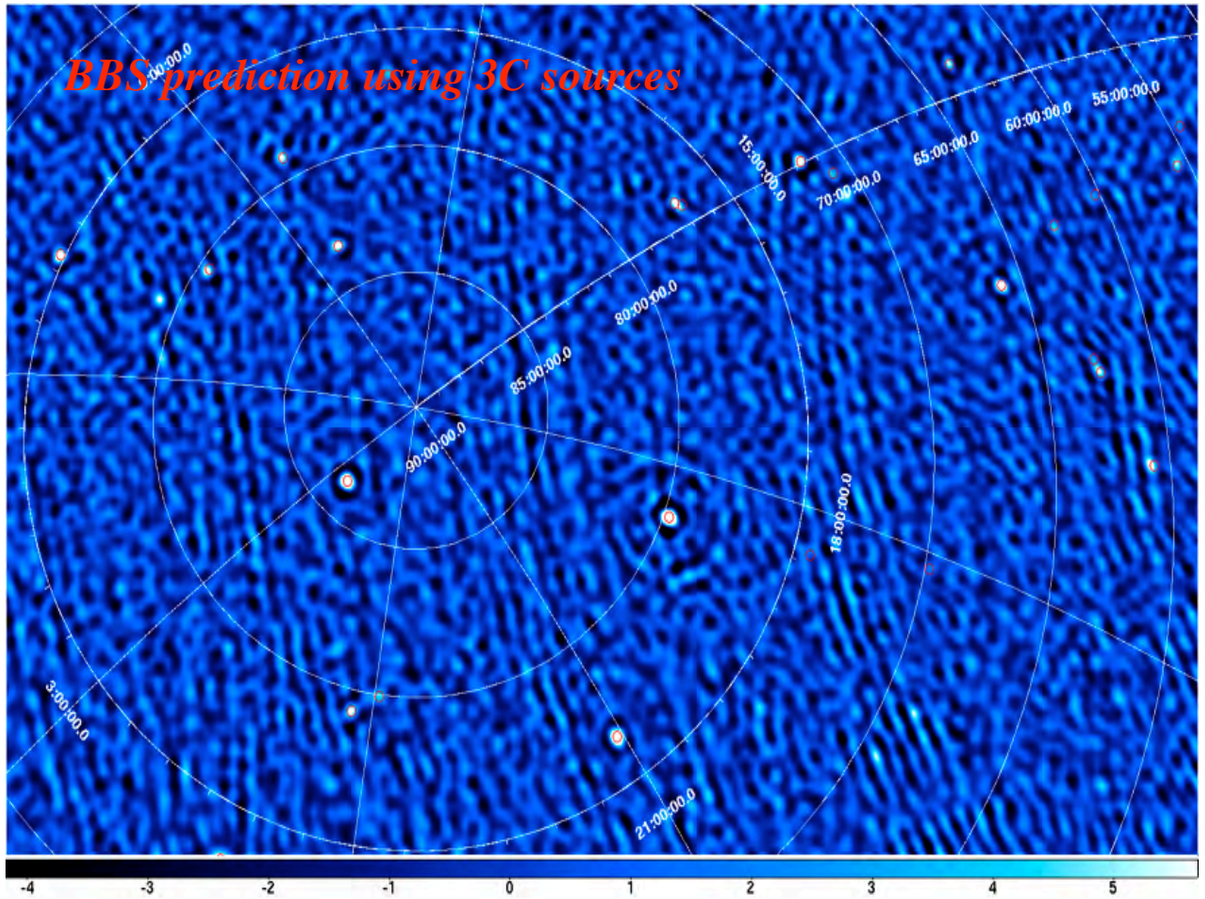
# BBS: Global Solver

- BBS supports parameter fitting across sub-bands



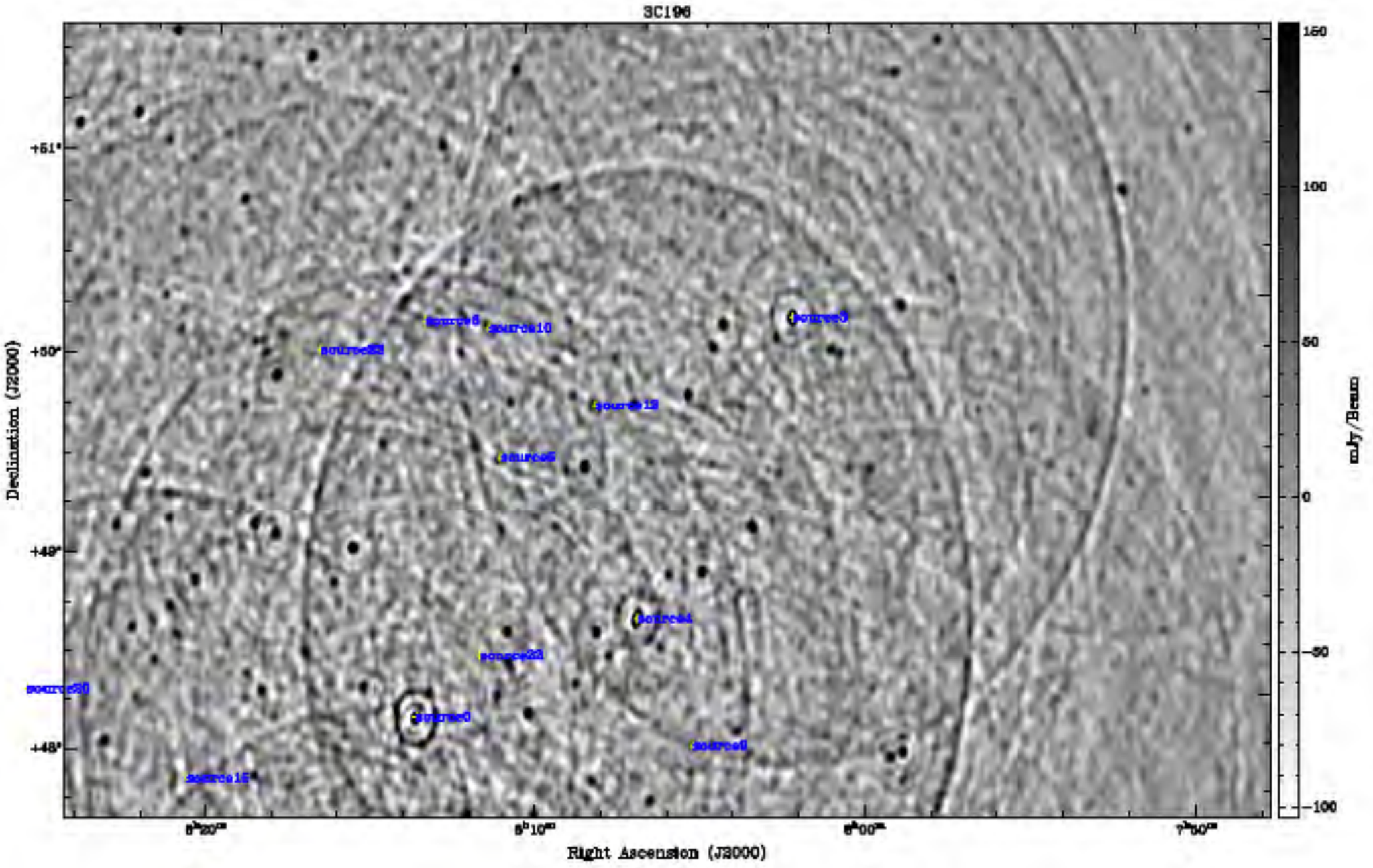
# BBS: Capabilities

- Parameter types
  - Constants
  - Polynomials of frequency and/or time
- Source models
  - Point source
  - Elliptical Gaussian: to be tested
  - Shapelets
  - (Higher order) Spectral index
- Instrument models
  - Bandpass
  - (Directional) Gain (Simultaneous)
  - Basic Ionospheric model (SPAM based; Mevius, Intema)
  - Beam models
    - Analytical dipole model (S. Yatawatta)
    - Semi-analytical dipole model (J.P. Hamaker)
    - Full station beam
  - Excising unphysical solutions: in progress



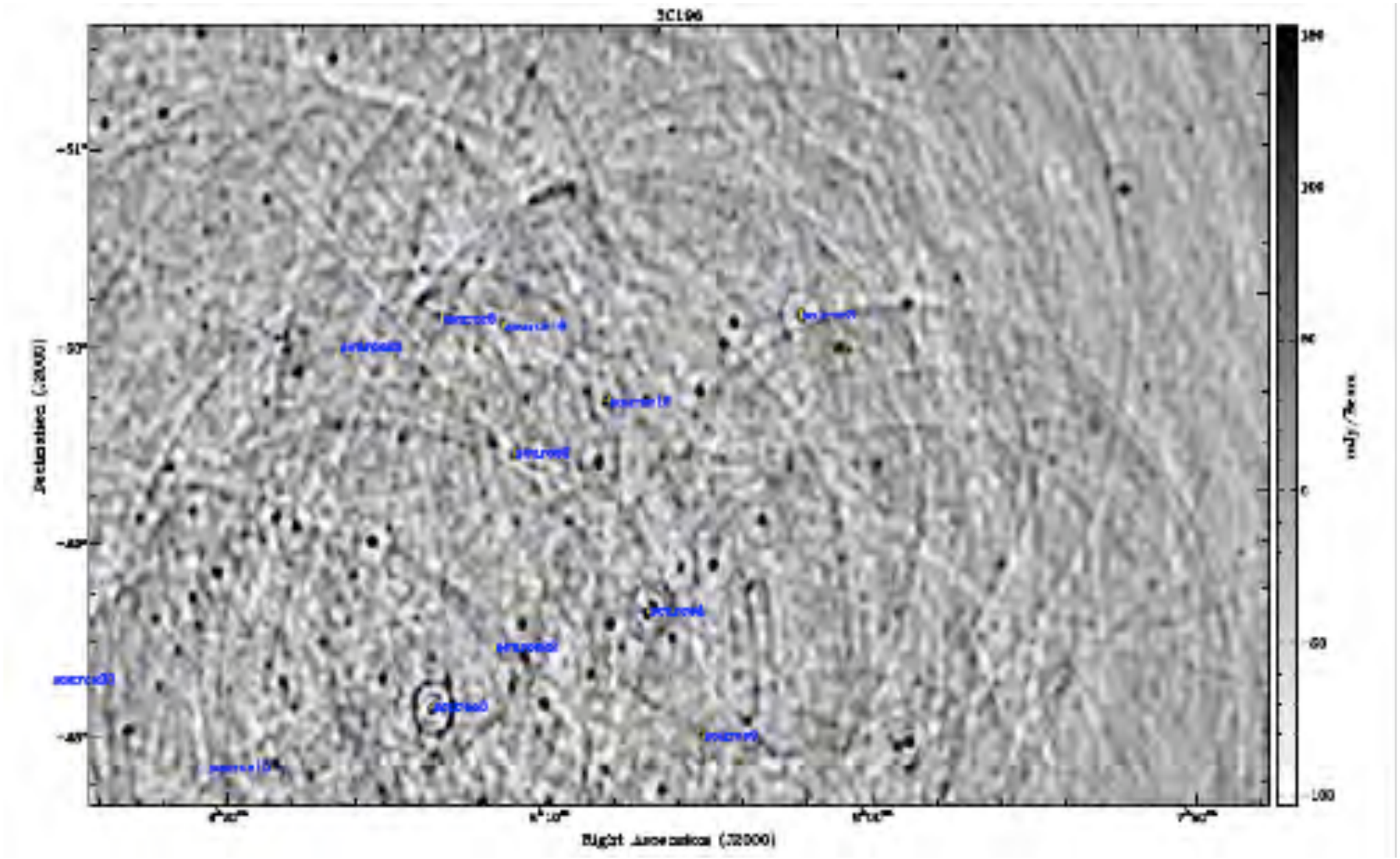

*(courtesy R.Nijboer, J. van Zwieten)*

# BBS: WSRT Ionosphere



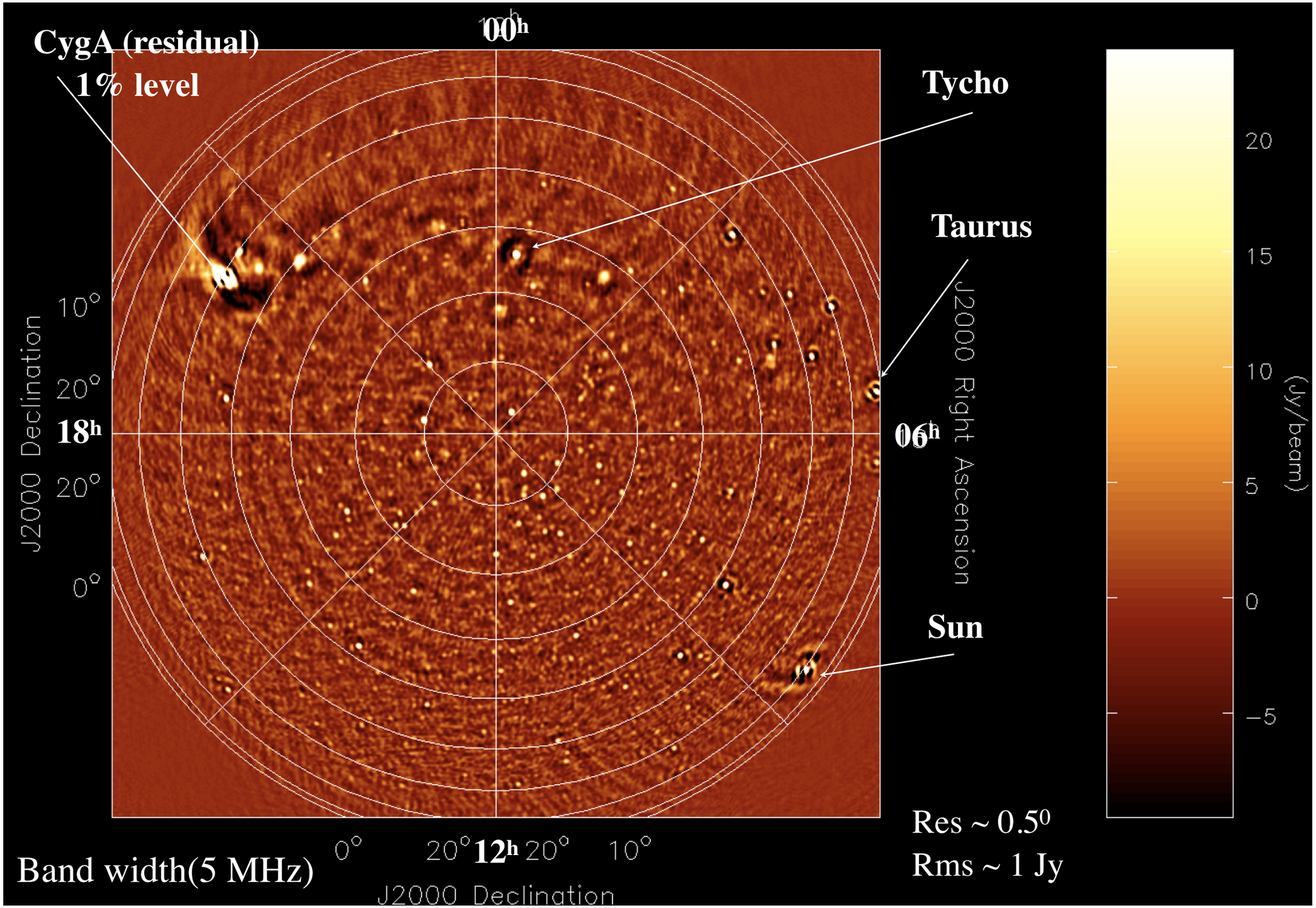

Residual image using 5 Peeling solutions

# BBS: WSRT Ionosphere




Residual image using 8 parameter phase screen

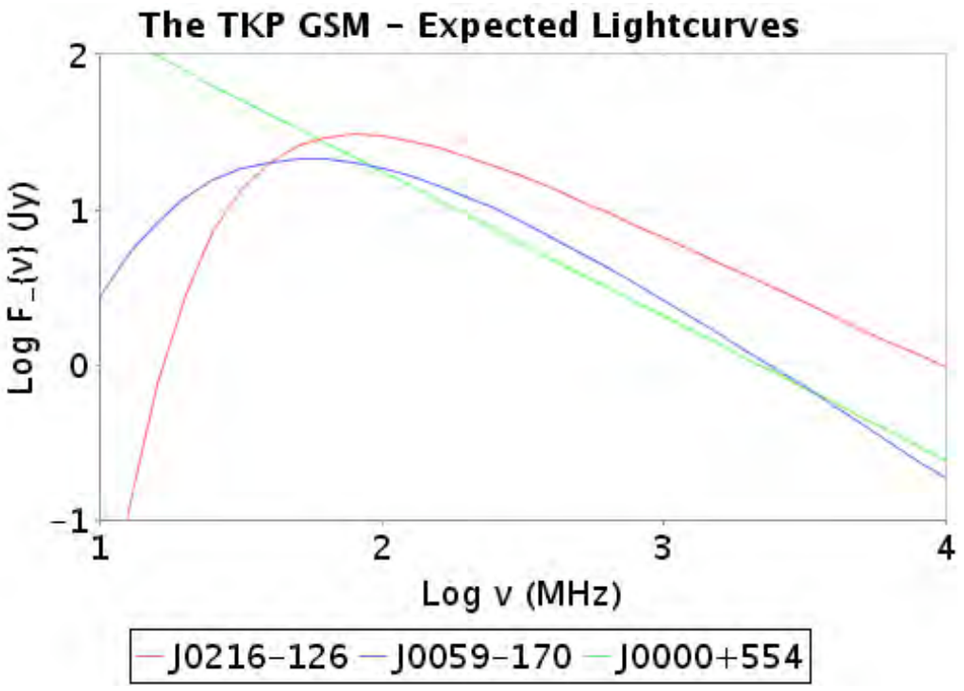
# CS1 All-sky Image

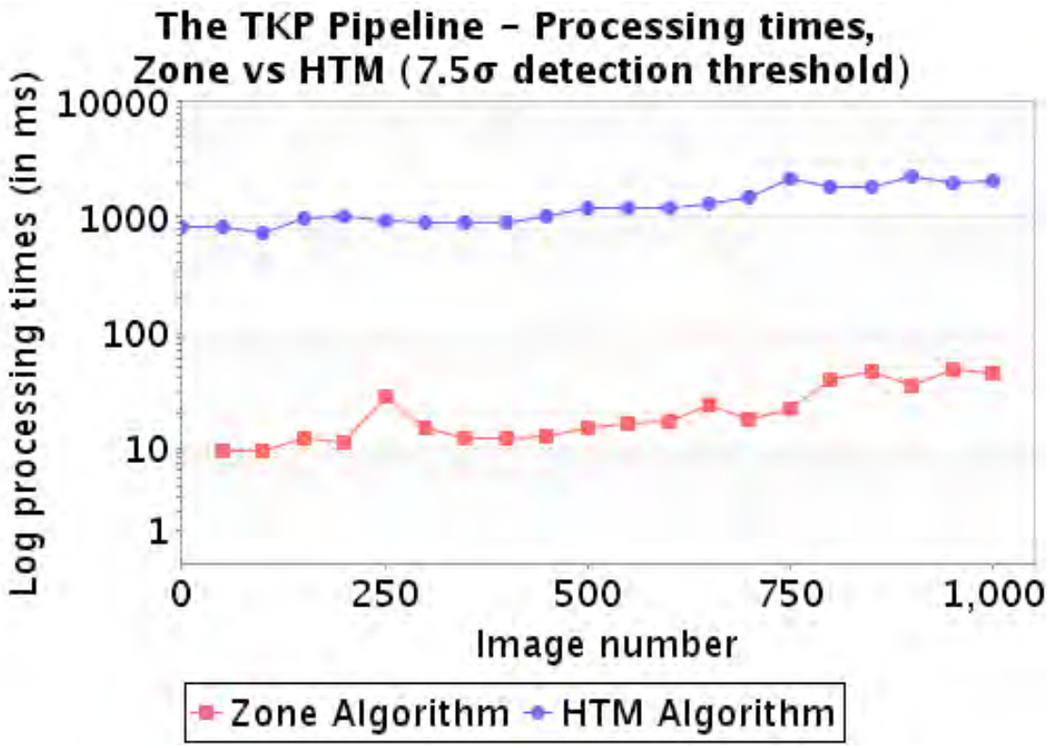



Deep all sky wide field (full hemisphere centered on North Celestial Pole)

# Sky Models (LSM / GSM)

- GSM stored as a database
  - Many predictive functions available
  - Python interface for access
  - Filled with VLSS, WENSS, NVSS, 3C, 8C, …
- LSM currently a text file
  - To be upgraded to a database



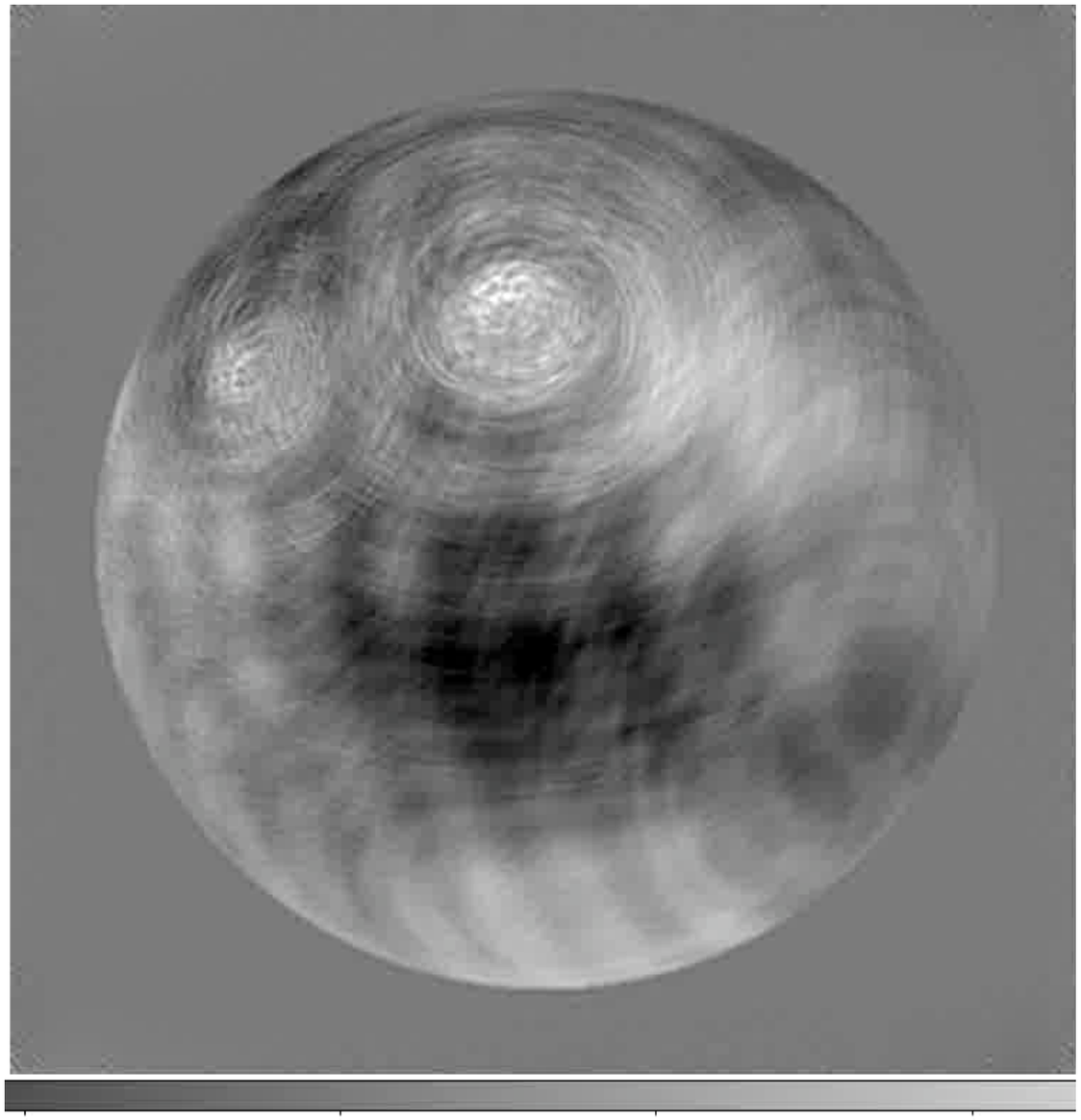
# Imaging Summary

## Current status

- Prototype working on CEP
- DP3, MWimager, source detection integrated
- Processes multiple sub-bands in parallel
- Prototype GSM database installed

## Upcoming work

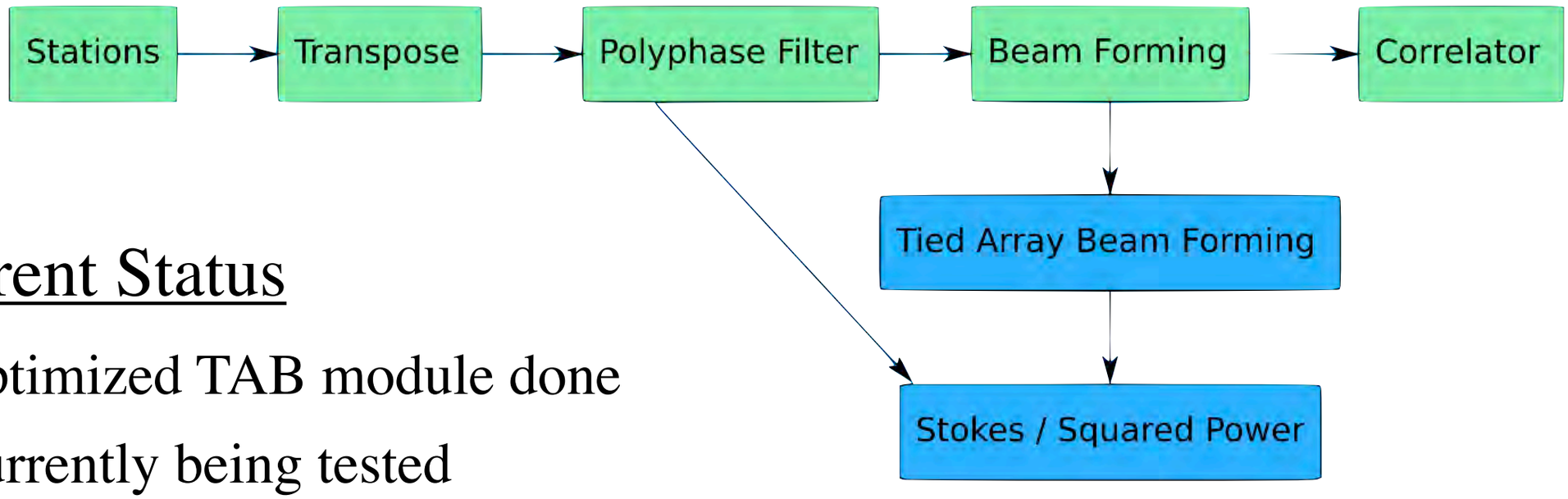
- Integrate BBS
- Integrate GSM
- Package data products
- Delivery end of June
- Testing and profiling
- Major cycle implementation



*L2007_03463, 48 sub-bands*

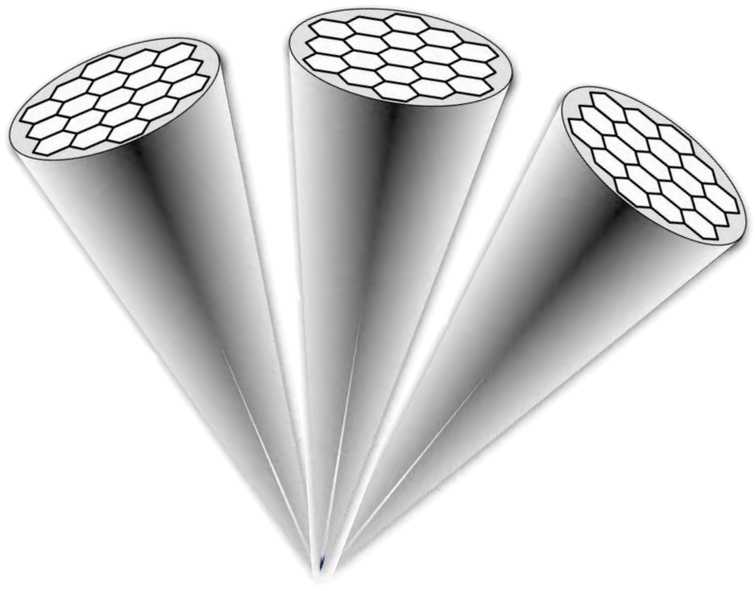
*(courtesy J. Swinbank)*

# Known Pulsar Pipeline




## Current Status

- Optimized TAB module done
- Currently being tested
- Streaming version of HDF5 BF data writer working

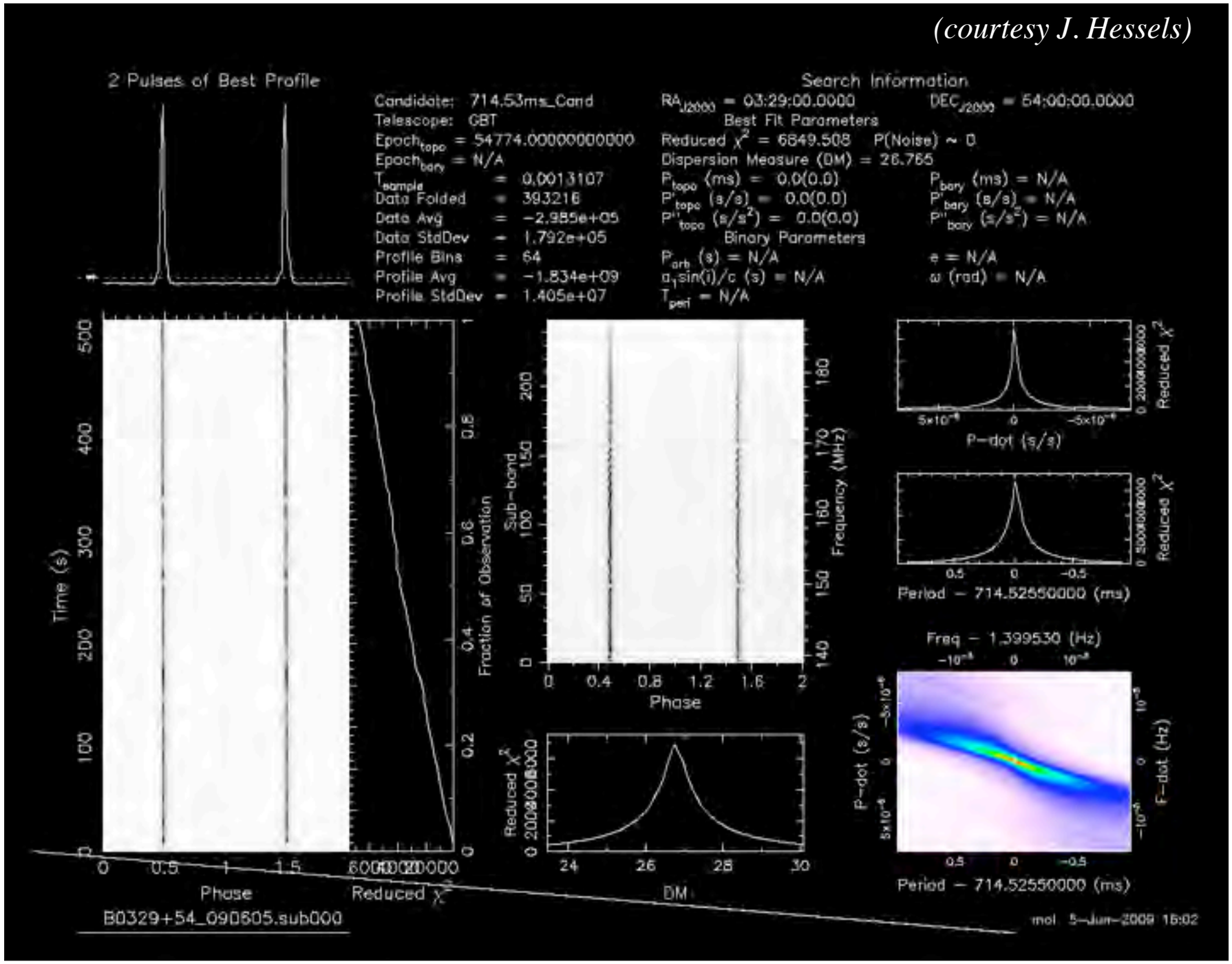


## Next steps

- Integrate BF data writer with OLAP
- Populate headers of BF data files
- Streaming down-sampling
- Post-processing pipeline

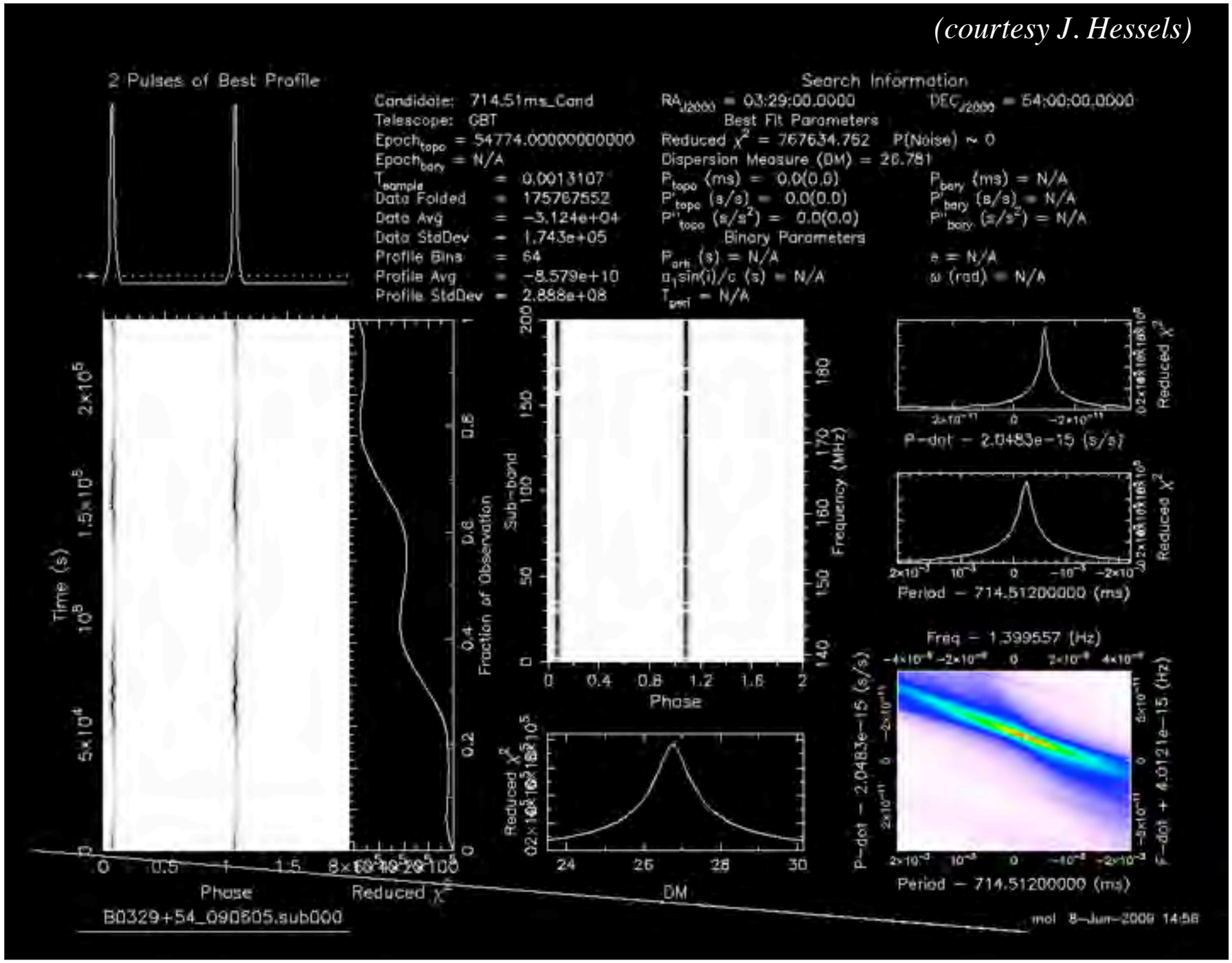
# Known Pulsar Pipeline

*(courtesy J. Hessels)*



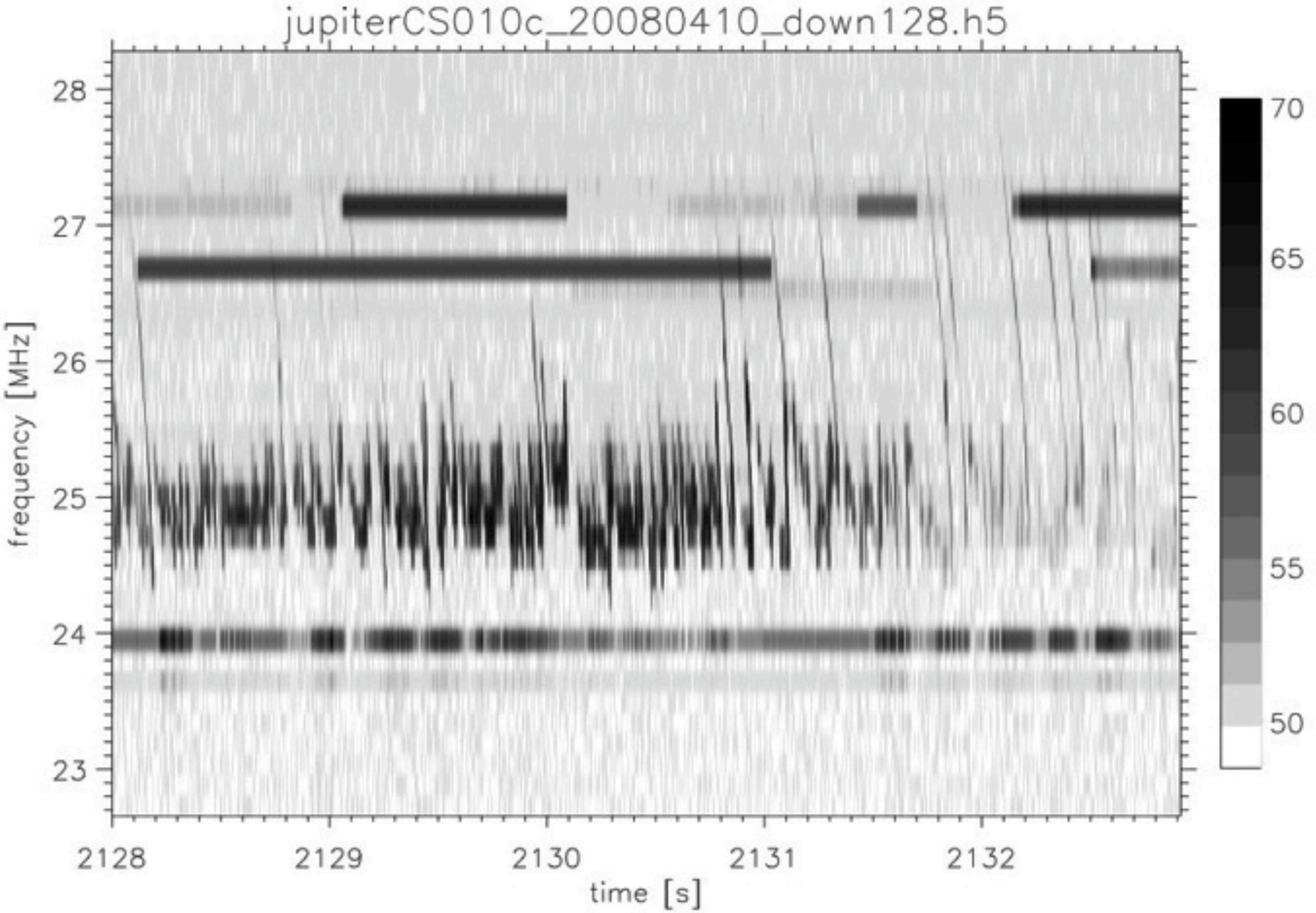

***PSRB0329+54 with the 48 HBA tiles of CS302, 48MHz, 500 sec.***
***"Awesome signal to noise!"***

# Known Pulsar Pipeline




***PSRB0329+54 with the 48 HBA tiles of CS302, 48MHz, 64 hr continuous observation. Excellent system stability.***

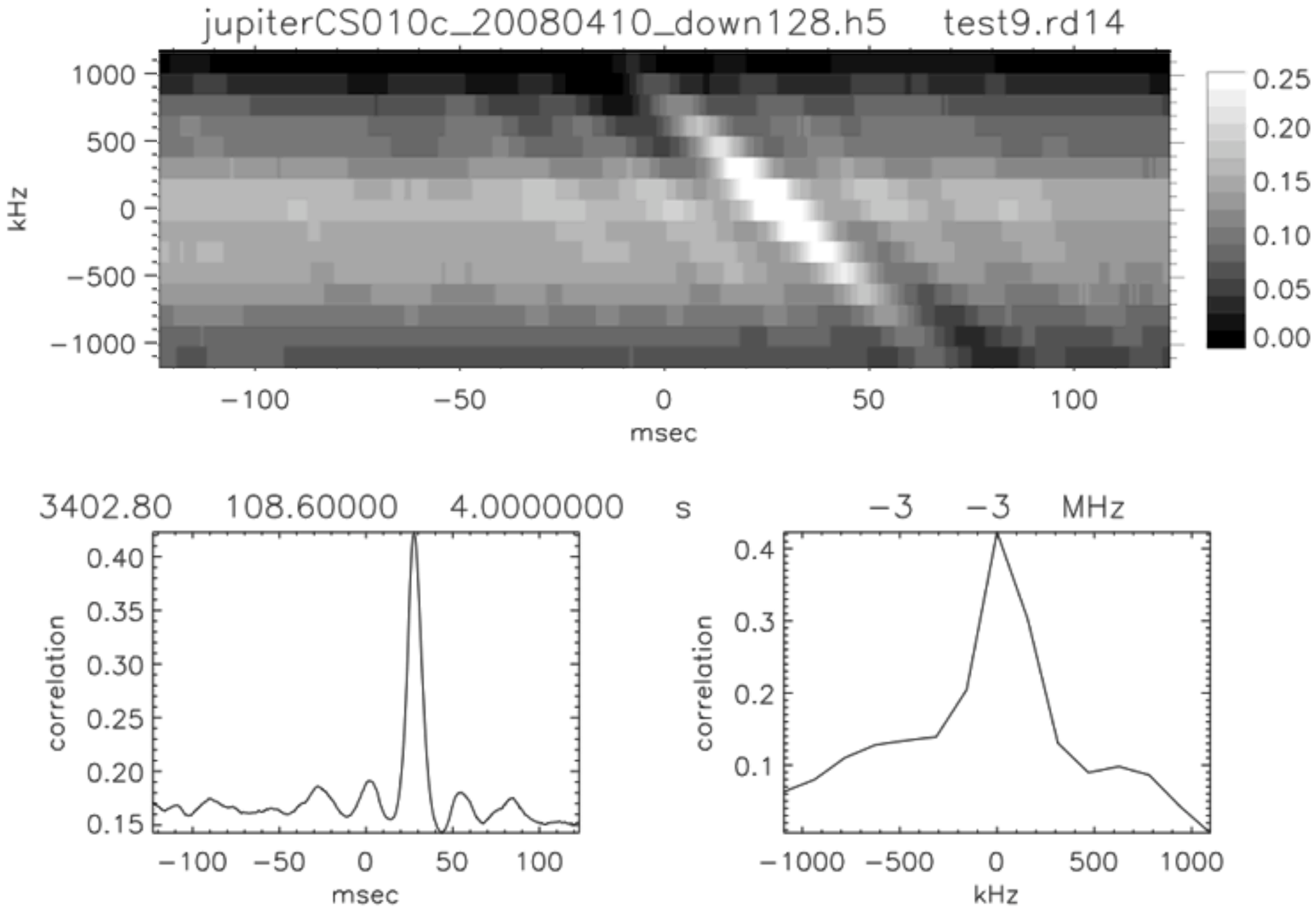
# Dynamic Spectra




*Jupiter bursts (courtesy J.-M. Grießmeier)*

# First Correlation CS10-Nancay

Time resolution: 0.8192 ms, Freq. resolution: 156.250 kHz

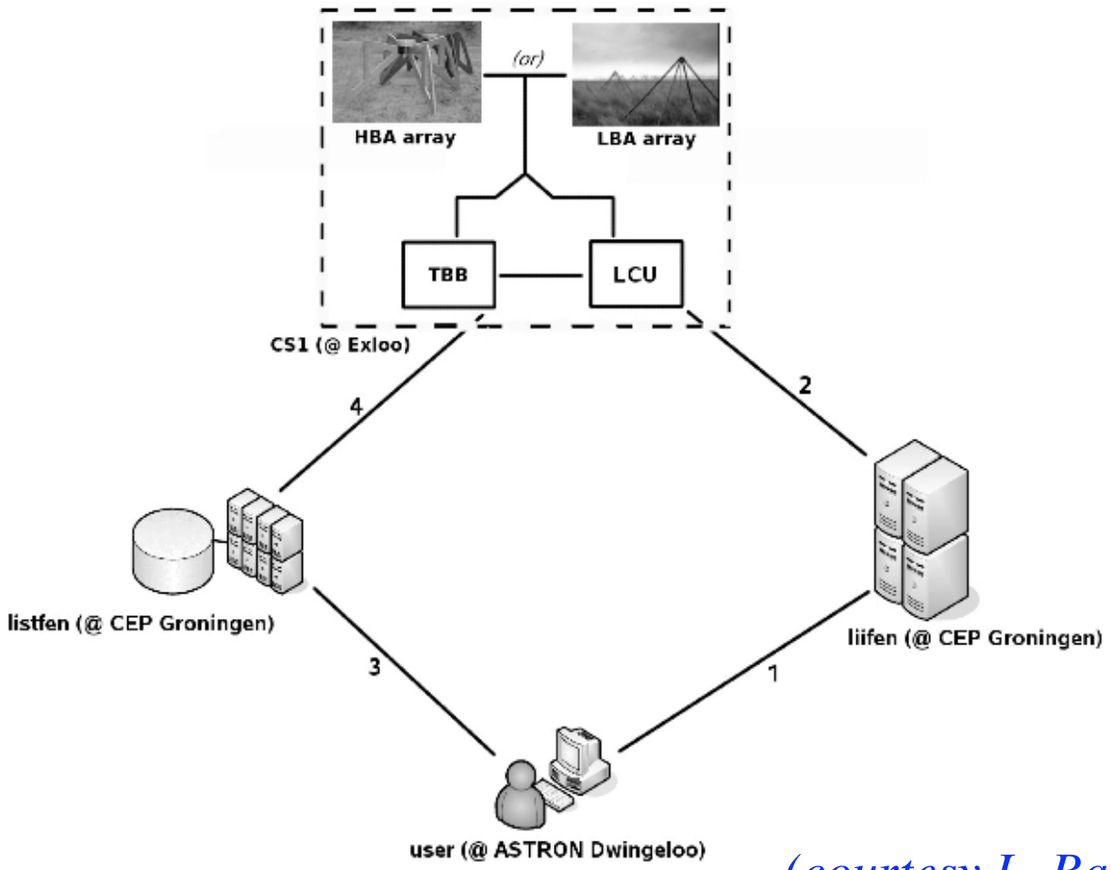



*(courtesy J.-M. Grießmeier)*

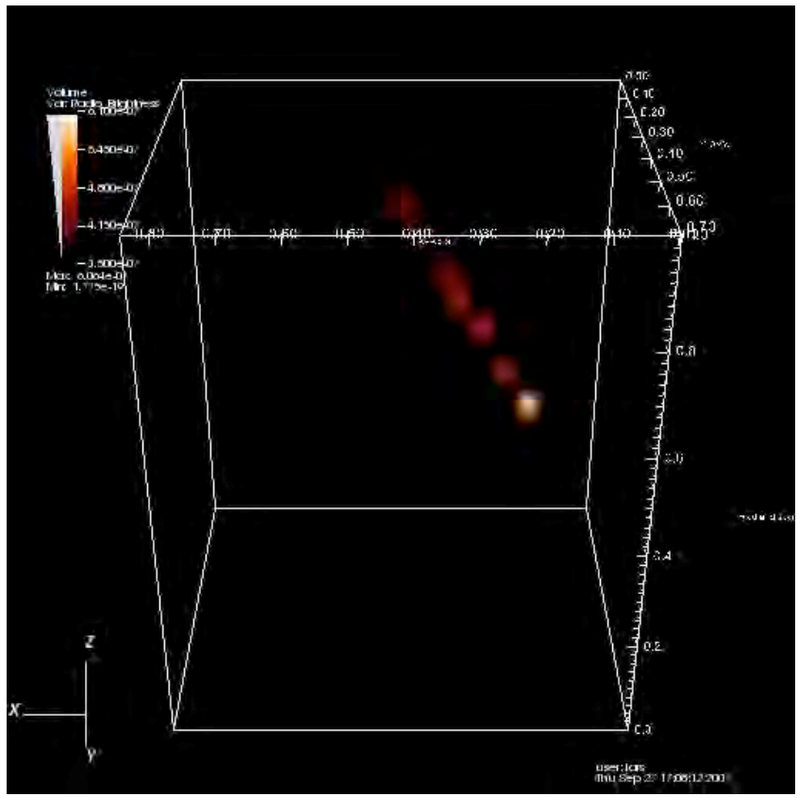
# VHECR Pipeline

## Current Status

- LCU trigger algorithm implemented
- Manual TBB data writer working
- Scripts to initiate TBB dumps
- SkyMapper almost ready




*Near-field imaging*

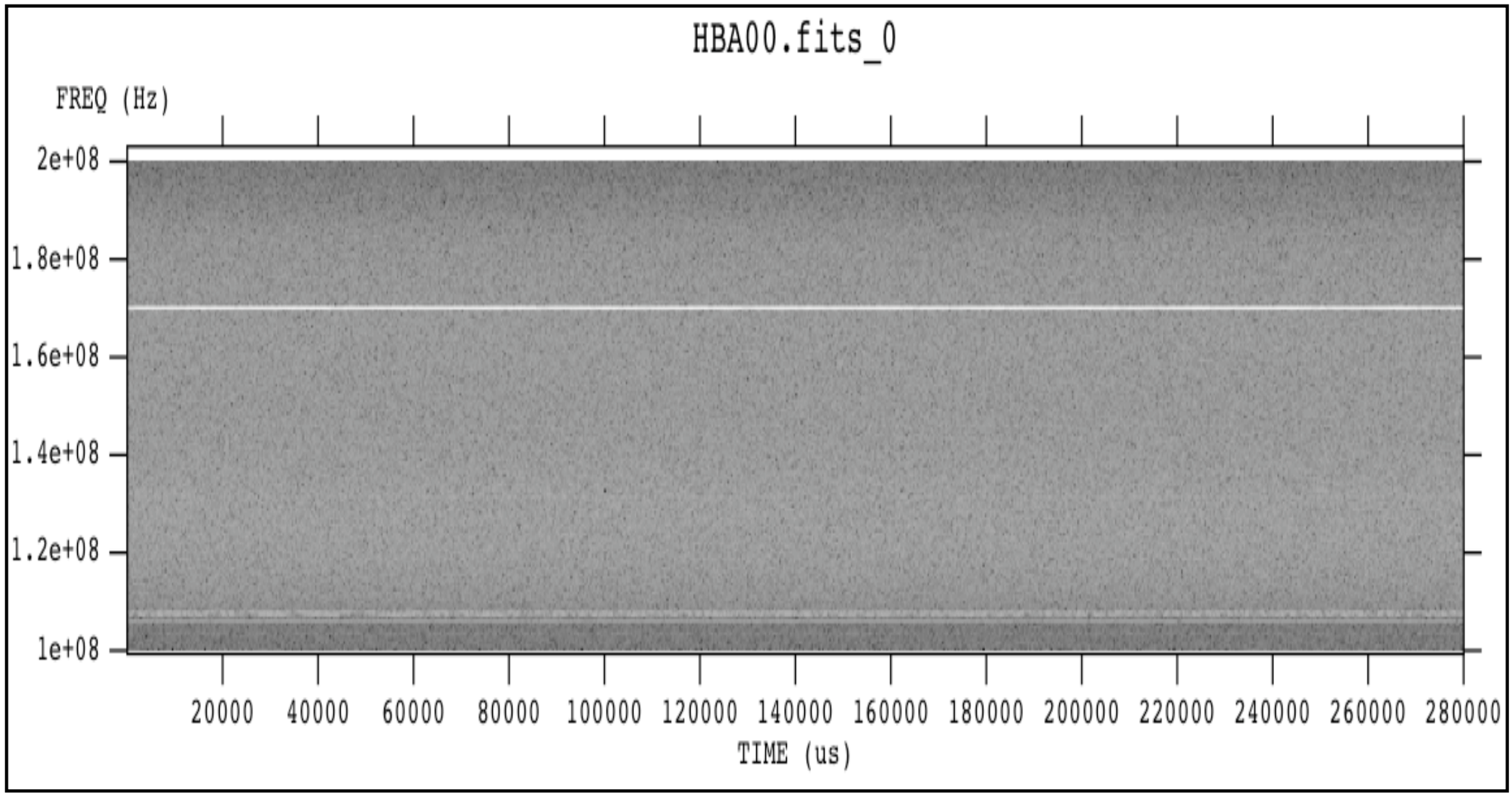


## Next steps

- Testing of LCU trigger code
- Testing of SkyMapper
- TBB data writer under MAC control
- CR post processing pipeline

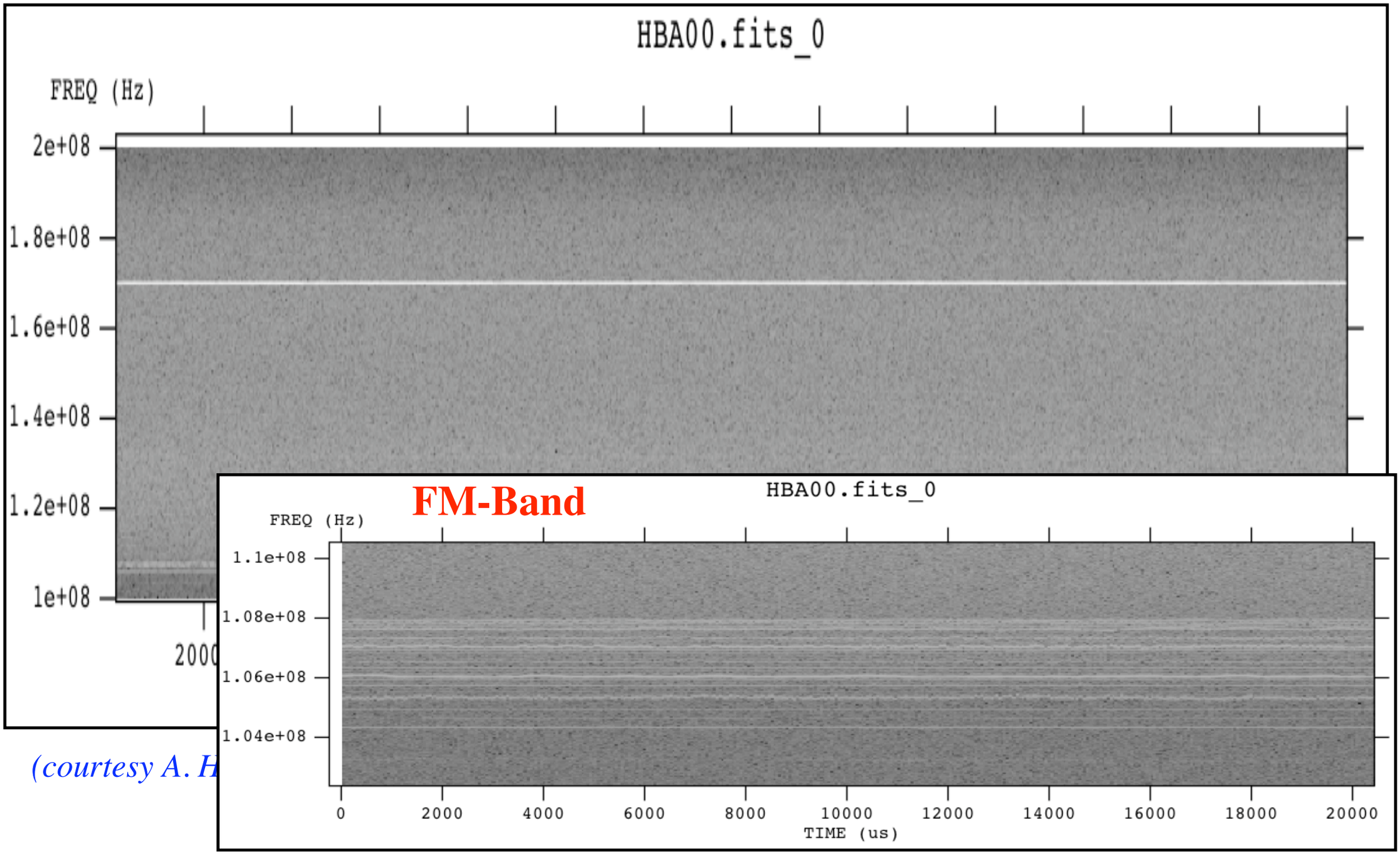
*(courtesy L. Bahren, M. Eikelboom & A.-J. Boonstra)*

# HBA Dynamic Spectrum



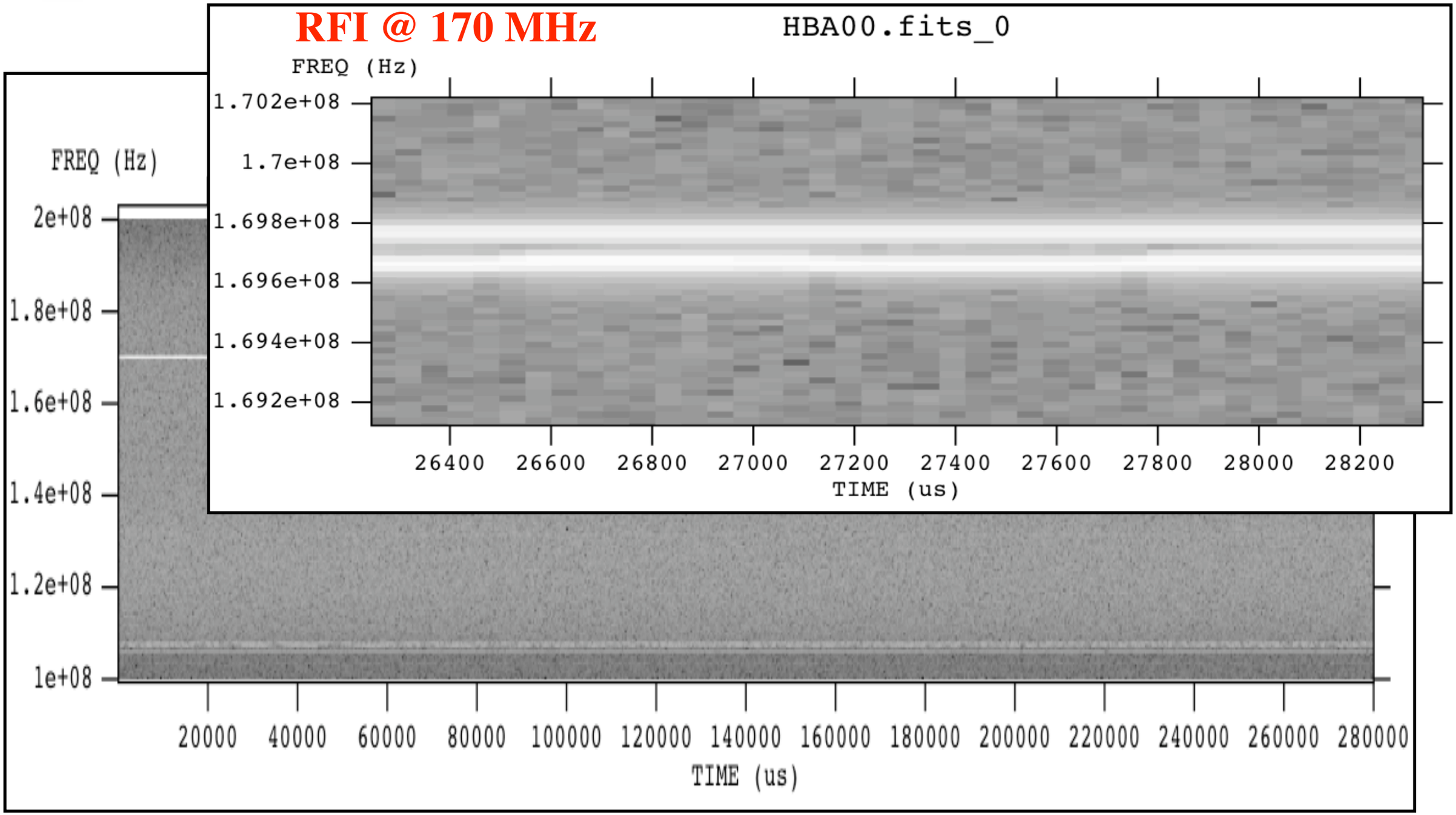

*(courtesy A. Horneffer)*

# HBA Dynamic Spectrum




*(courtesy A. H*

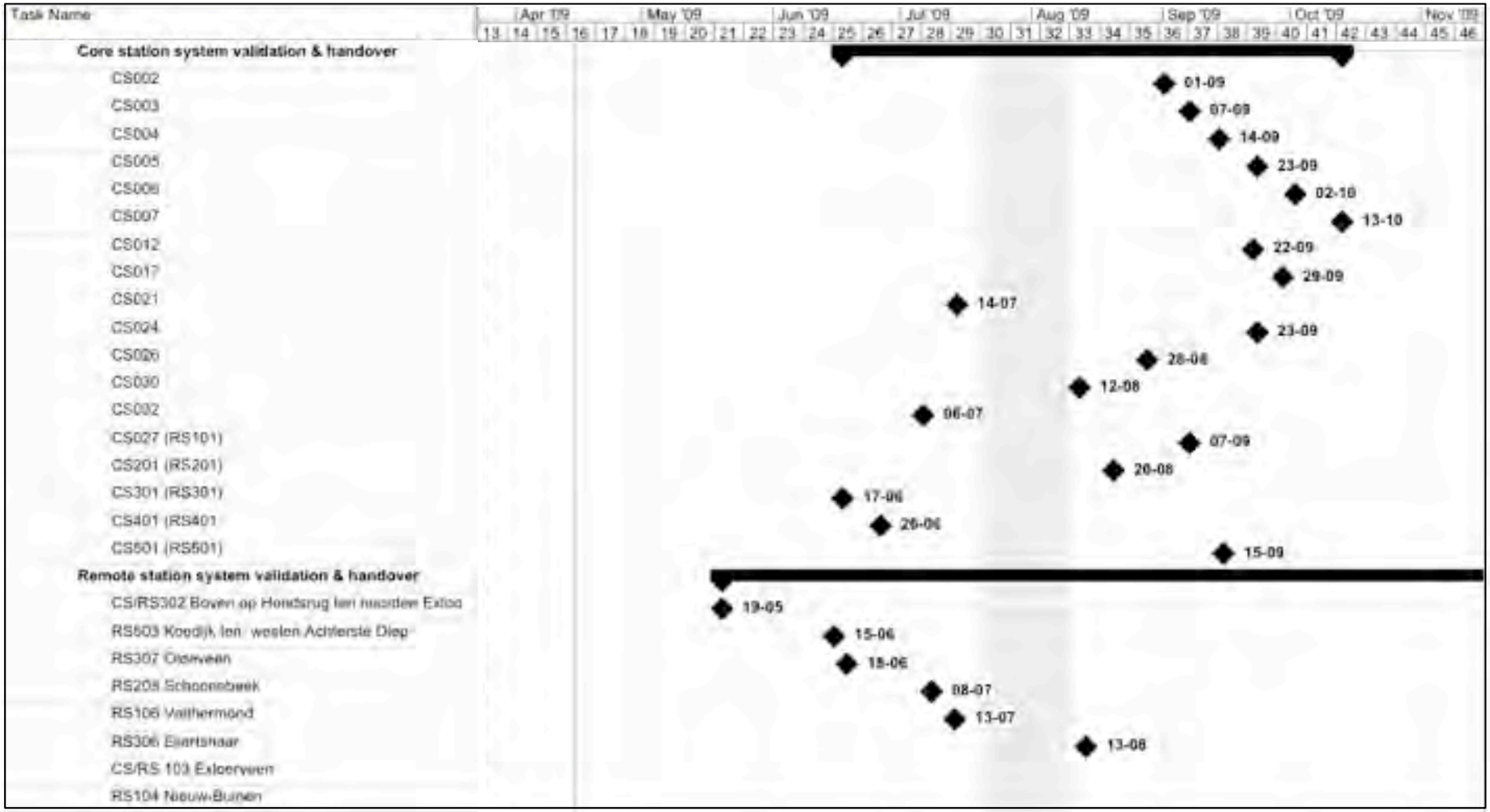
# HBA Dynamic Spectrum




*(courtesy A. Horneffer)*

# Timelines

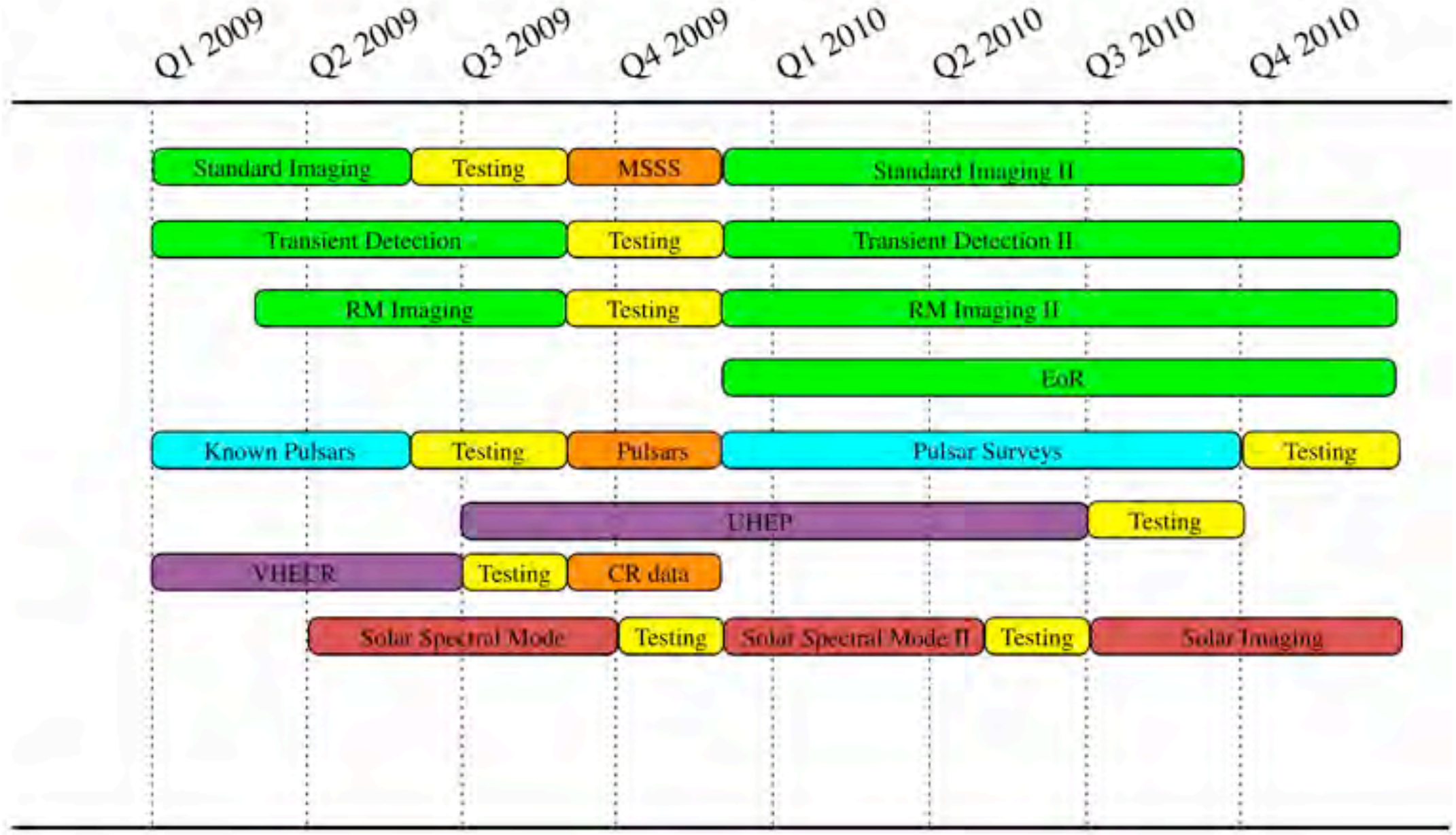
# Hardware Roll-out




***Milestones ⇒ LOFAR 3 (mid-June)***
***LOFAR 10 (mid-Aug.)***
***LOFAR 20 (late-Sept.)***

***0.5 CEP (mid-June)***
***Superstation (mid-Oct.)***

# Pipeline Roll-out




***Milestones ⇒ Standard imaging (June 09)***
***Known pulsars (July 09)***
***VHECR (Aug. 09)***

# Phase I

***Present - Aug 2009***

*Station and Pipeline Integration*

## Operations I

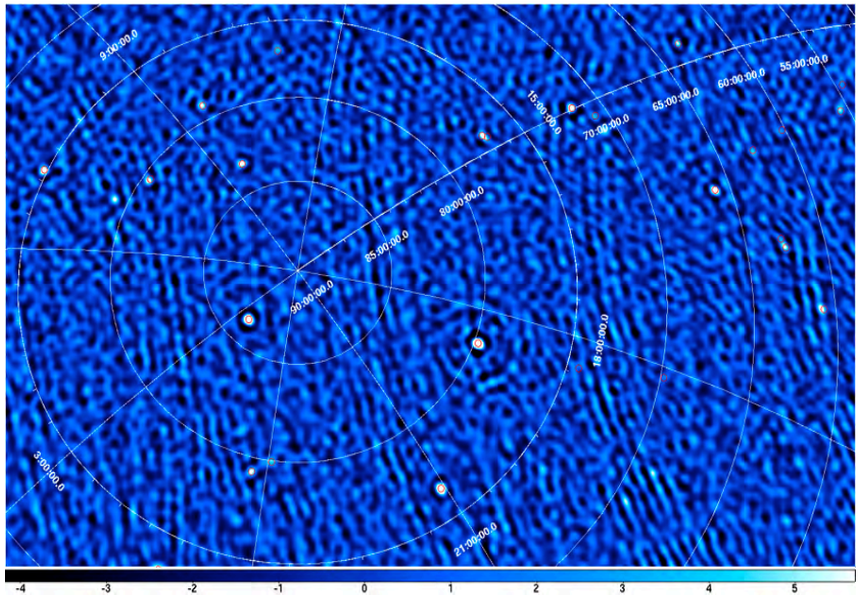
- Basic data-taking
- Manual pipeline execution
- No parallel observations
- Station test procedures

## Station Integration I

- LOFAR01
- LOFAR03
- LOFAR05
- LOFAR10
- LOFAR10+INTBL04

## Pipeline Integration I

- Standard Imaging
- Known Pulsars
- VHECR mode



# Phase II

***Sept 2009 - Dec 2009***

*Pipeline Testing and Validation*

## Operations II

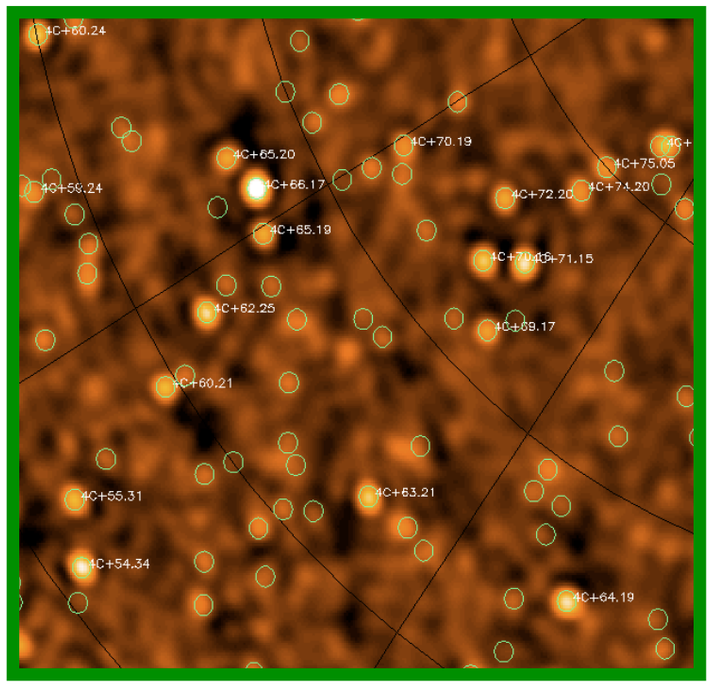
- Routine data-taking
- Automatic pipeline execution
- Limited parallel observations
- Initial archive integration

## Station Integration II

- LOFAR15
- LOFAR20
- LOFAR20+INTBL06
- Core Superstation

## Pipeline Validation I

- MSSS
- Timing survey
- Offline transient searches
- Latency tests
- RM experiments



# Phase III

***Jan 2010 - Jun 2010***

*Full Array Testing and Early Science*

## Operations III

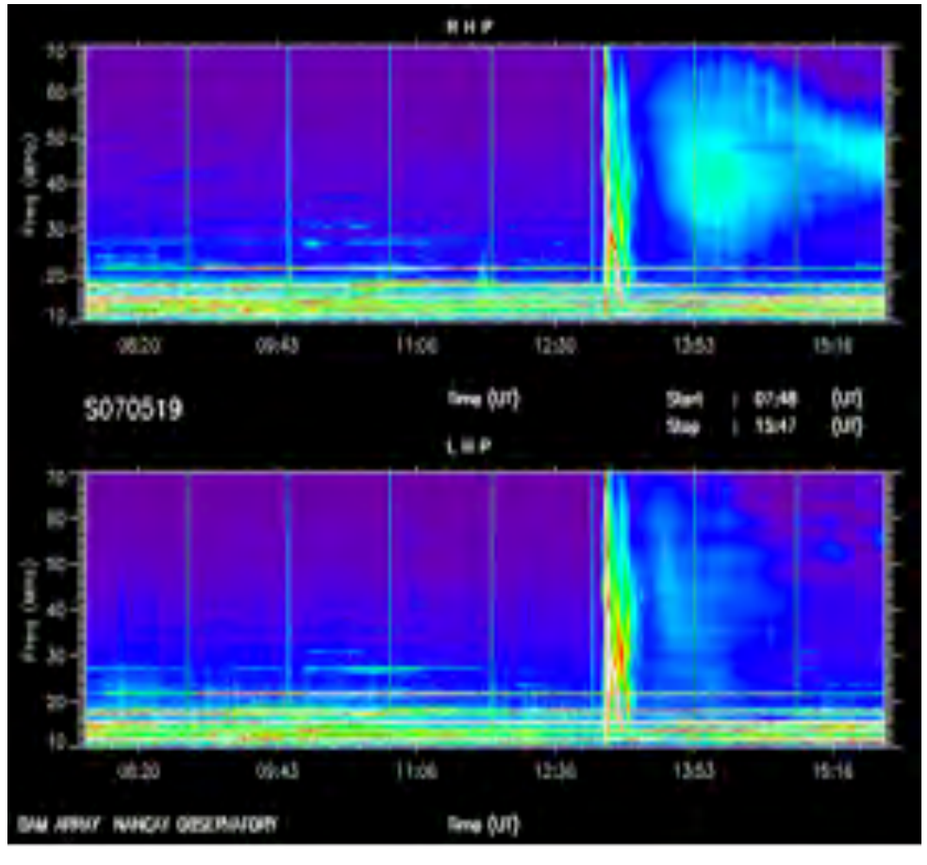
- Automatic pipeline execution
- Routine parallel observations
- Routine archive operations
- Support direct storage modes

## Pipeline Integration II

- Standard Imaging upgrades
- Transient Detection
- Pulsar Surveys
- Solar Spectral mode
- UHEP mode

## Station Integration III

- LOFAR36
- LOFAR36+INTBL08



# The End