



# An introduction to LOFAR

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# Overview

- ➔ “Next-generation” radio telescopes
- ➔ Overview of the LOFAR system
- ➔ Science goals, pipelines and data products





# THE "BIG DISH"

ARECIBO, PUERTO RICO (305 METRES)



EFFELSBERG, GERMANY (100 METRES)





# HIGH RESOLUTION: APERTURE SYNTHESIS

VERY LARGE ARRAY, NEW MEXICO

WESTERBORK SYNTHESIS RADIO TELESCOPE, NL





# LOFAR HAS DIPOLES, NOT DISHES

LOW BAND (30–80 MHz)



HIGH BAND (120–240 MHz)





# ARRANGED IN STATIONS

96 LOW-BAND AND 48 (96 INTERNATIONAL) HIGH-BAND ANTENNAE PER STATION

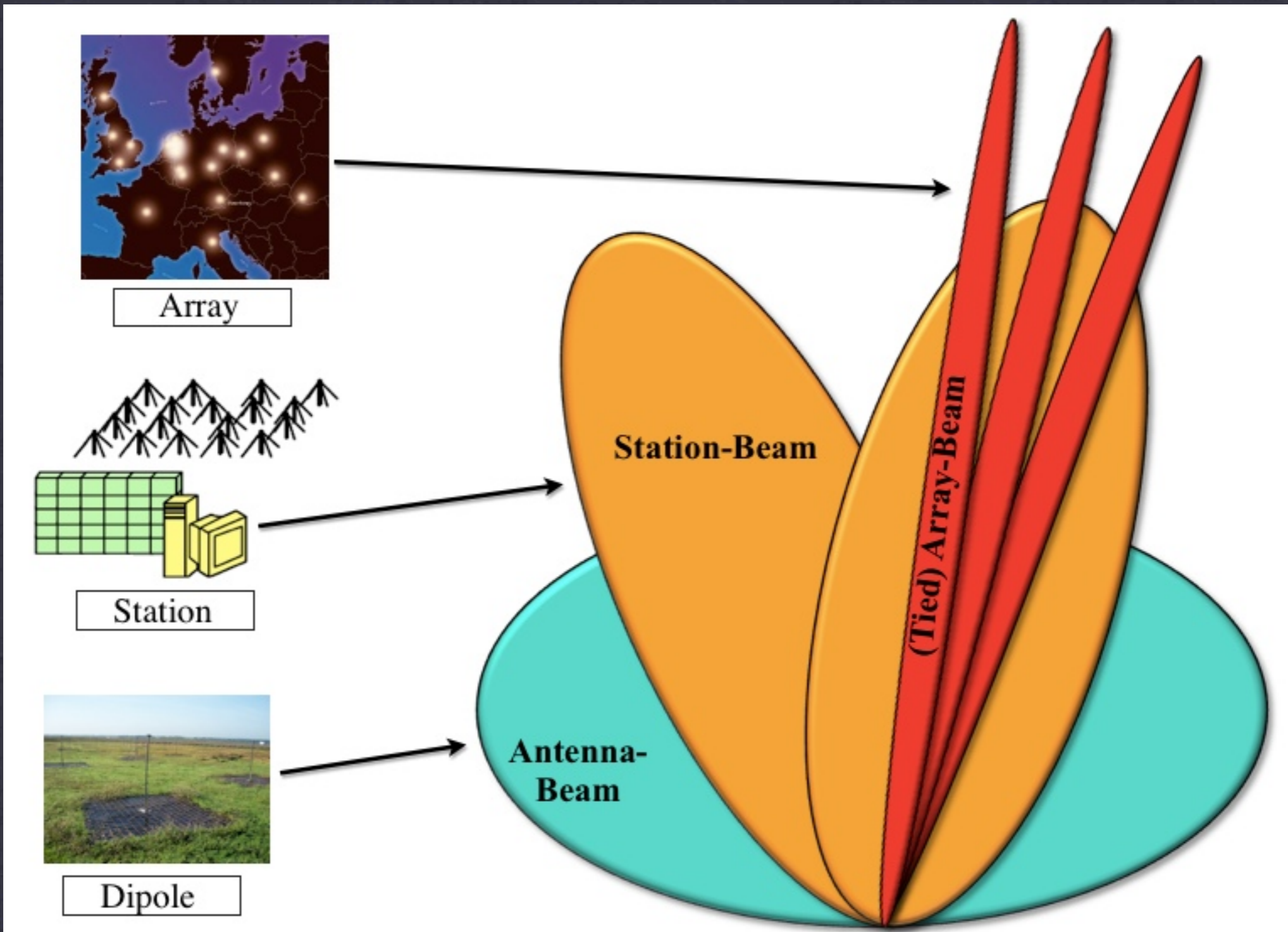




# ACROSS EUROPE

~40 DUTCH AND ~10 INTERNATIONAL STATIONS

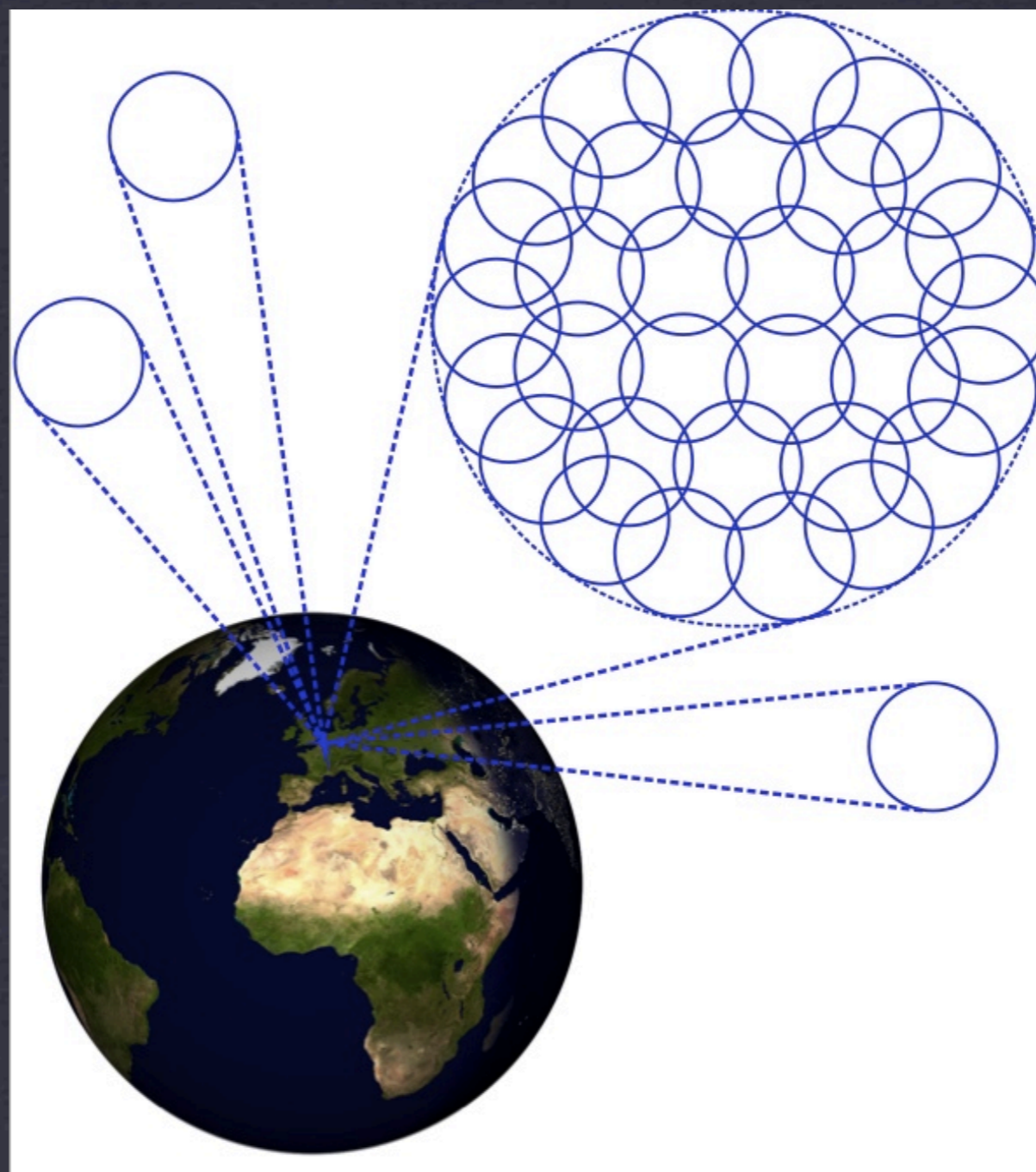




# DIGITAL BEAM-FORMING

PARALLEL OBSERVATIONS. FAST RECONFIGURATION. RAPID RESPONSE.





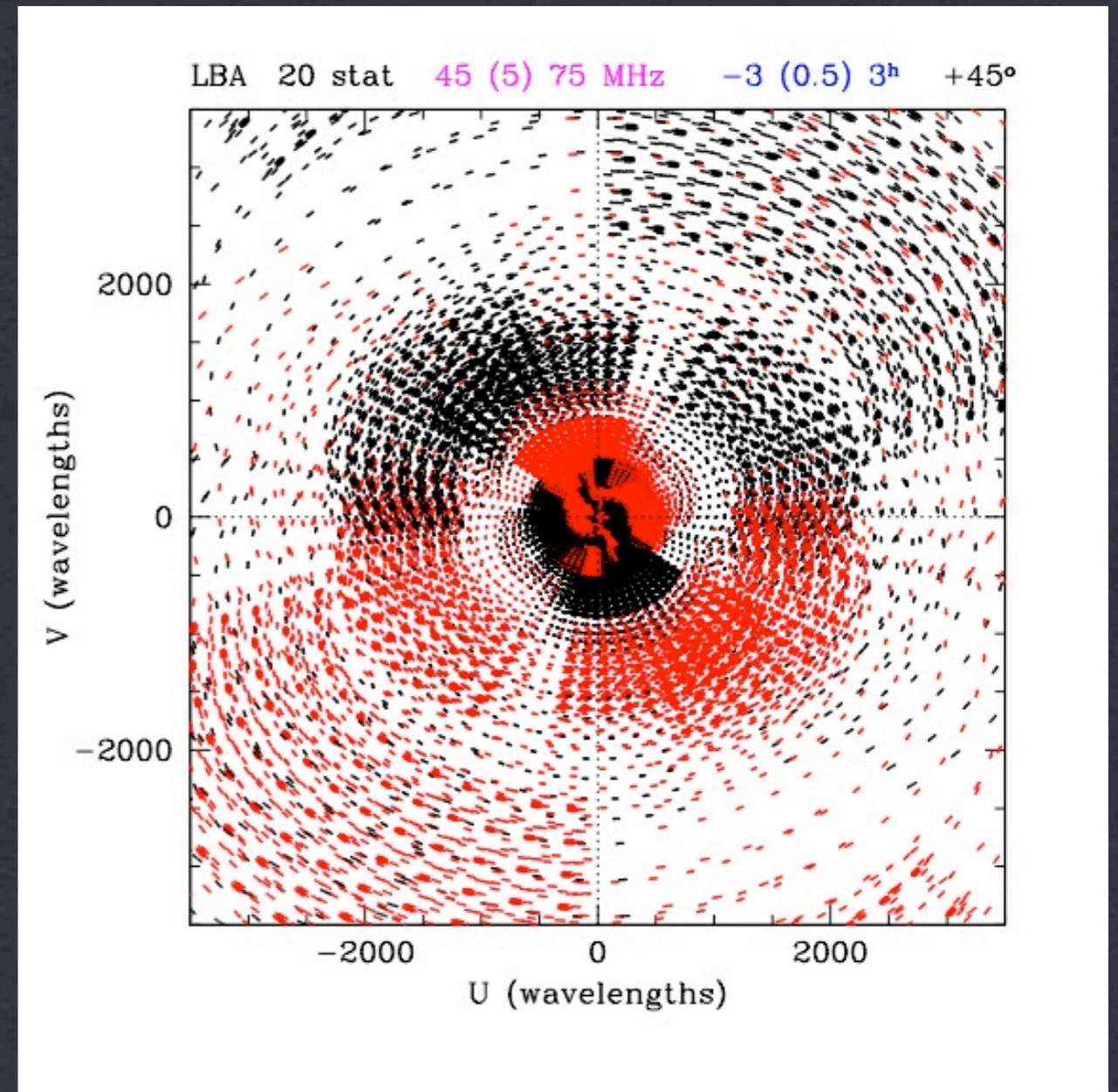
# MULTIPLE BEAMS

HUGE FIELD OF VIEW. MULTIPLE SIMULTANEOUS OBSERVATIONS.



Freq. (MHz)	$\lambda$ (m)	Resolution L = 2 km (arcsec)	Resolution L = 10 km (arcsec)	Resolution L = 80 km (arcsec)
15	20.0	1650	330	41.3
30	10.0	825	165	20.6
45	6.67	550	110	13.8
60	5.00	413	82.5	10.3
75	4.00	330	66.0	8.25
120	2.50	206	41.3	5.16
150	2.00	165	33.0	4.13
180	1.67	138	27.5	3.44
210	1.43	118	23.6	2.95
240	1.25	103	20.6	2.58

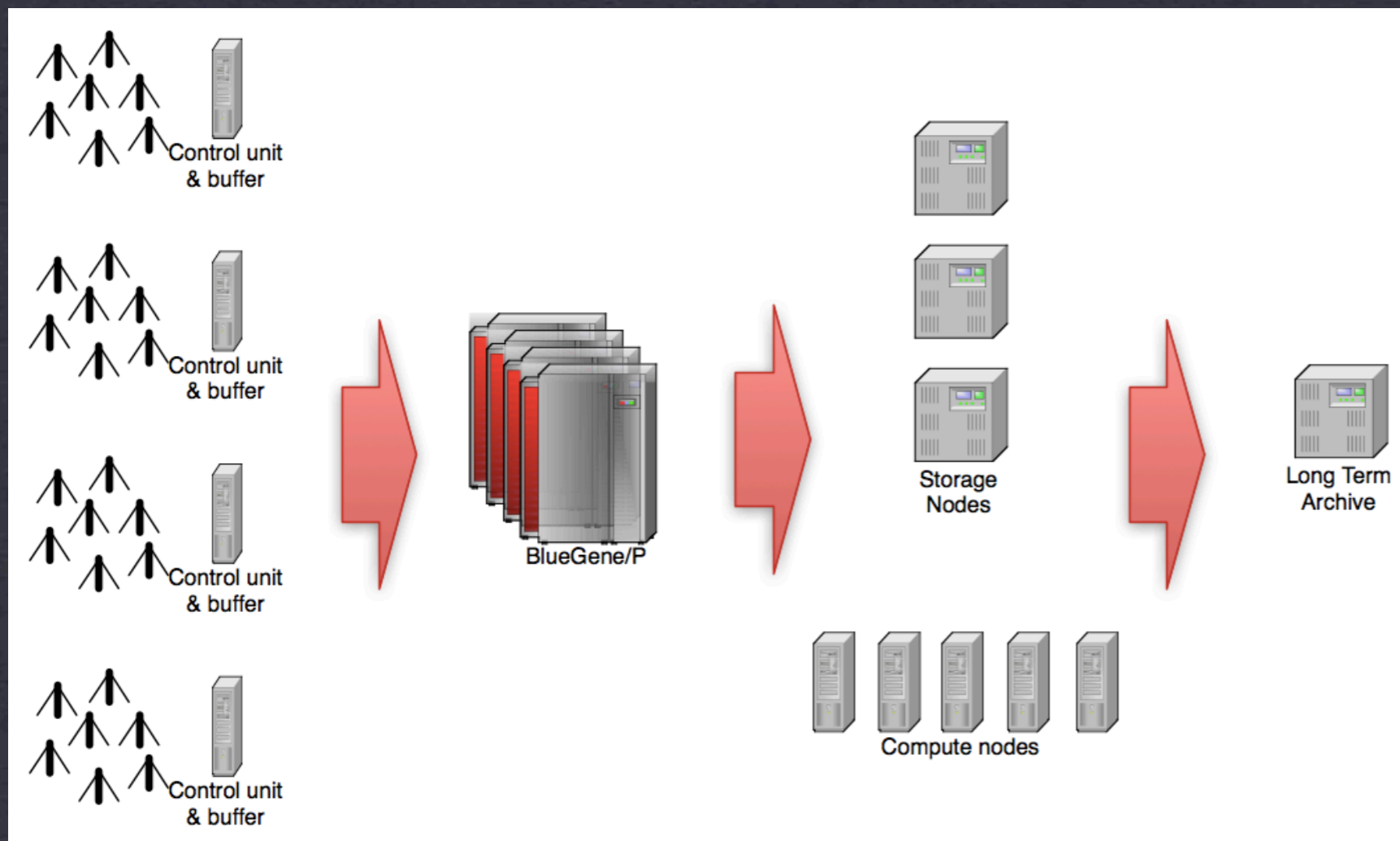
Freq. (MHz)	$\lambda$ (m)	$\Delta S_{13+7}$ (mJy)	$\Delta S_{13+7}$ Tapered (mJy)	$\Delta S_{18+18}$ (mJy)	$\Delta S_{25+25}$ (mJy)
15	20.0	201		110	79
30	10.0	37		20	15
45	6.67	20		11	7.8
60	5.00	13		7.2	5.2
75	4.00	21		12	8.4
120	2.50	0.74	0.89	0.41	0.29
150	2.00	0.58	0.71	0.32	0.23
180	1.67	0.67	0.81	0.37	0.26
210	1.43	0.76	0.91	0.42	0.30
240	1.25	0.84	1.0	0.46	0.33



# SYSTEM PERFORMANCE

## DUTCH BASELINES





## STATION PROCESSING

- ➔ Amplification
- ➔ Digitization
- ➔ Filtering
- ➔ Beam-forming
- ➔ Transient buffer

## CENTRAL PROCESSING

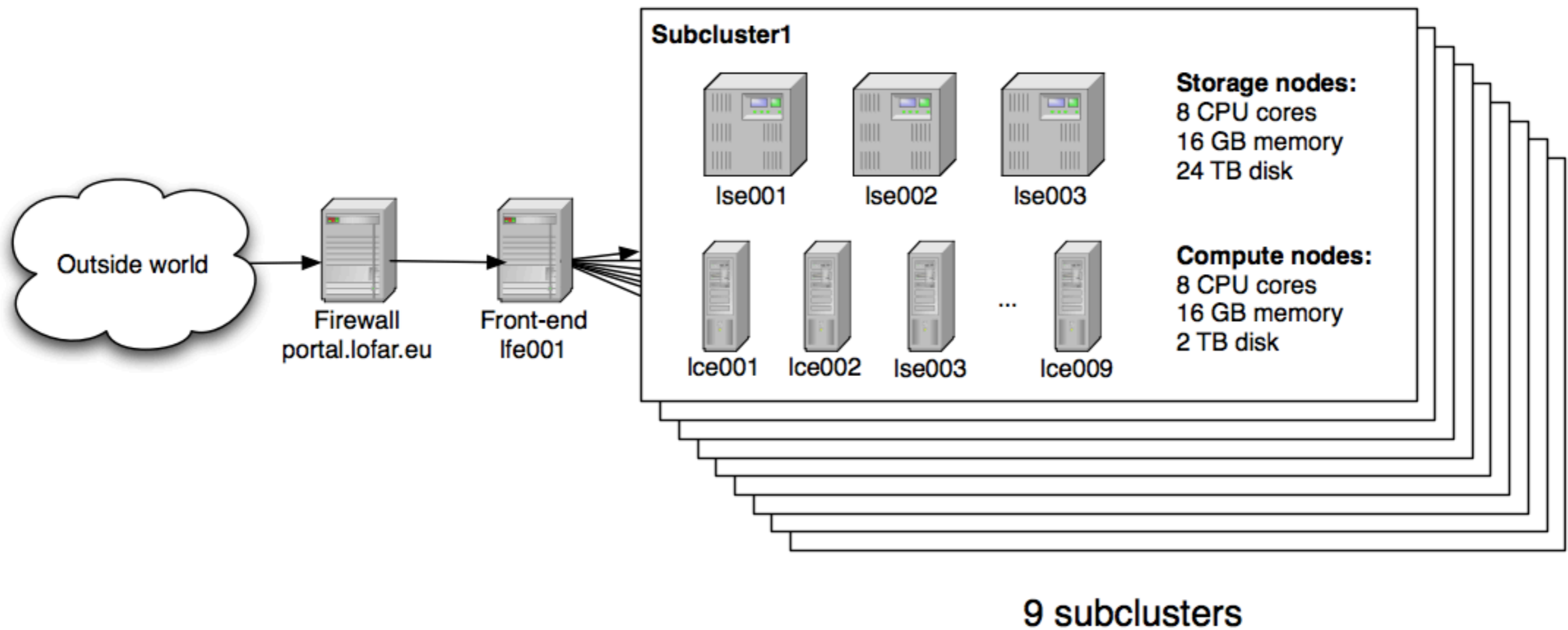
- ➔ Delay compensation
- ➔ Correlation
- ➔ Calibration
- ➔ Science pipelines

- ➔ Input is 40+ stations @ 10 Gbit/s per station
- ➔ Delivering unprocessed data to end-users not practical
- ➔ At each stage of processing, data rate is diminished
- ➔ Users received pipeline-processed data products

## DATA FLOW

STATIONS → CORRELATOR → CLUSTER → ARCHIVE





# “OFFLINE” PROCESSING CLUSTER

FUTURE HARDWARE CURRENTLY UNDER DISCUSSION

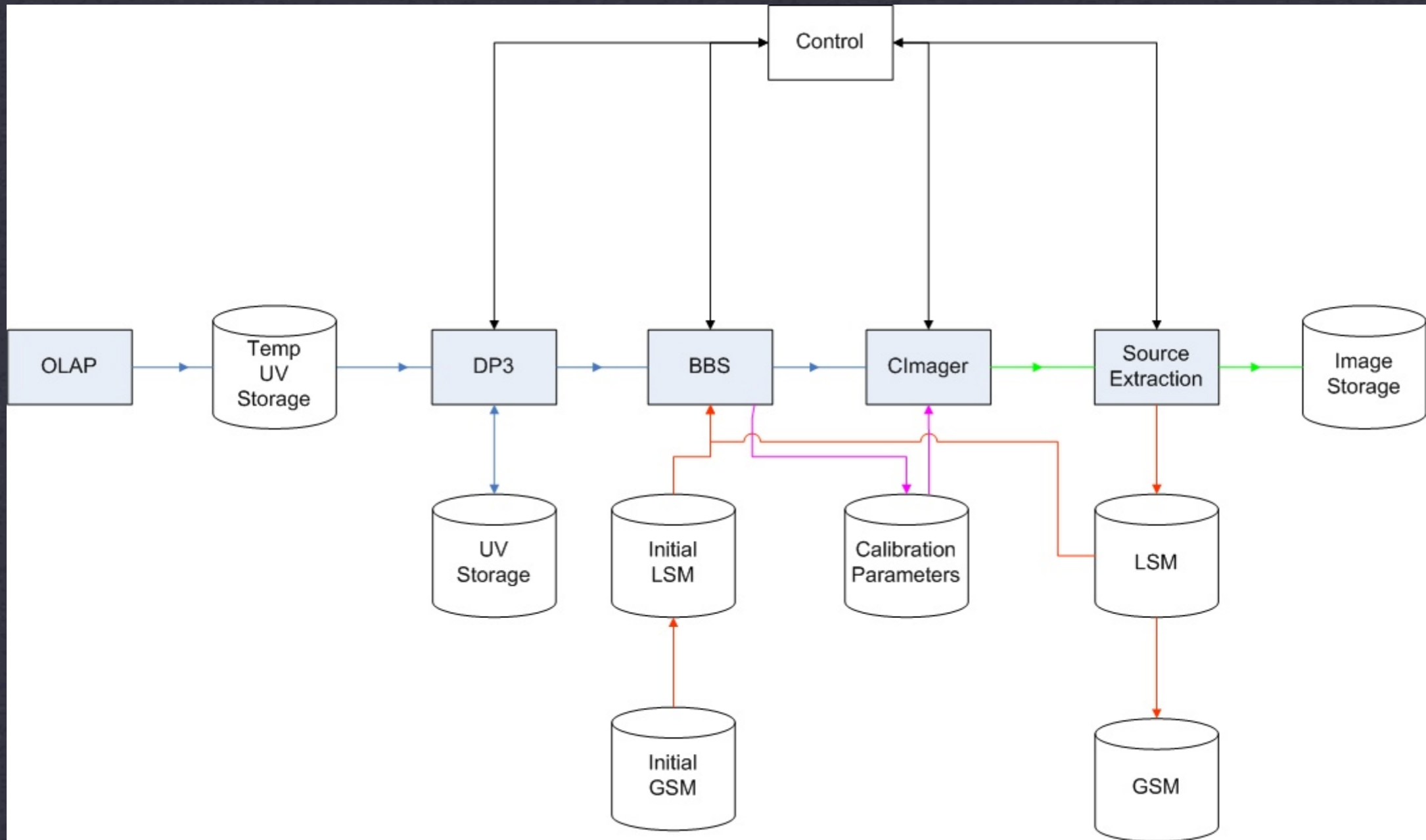


# Key Science Projects

- Epoch of Reionization
- Transients and Pulsars
- High Energy Cosmic Rays
- Surveys & the Distant Universe
- Cosmic Magnetism
- Solar Physics and Space Weather

**SCIENCE GOALS  
DRIVE THE DESIGN  
OF PIPELINES AND  
DATA PRODUCTS**



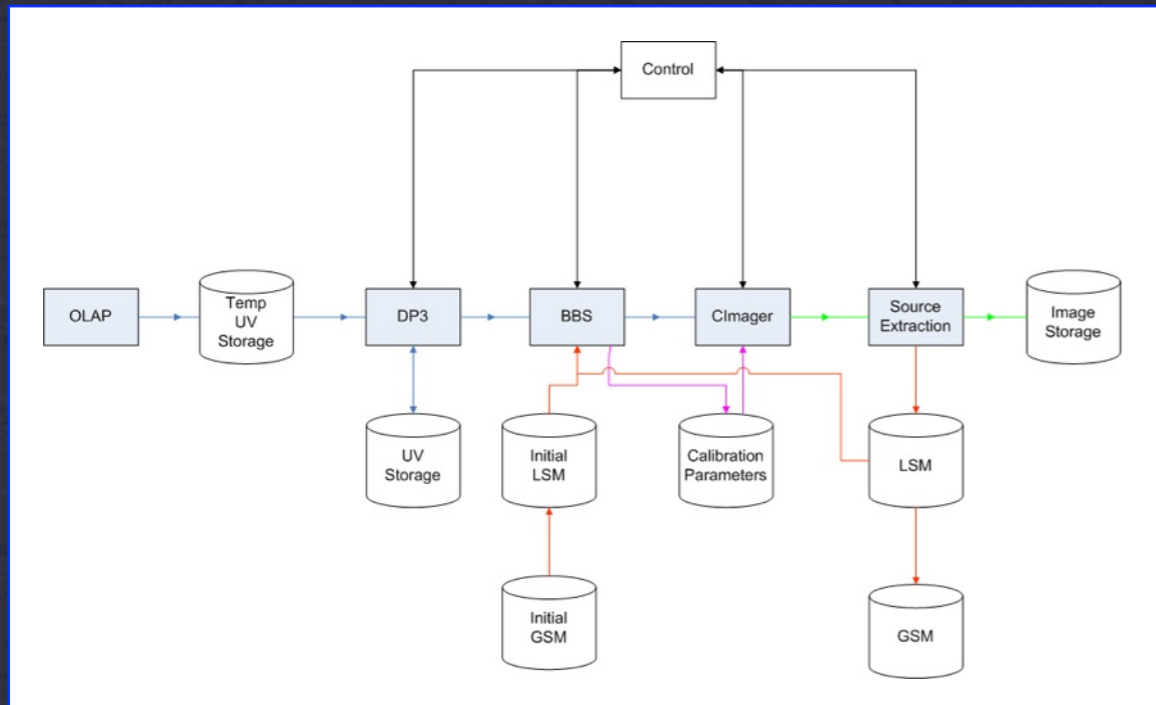


# THE STANDARD IMAGING PIPELINE DESIGN

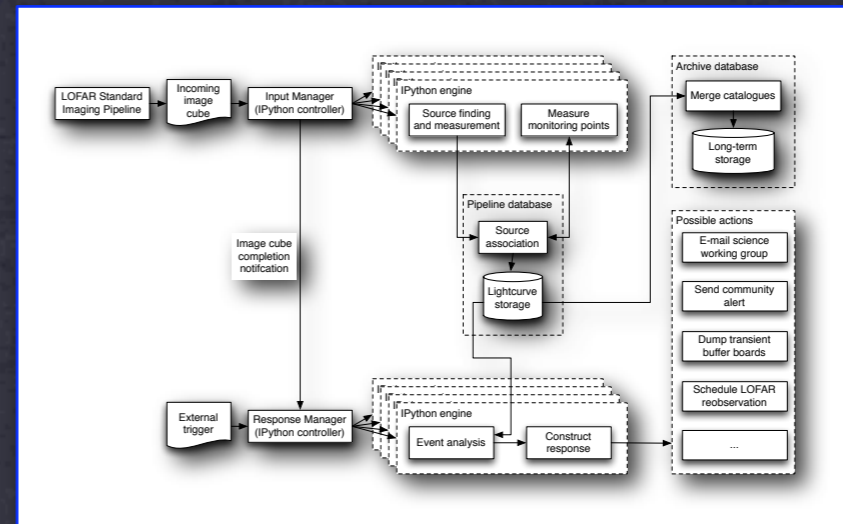
EVEN MAKING IMAGES WITH LOFAR REQUIRES ELABORATE PROCESSING STEPS



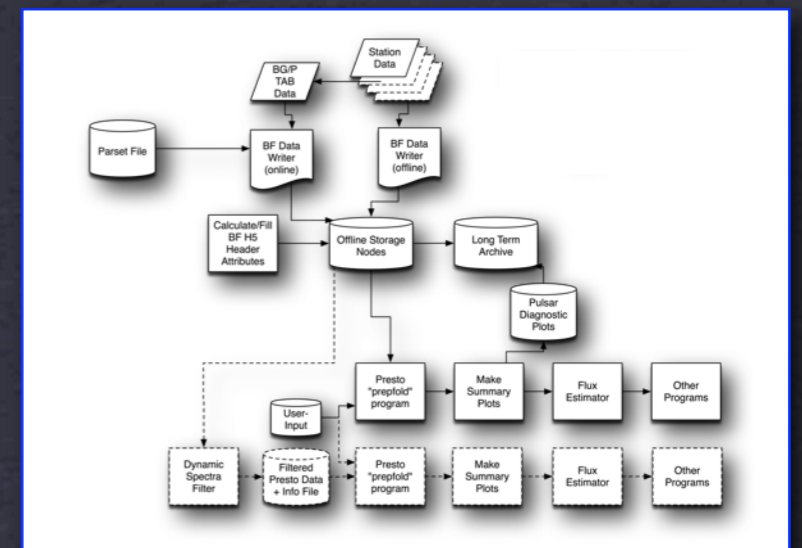
# Standard Imaging



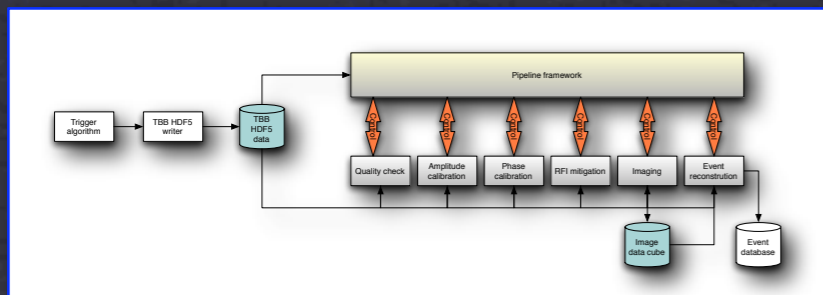
# Transient Detection



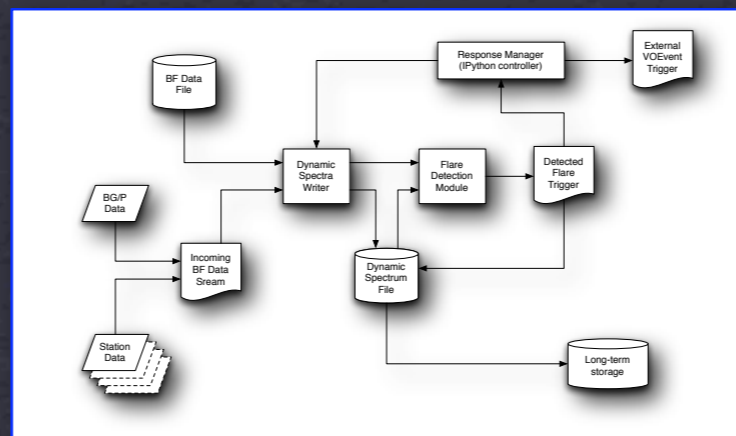
# Known Pulsars



# VHECR



# Dynamic Spectra



...THERE ARE MANY OTHER SCIENCE PIPELINES  
EACH PRODUCING A DIFFERENT KIND OF DATA



## LOFAR Data Format ICD TBB Time-Series Data

Document ID: LOFAR-USG-ICD-001.tex

Version 2.00.00

SVN Repository Revision: 5314

L. Bähren, K. Anderson, A. Corstanje, A. Horneffer, J. Masters

SVN Date: 2010-07-14

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## LOFAR Data Format ICD Radio Sky Image Cubes

Document ID: LOFAR-USG-ICD-004

Version 2.00.01

SVN Repository Revision: 5506

K. Anderson, A. Alexov, L. Bähren

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## LOFAR Data Format ICD Representations of World Coordinates

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L. Bähren, A. Alexov, K. Anderson, J.-M. Grießmeier

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## LOFAR Data Format ICD Beam-Formed Data

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Version 2.00.02

SVN Repository Revision: 5493

A. Alexov, K. Anderson, L. Bähren, J.-M. Grießmeier, J.W.T. Hessels,  
J.S. Masters, B.W. Stappers

SVN Date: 2010-08-06

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## LOFAR Data Format ICD File Naming Conventions

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A. Alexov, K. Anderson, L. Bähren, A. Gunst, H. Holtjes, M. Wise

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## LOFAR Data Format ICD Dynamic Spectrum Data

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J.-M. Grießmeier, A. Alexov, K. Anderson, L. Bähren

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## LOFAR Data Format ICD Visibility Data

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K. Anderson

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## LOFAR Data Format ICD Rotation Measure Synthesis Cubes

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Version 0.03.01

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J. Anderson, L. Bähren, M. Bell, T. Riller

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**MANY PIPELINES → MANY DATA PRODUCTS**  
**LOFAR WILL PROVIDE A COMPLETE SUITE, BASED ON HDF5**



# Current Status

- ➔ 20+ Dutch & 2 international stations complete
- ➔ Further 10+ stations currently under construction
- ➔ Initial science pipelines undergoing testing
- ➔ MSSS: Million Source Sky Survey, first major science project, to start within (a very few) months



Long Wavelength Array

MeerKAT



Allen  
Telescope  
Array

ASKAP

Murchison Widefield Array

**THE “NEW GOLDEN AGE” OF RADIO ASTRONOMY**

NEW DATA FORMATS NEEDED NOT JUST FOR LOFAR, BUT MOVING FORWARDS TO SKA