

# LOFAR Overview

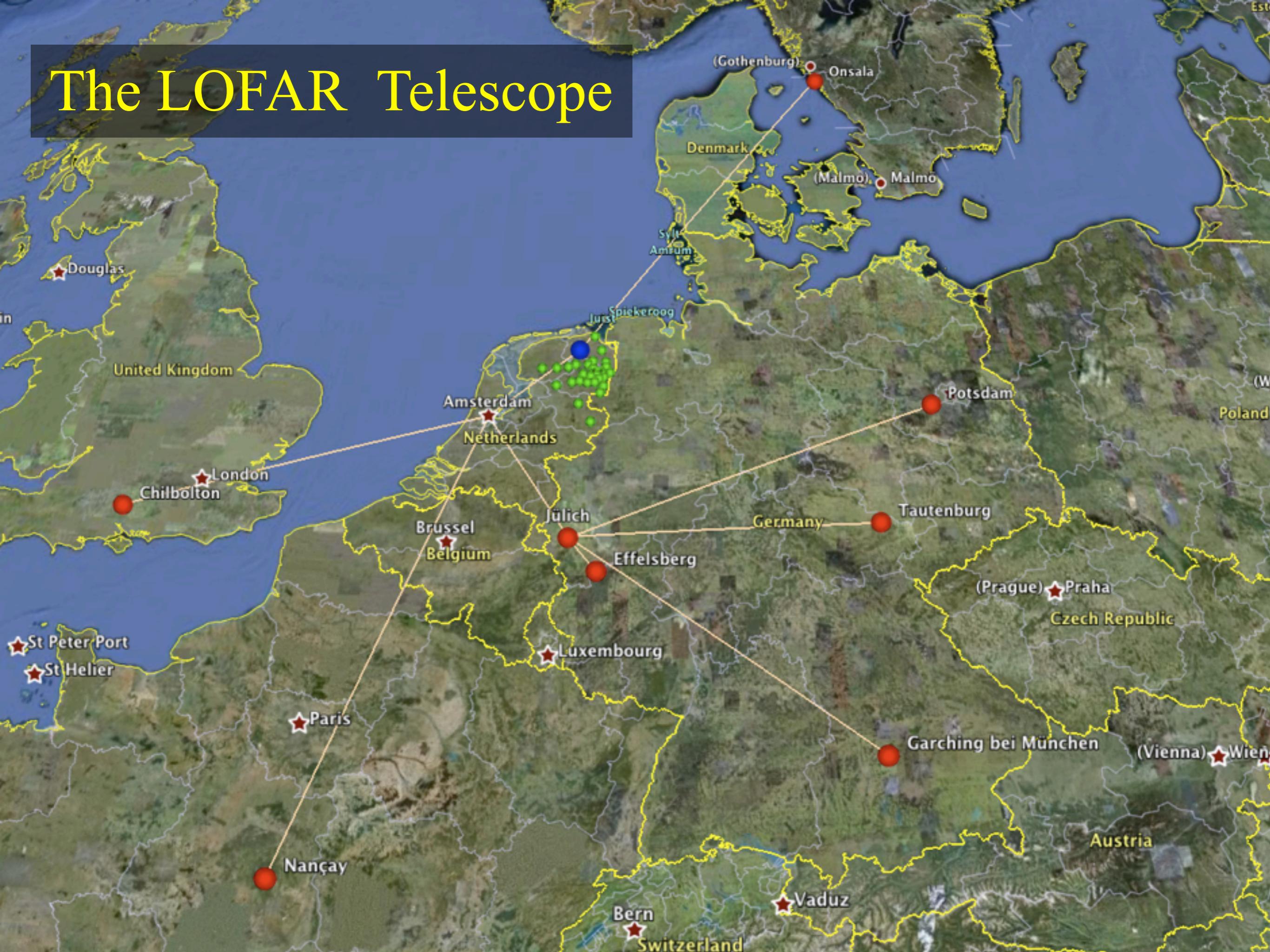
*2<sup>nd</sup> LOFAR Data Analysis School  
October 11, 2010*

Michael Wise  
ASTRON / LOFAR / UvA

# LOFAR Overview

*Station and System Components  
Dataflow and Processing Hardware  
Key Science Drivers  
Science Pipelines*

# The LOFAR Telescope



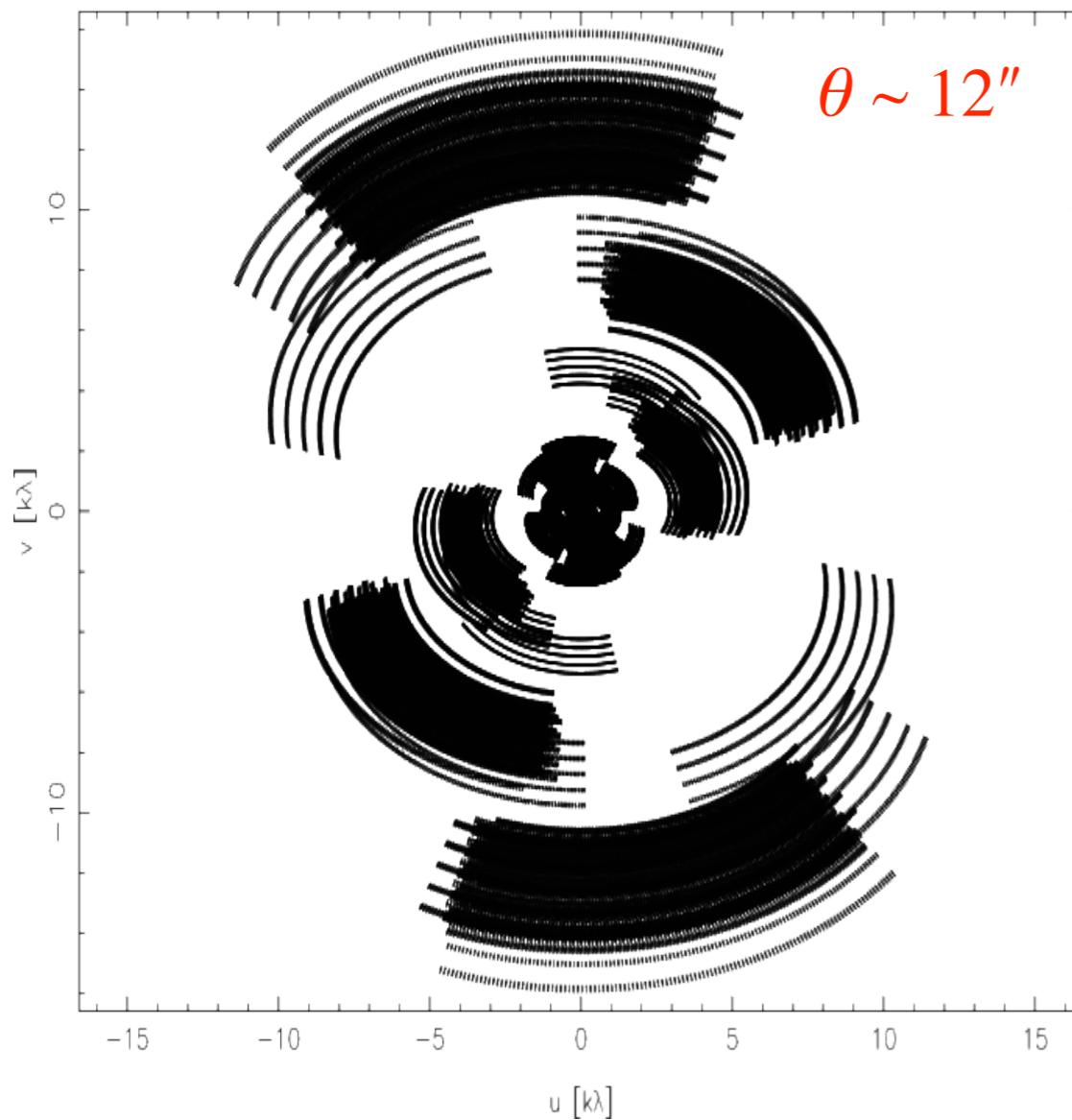
# LOFAR Superterp

*June 2010*

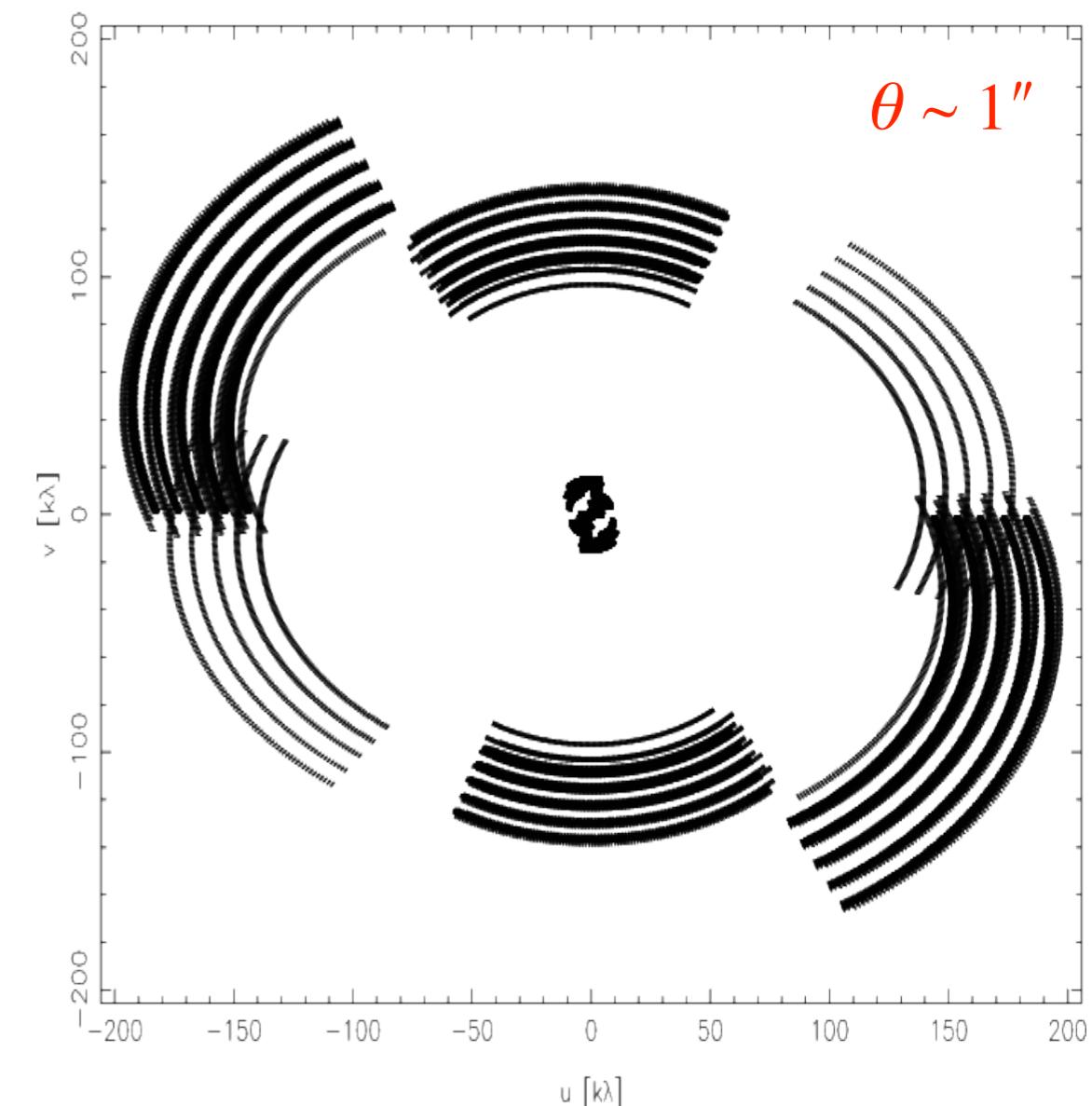


# Current $uv$ -plane coverage

*NL-only baselines*



*NL+International baselines*



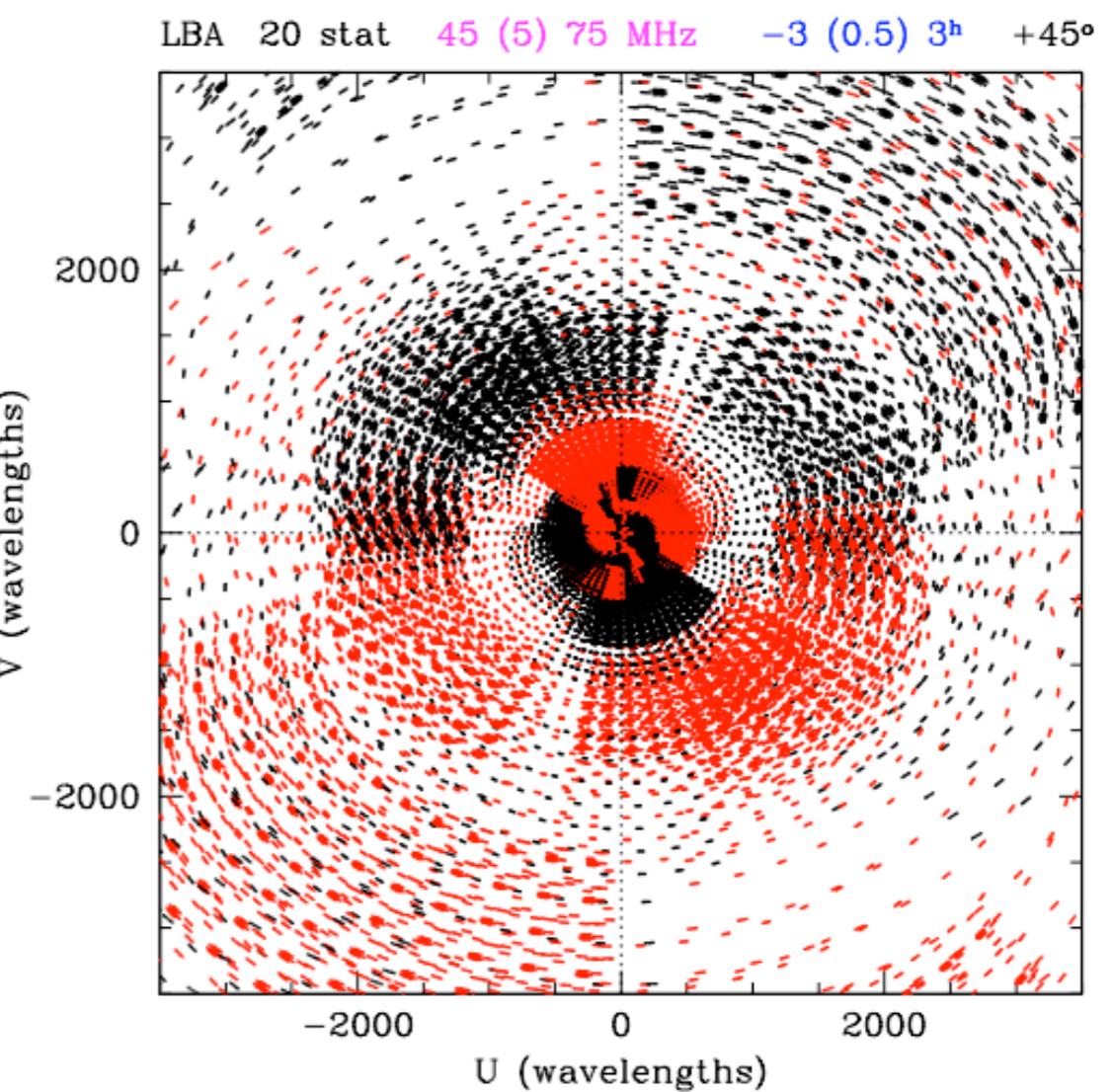
Dec=+47 deg 120-155 MHz

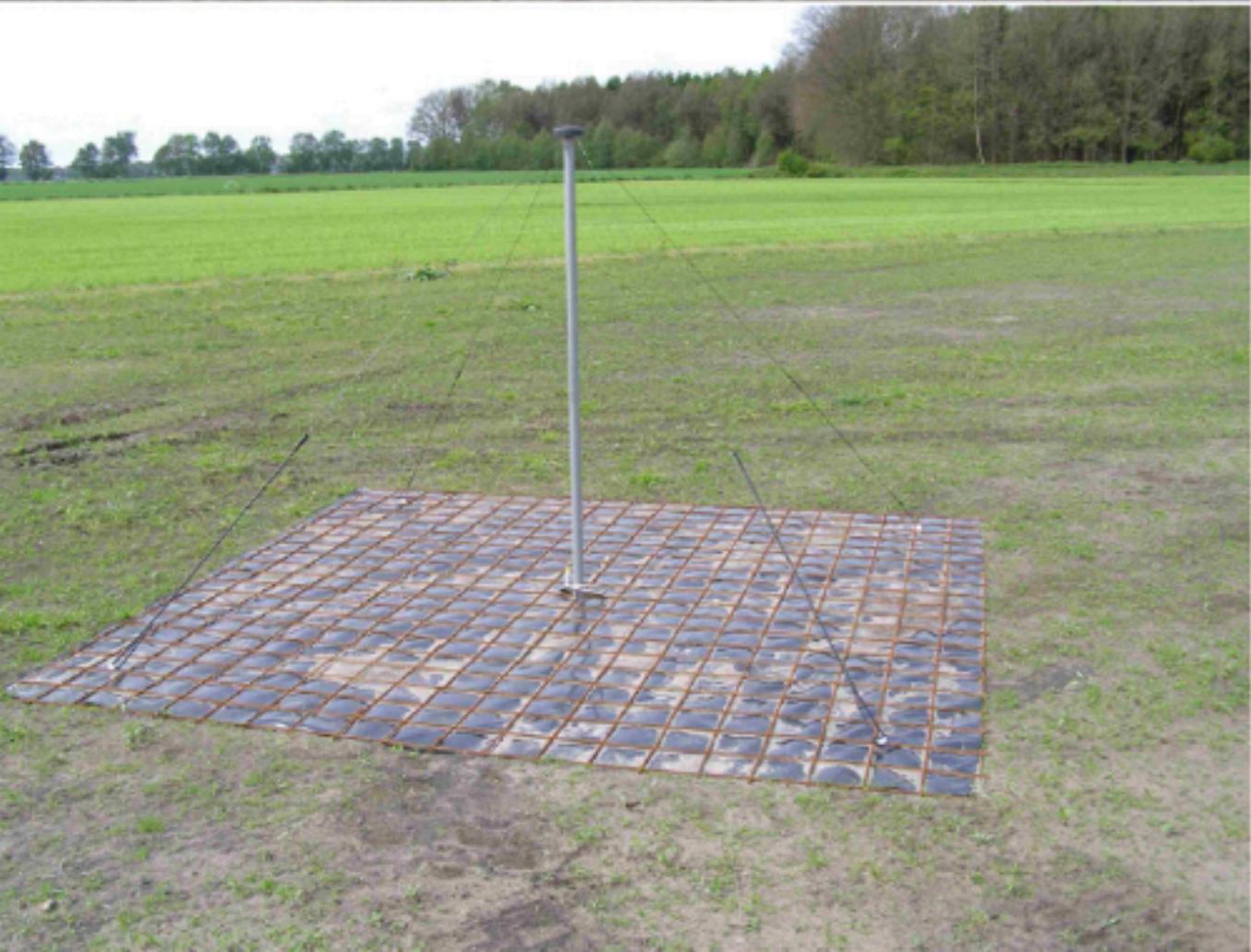
Freq. (MHz)	$\lambda$ (m)	Resolution $L = 2 \text{ km}$ (arcsec)	Resolution $L = 10 \text{ km}$ (arcsec)	Resolution $L = 80 \text{ km}$ (arcsec)
15	20.0	1650	330	41.3
30	10.0	825	165	20.6
45	6.67	550	110	13.8
60	5.00	413	82.5	10.3
75	4.00	330	66.0	8.25
120	2.50	206	41.3	5.16
150	2.00	165	33.0	4.13
180	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

*(NL-only baselines)*



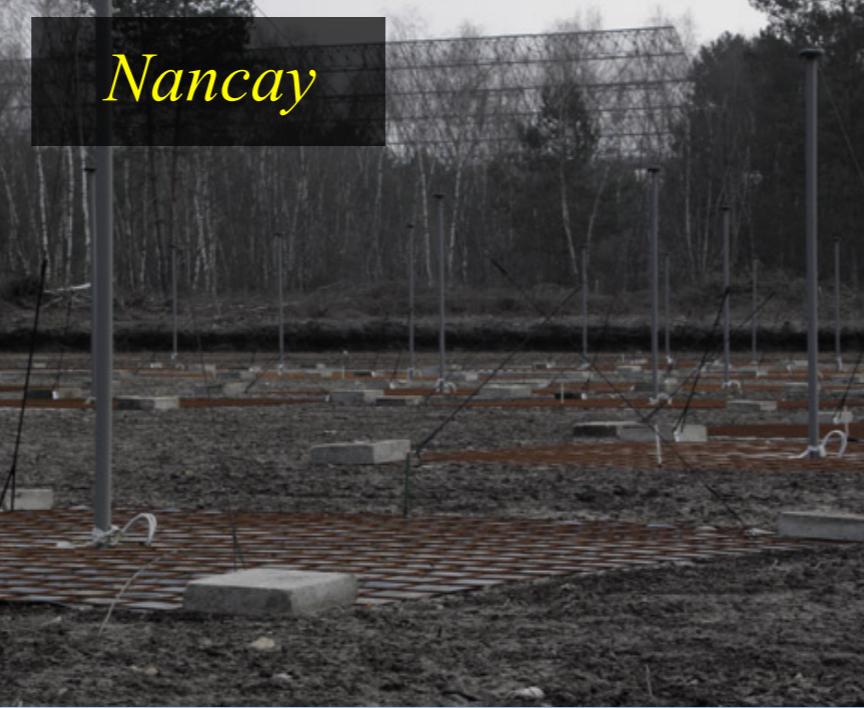




*Effelsberg*



*Nancay*



*Garching*



*Chilbolton*



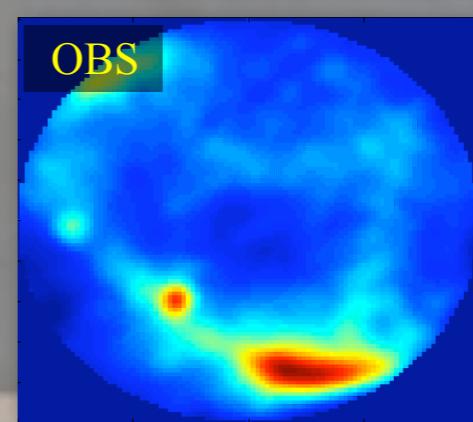
*Tautenburg*



*Potsdam*



Station/Item	Cabinet	LBA	HBA	Fibre	CEP connection	Validated
CS302						
RS307						
RS503						
RS106						
RS208						
CS030						
CS401						
CS021						
CS032						
RS306						
CS301						
CS501						
RS509						
CS103						
CS001						
CS002						
CS003						
CS004						
CS005						
CS006						
CS007						
CS024						
CS201						
CS101						
CS026						
RS205						
CS017						
CS011						
CS013						
CS028						
CS031						
RS104						
RS210						
RS310						
RS404						
RS406						
RS407						
RS409						
RS410						
RS508						
Effelsberg						
Tautenburg						
Garching						
Potsdam						
Juelich						
Nancay						
Onsala						
Chilbolton						
Totals	39	39	37	35	30	28



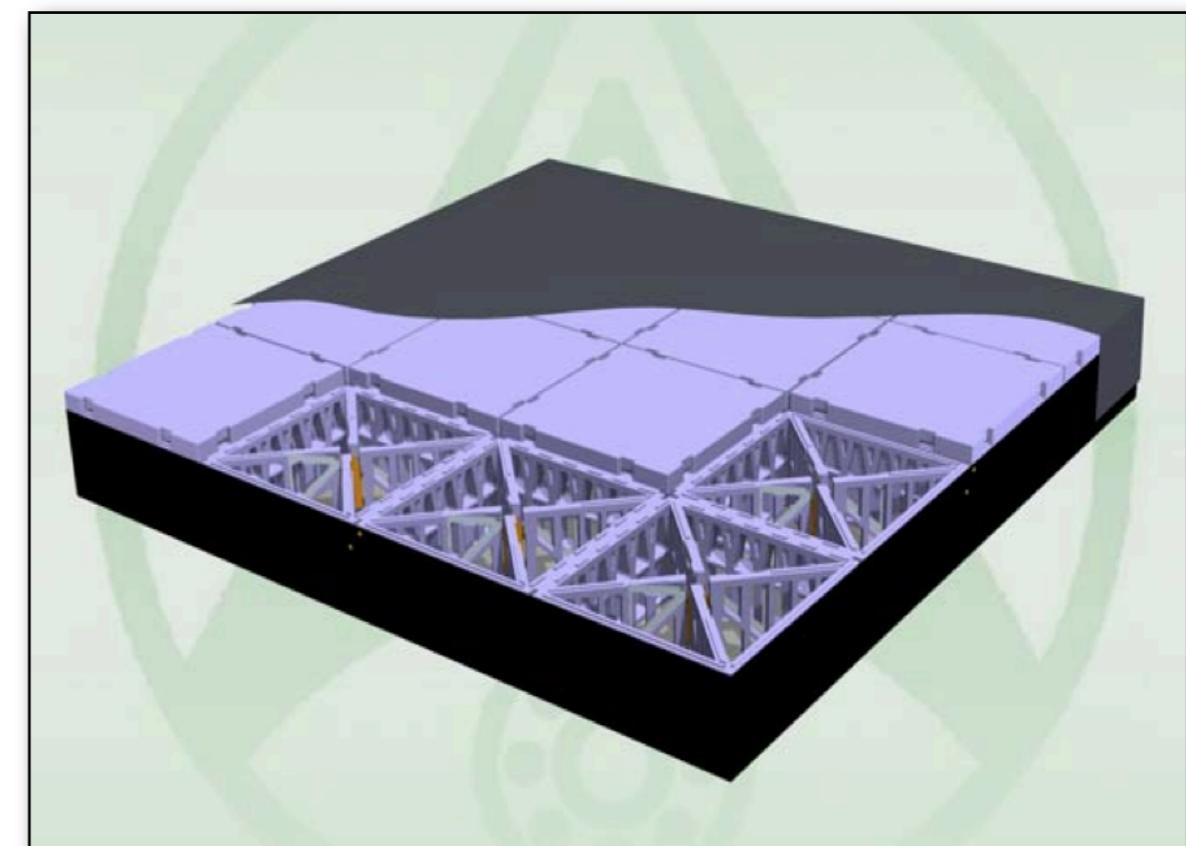


Low band antenna: 30 – 80 MHz  
48/96 antennas per station

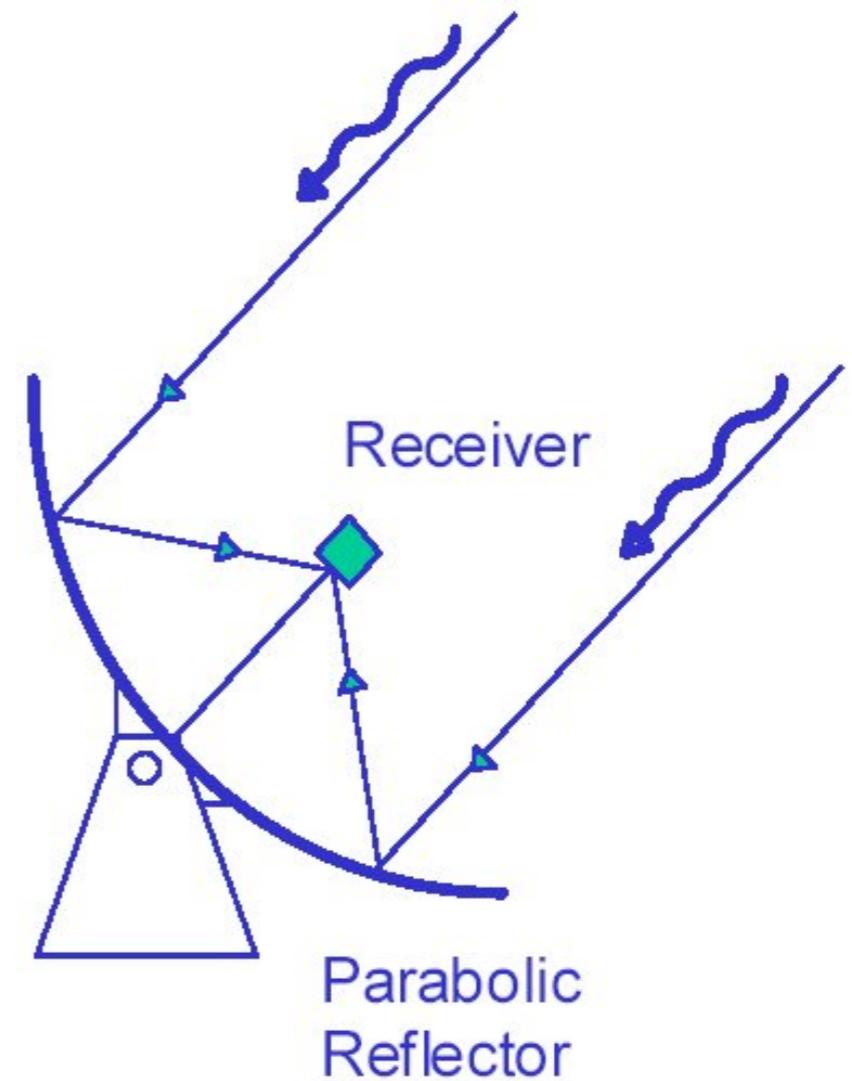
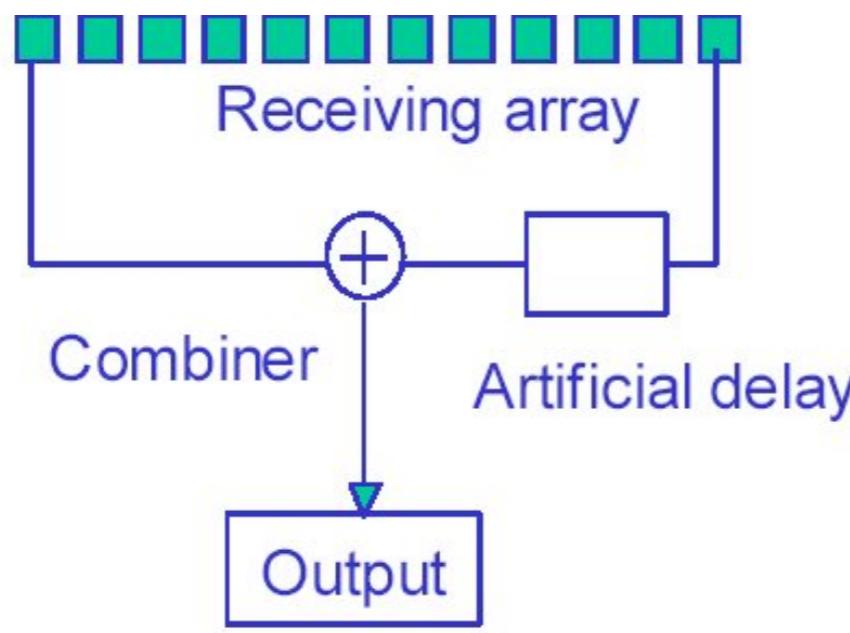
- 40 NL + 8 EU stations of dipoles
- Replace big dishes by many cheap dipoles
- No moving parts: electronic beam steering
- Flexible digital beam forming

## LOFAR Antennas

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

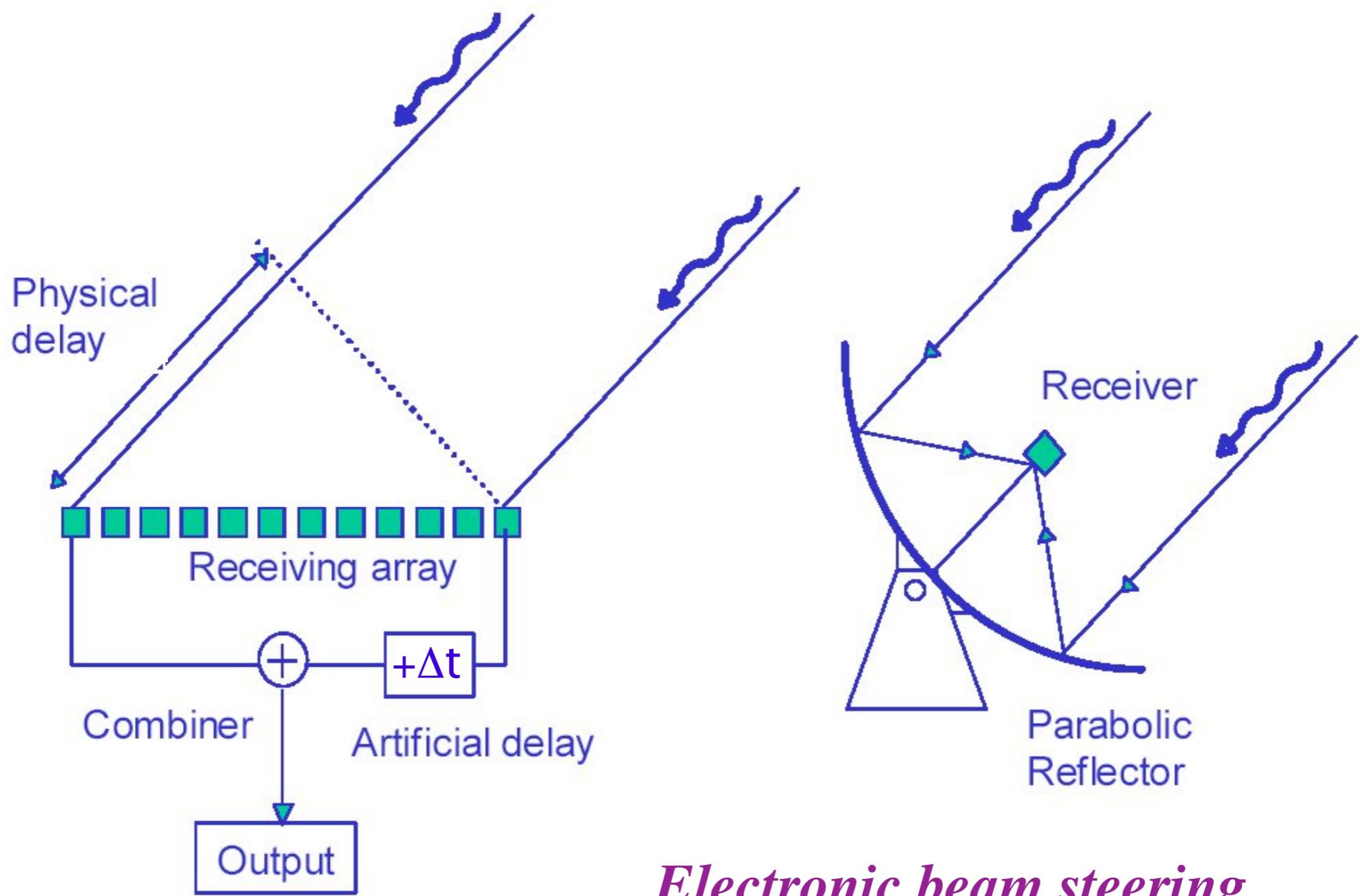


# Phased Array Detectors

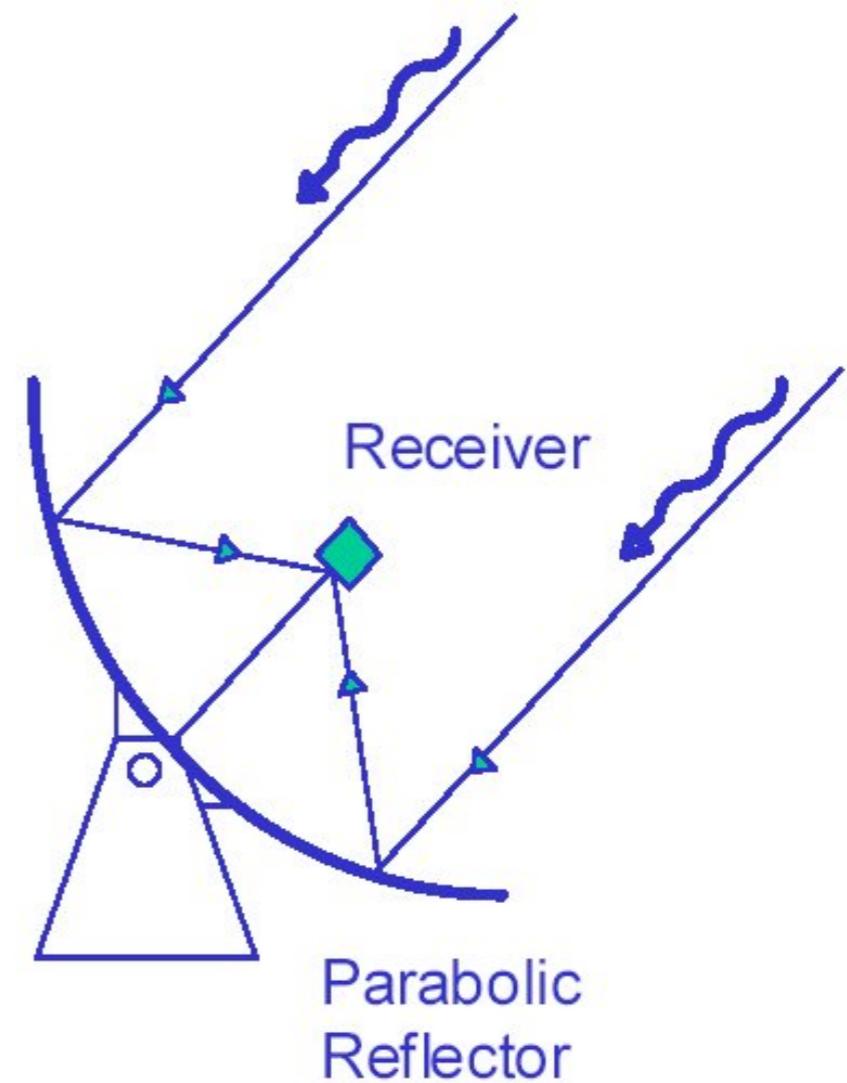
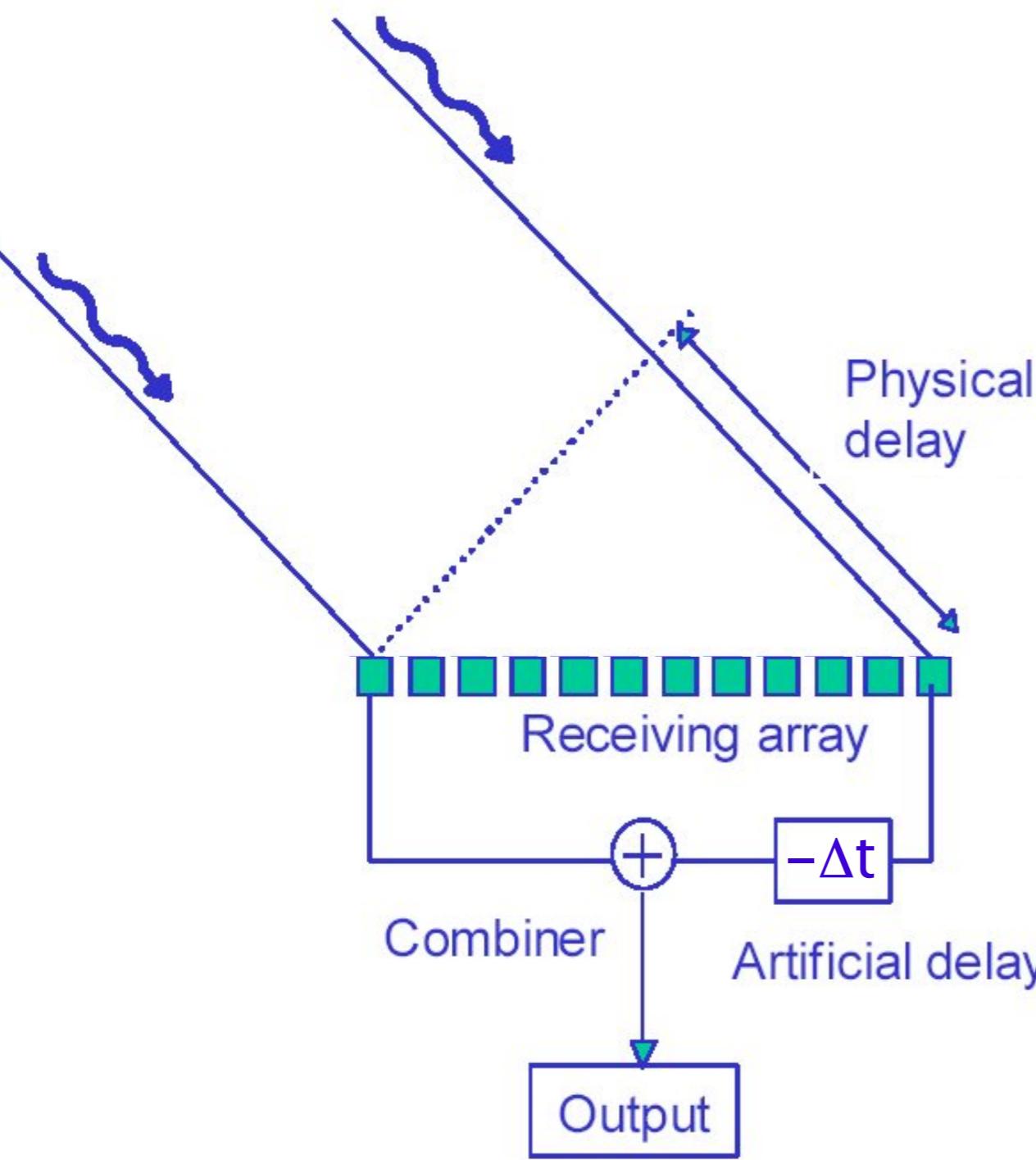


*Electronic beam steering*

# Phased Array Detectors

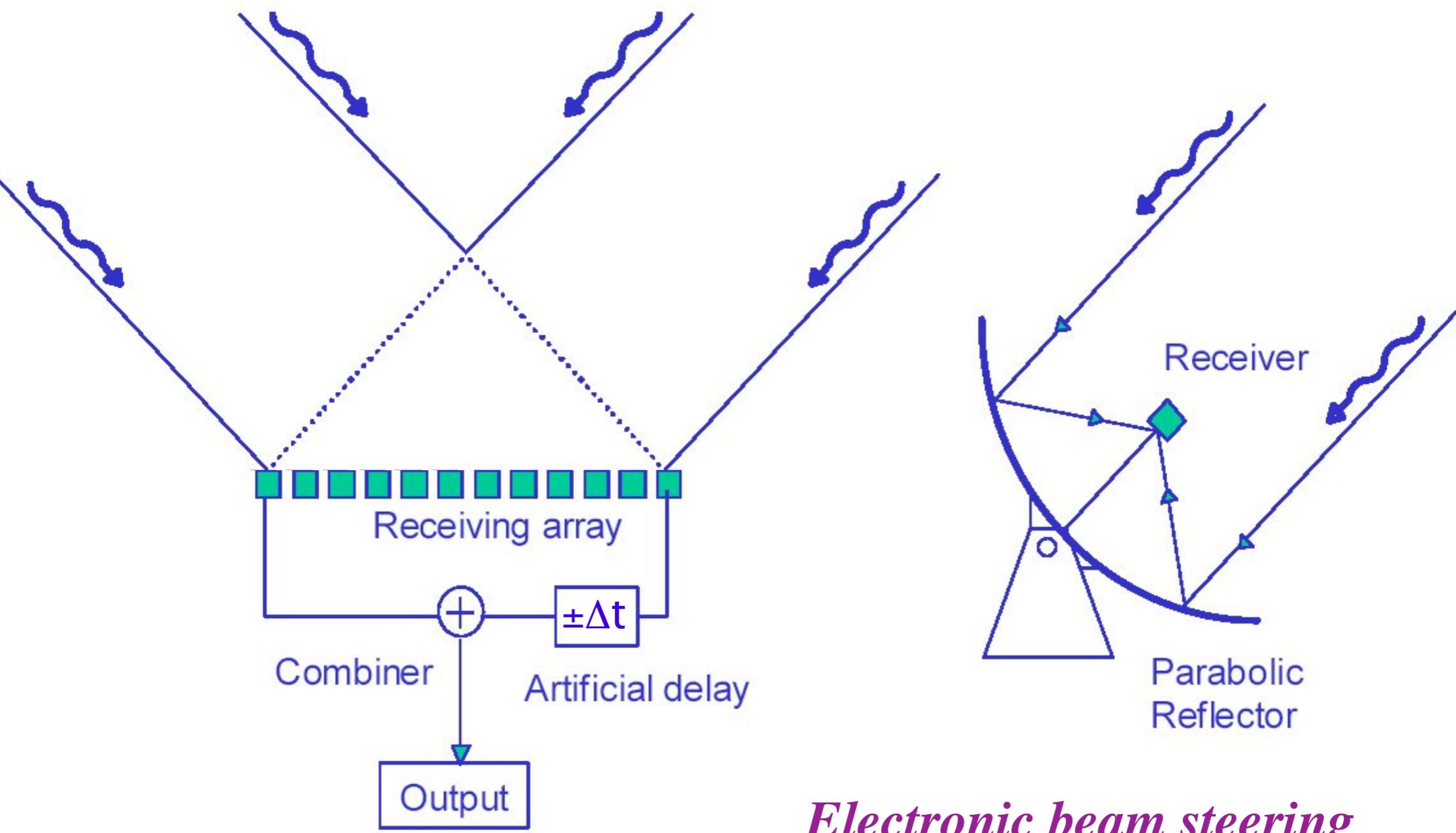


# Phased Array Detectors



*Electronic beam steering*

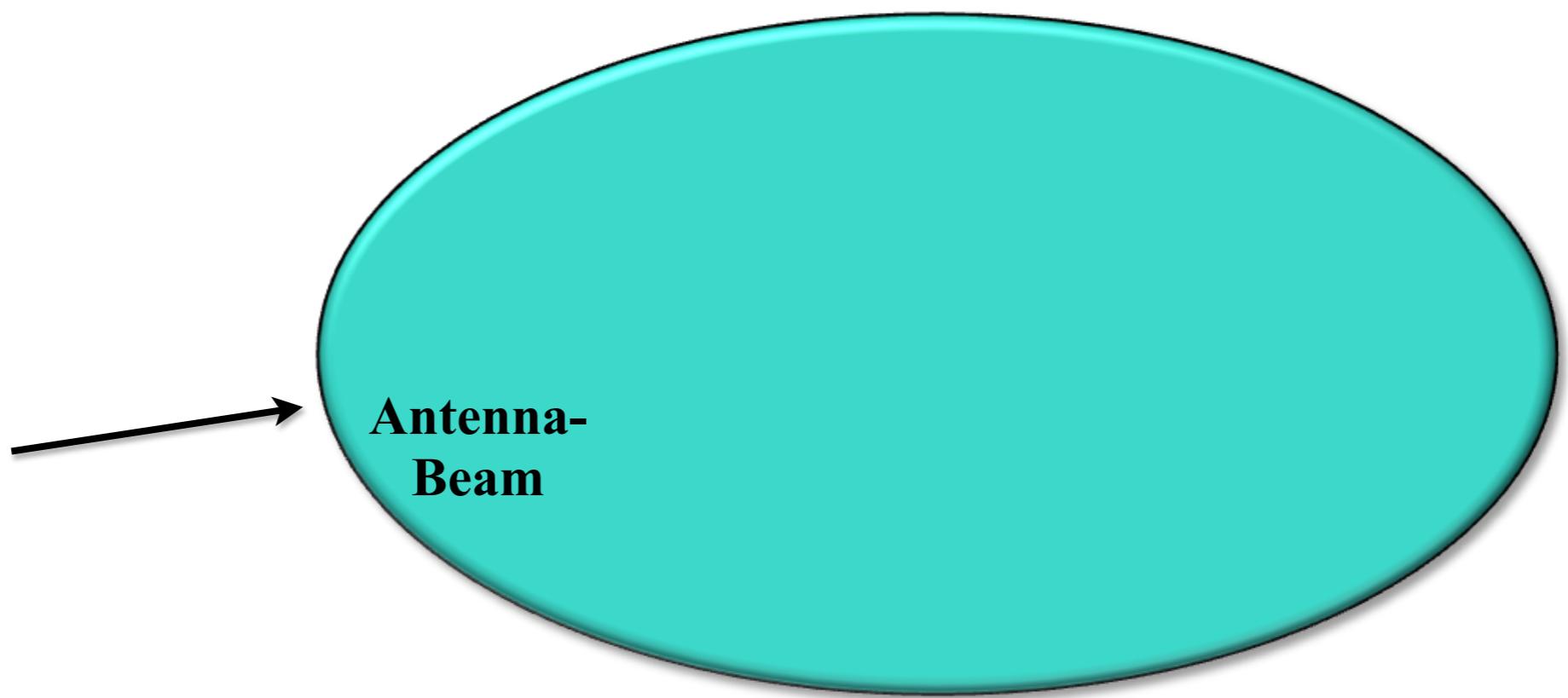
# Phased Array Detectors

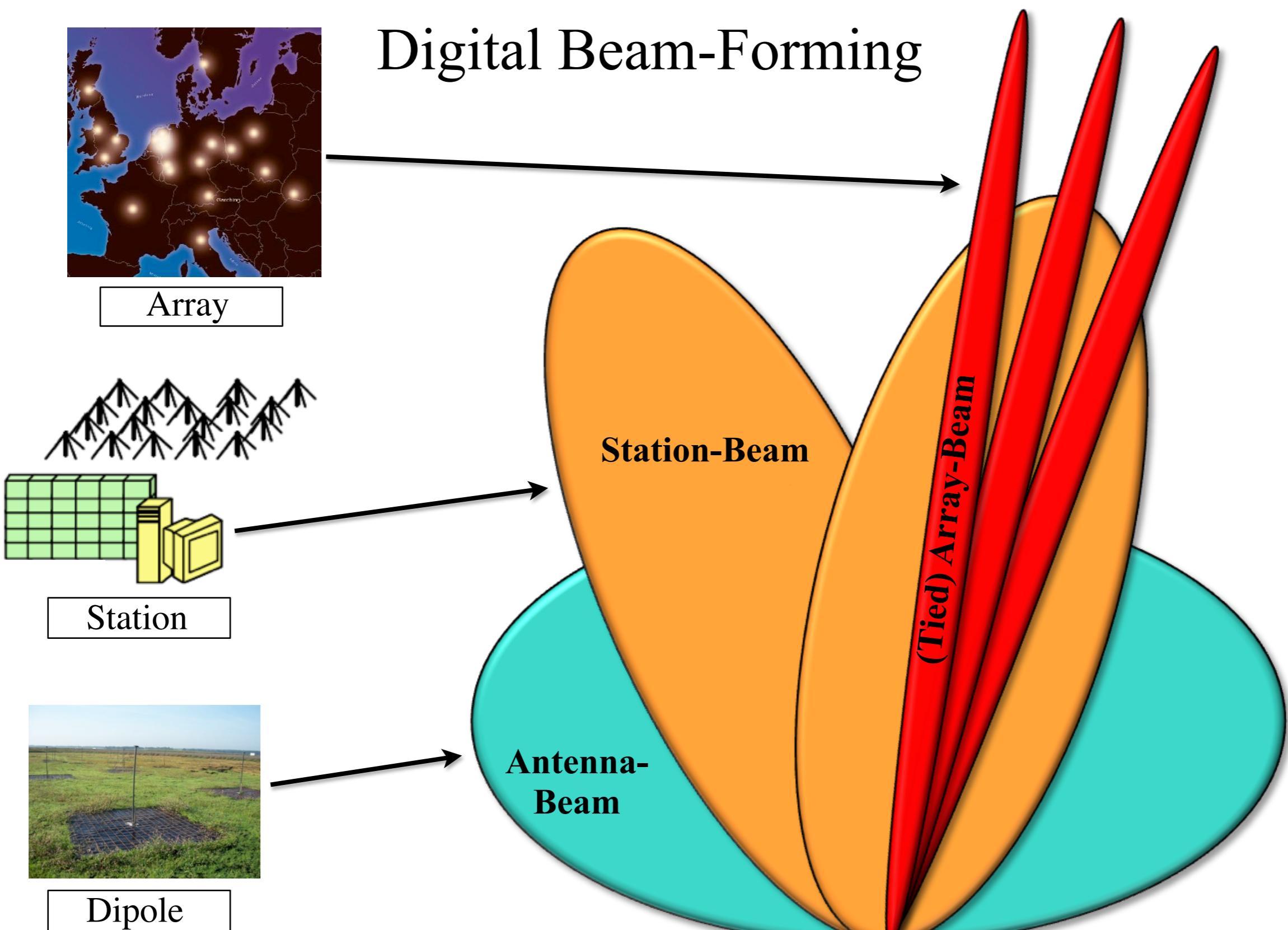


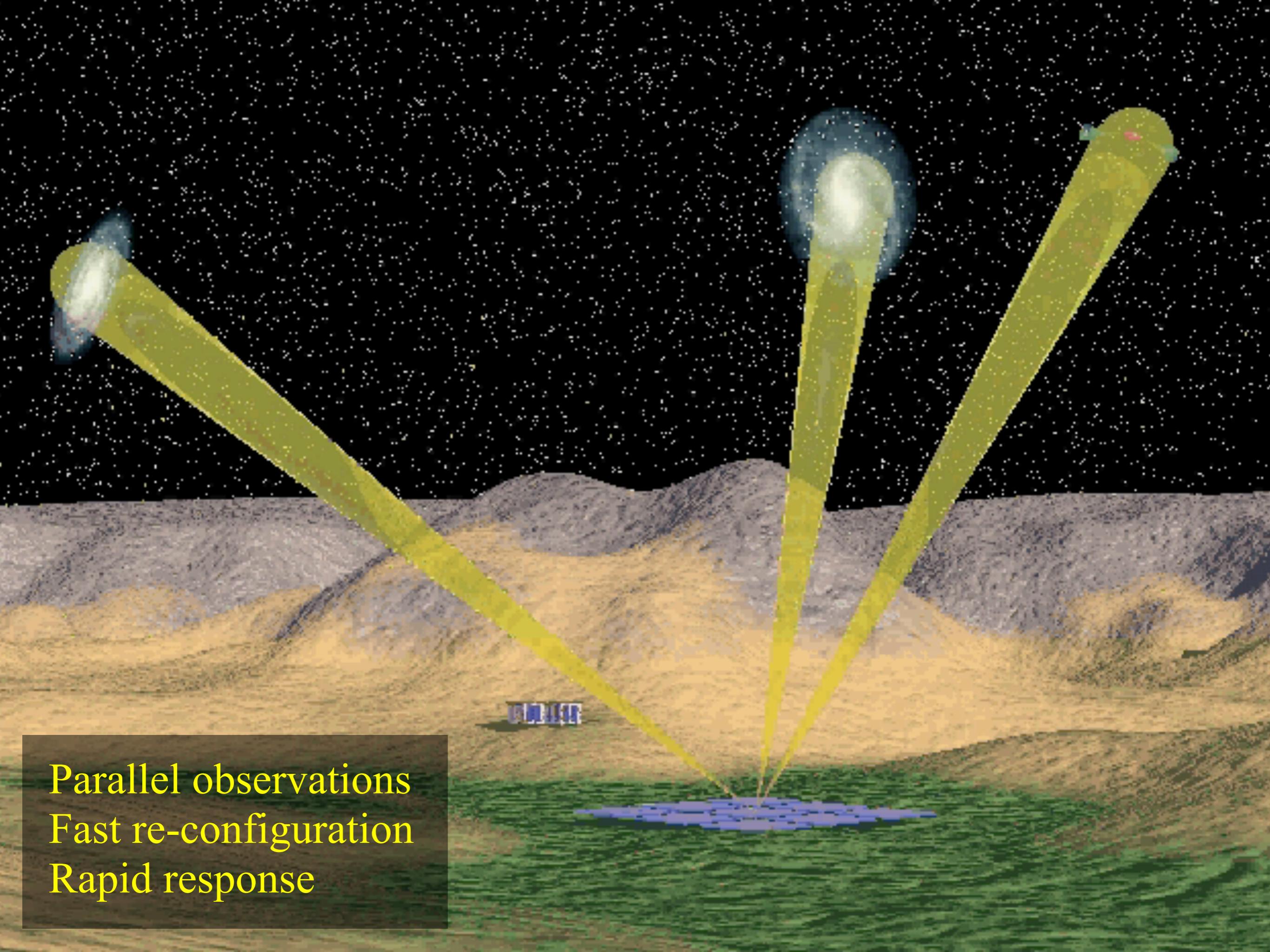
# Digital Beam-Forming



Dipole



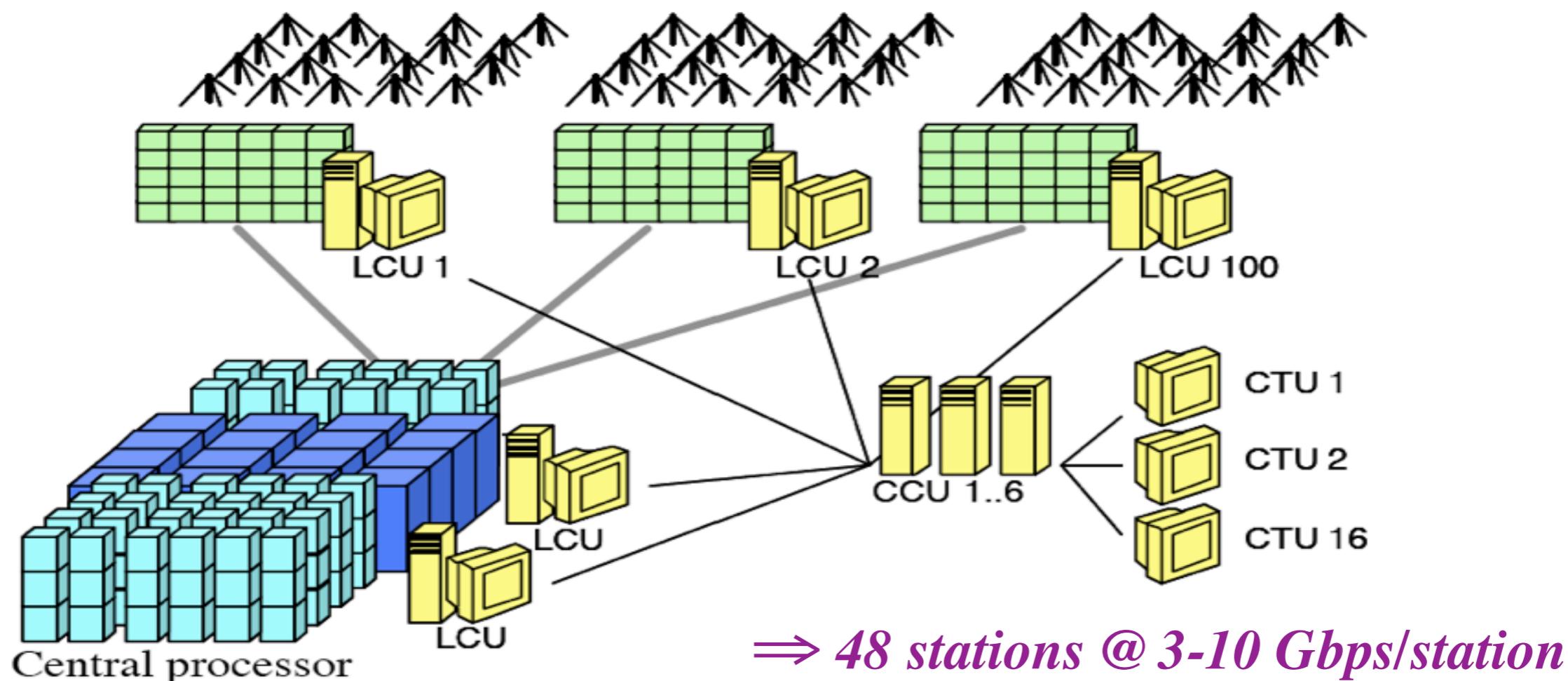




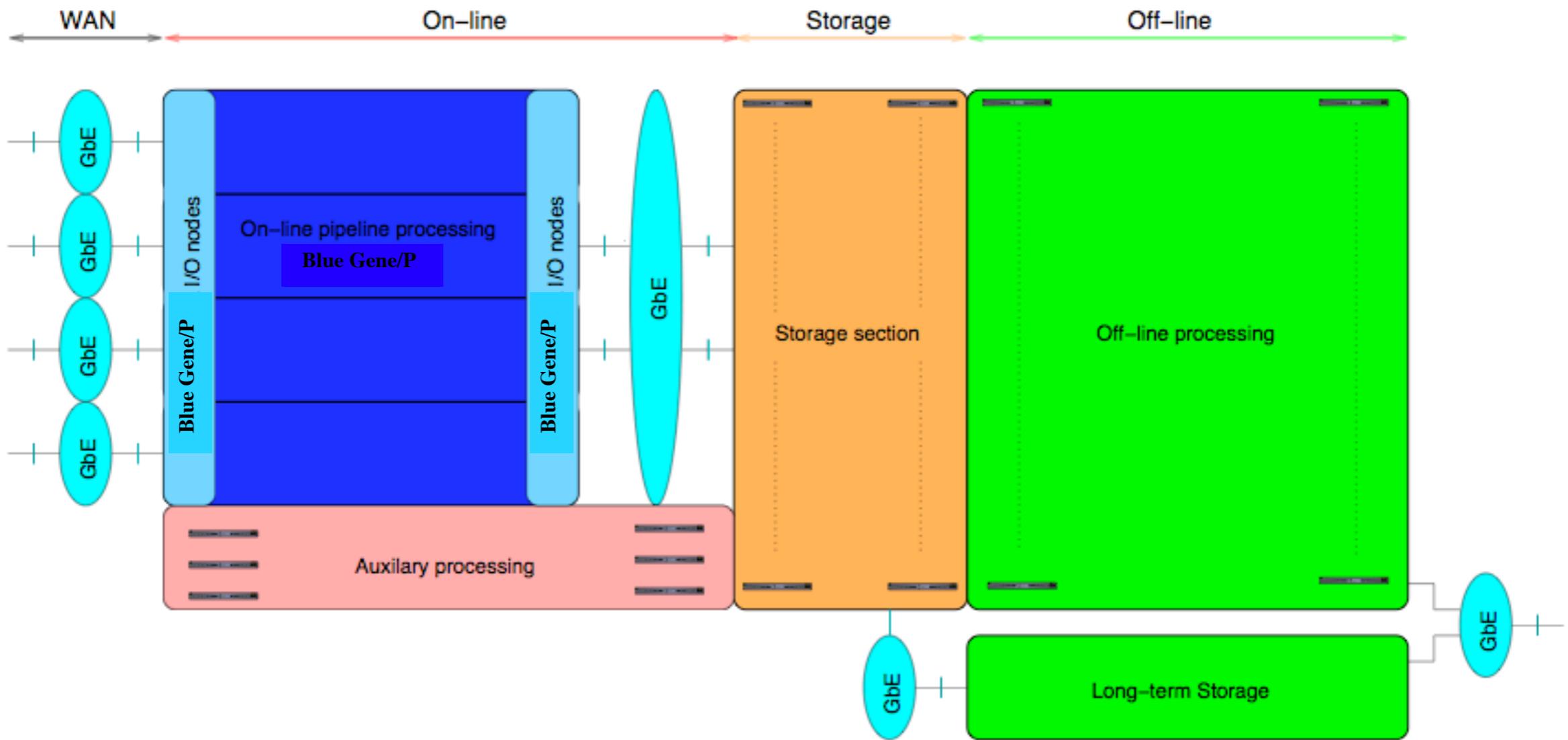
Parallel observations  
Fast re-configuration  
Rapid response

# LOFAR Data Flow

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



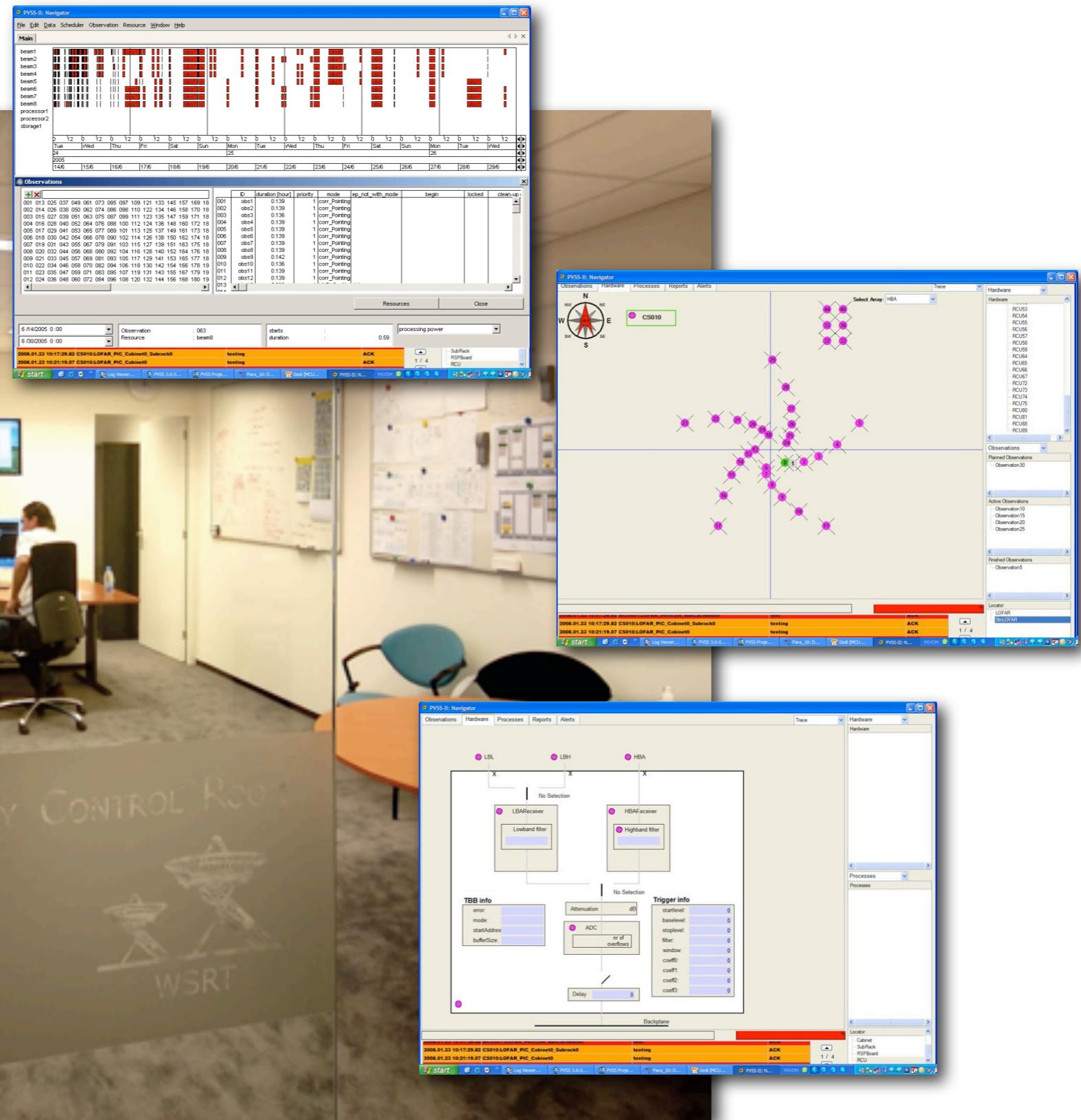
# Central Processing



- BG/P *Data reception, transpose, correlation, beam-forming, de-dispersion, 45 TFLOPS*
  - Storage system *Short term storage of data, ~2 PByte, >100Gb/s I/O*
    - Offline cluster *Pipelines, data products, off-line analysis, ~25 TFLOPS*



# Remote Operation



# LOFAR Science Drivers

## Key Science Projects

*Epoch of Reionization*

*Transients and Pulsars*

*High Energy Cosmic Rays*

*Surveys and the Distant Universe*

*Cosmic Magnetism*

*Solar Physics and Space Weather*

⇒ International membership from all partner countries  
Contribute development and commissioning resources

**45 Mhz, 24 hrs**

1500

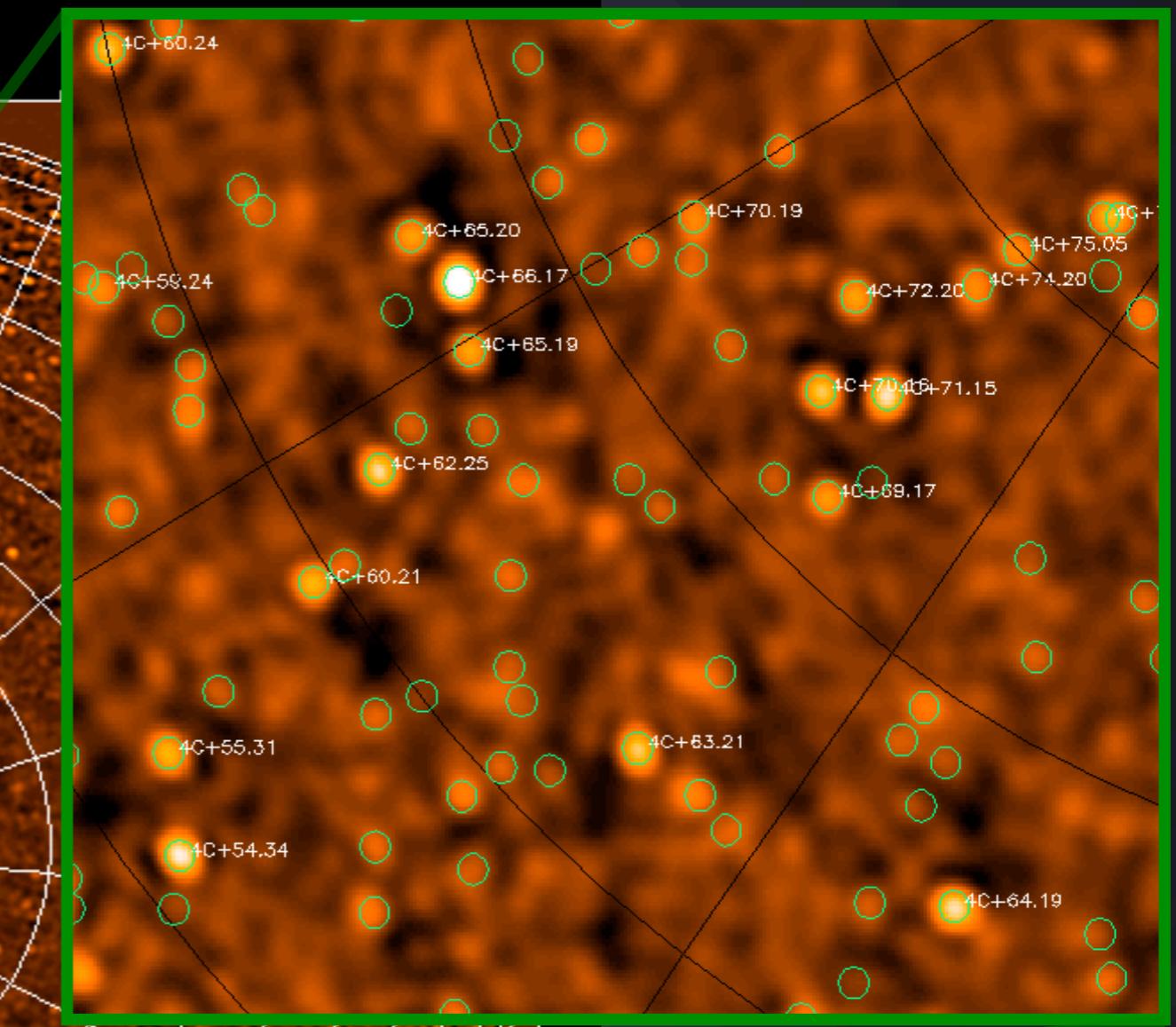
1000

500

500

1000

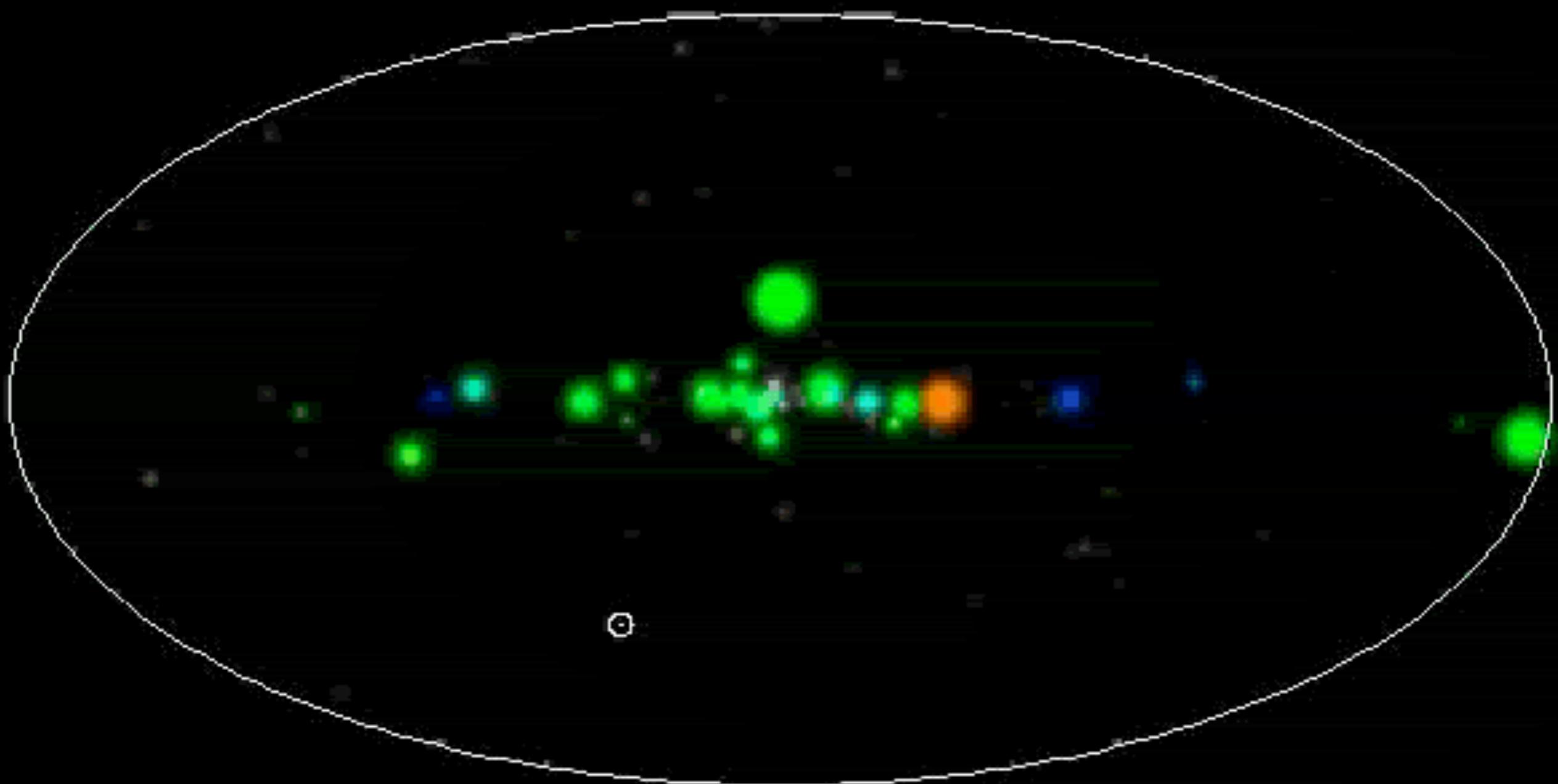
1500



## All-sky Surveys with LOFAR

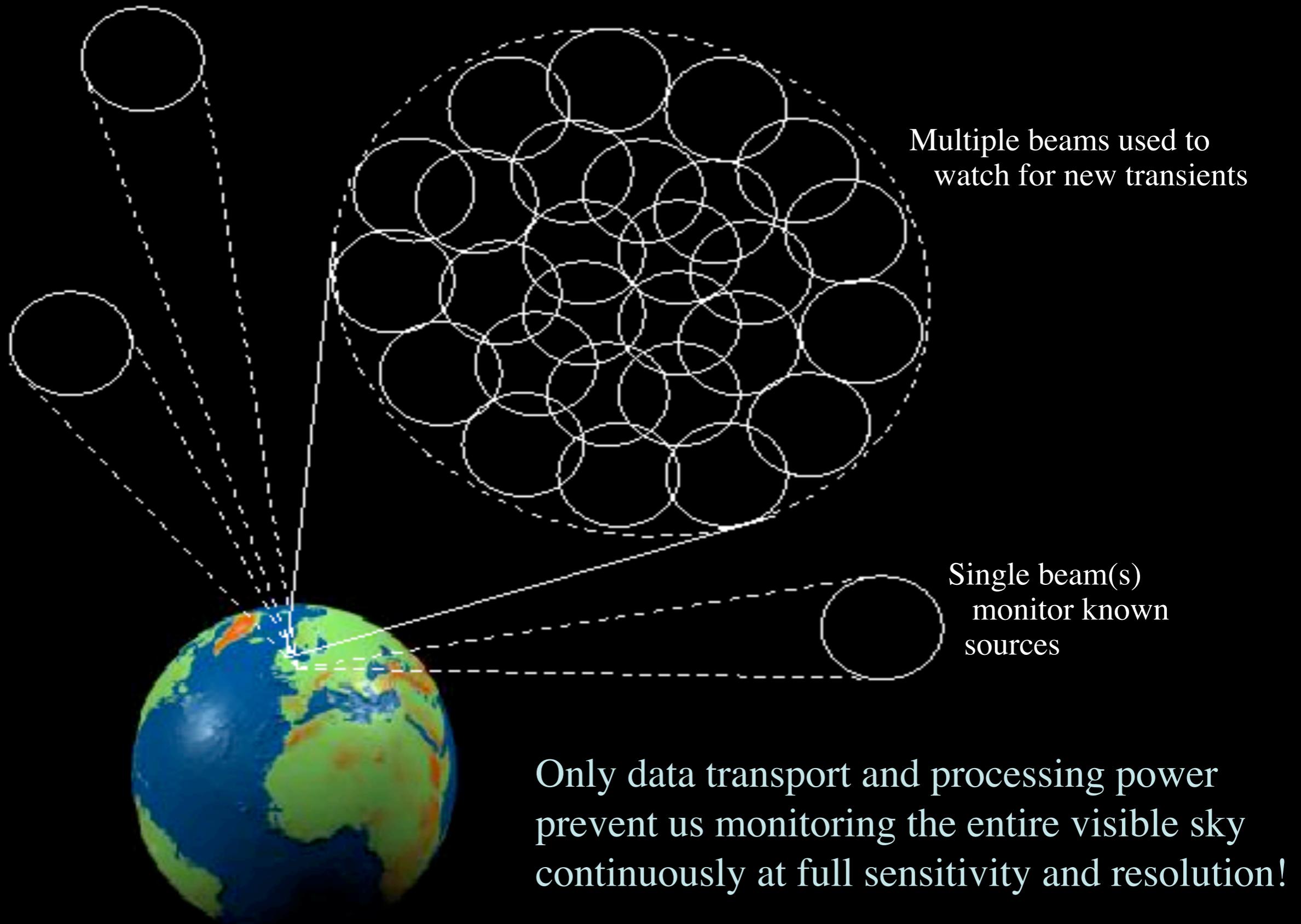
50+ supernova remnants,  
100's of clusters  $z < 0.6$ ,  
Protoclusters at  $z \sim 2$ ,  
Many  $z > 2$  radio galaxies,  
Halos, relics, etc...

# The RXTE All-Sky Monitor Movie

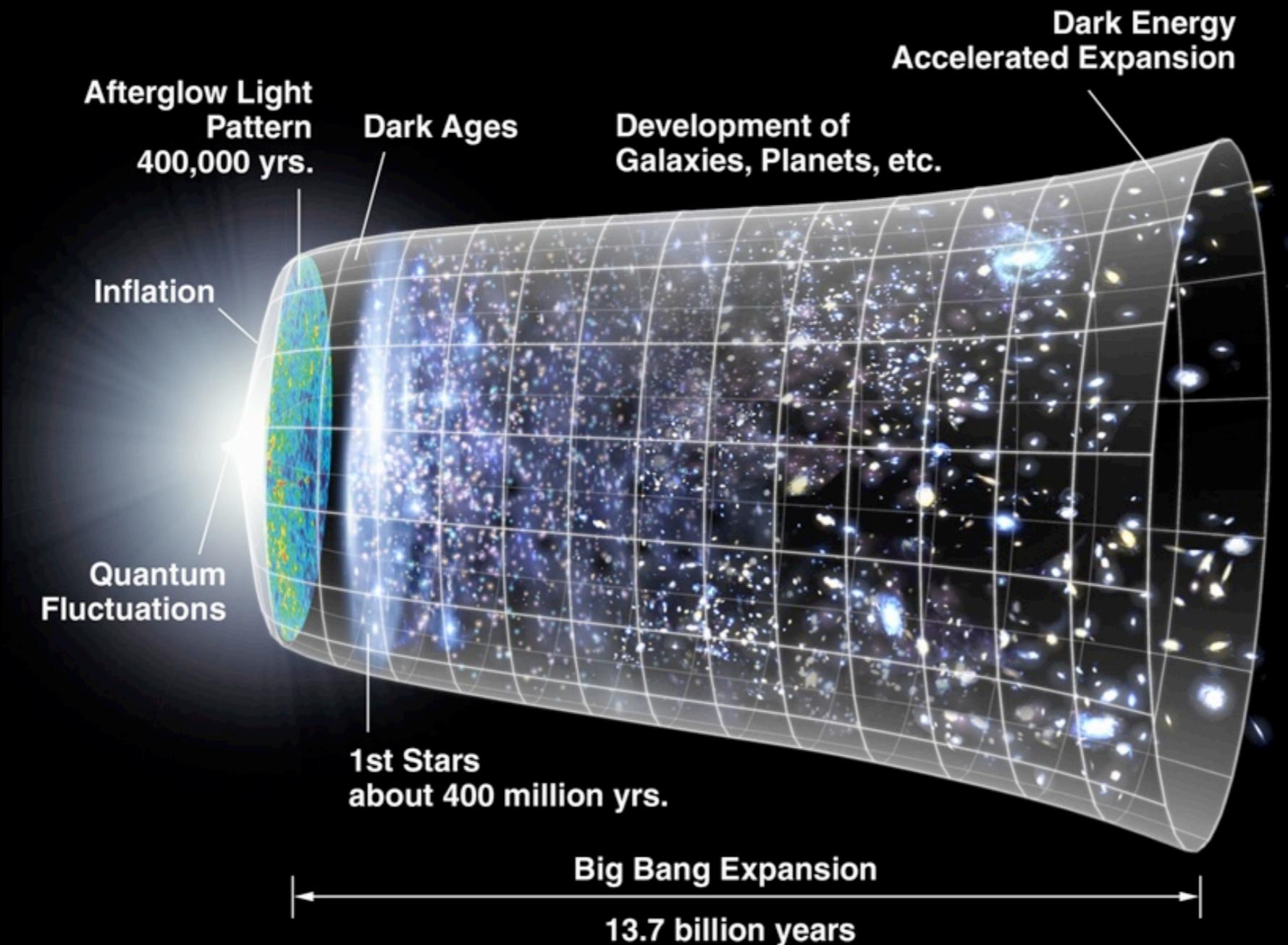


02 / 23 / 1996

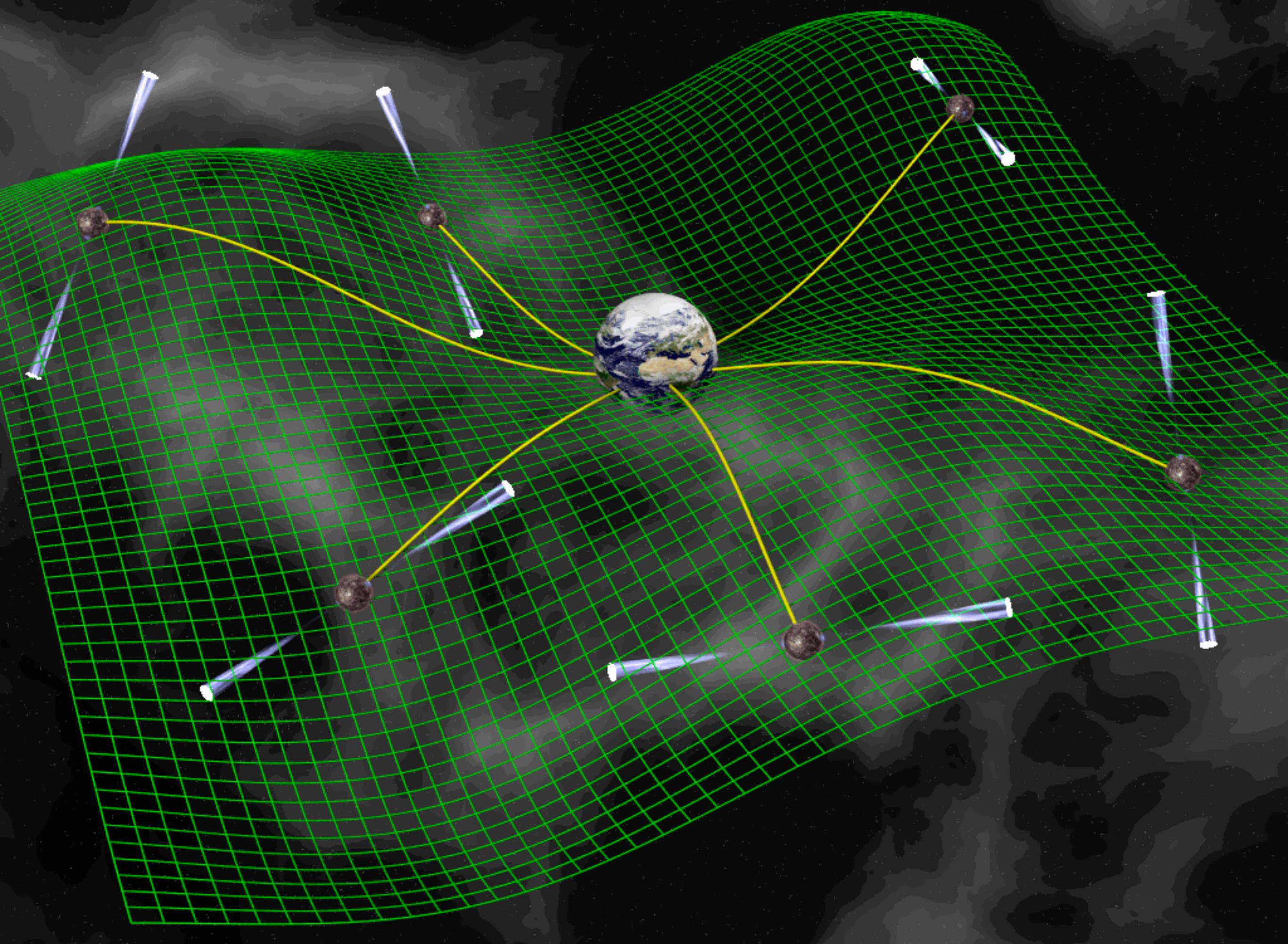
**Radio Sky Monitor:** Multiple station beams tile out a significant fraction of the sky and detect transients sources on timescales down to 1 second



# The LOFAR Epoch of Reionization Key Science Project



Goal: Tracing the EoR in HI and possibly the late stages of the Dark Ages  
⇒ 1.5 Pbytes and  $10^{21}$ - $10^{22}$  FLOP to extract signal!



# Detection of Particle Showers from Cosmic Rays



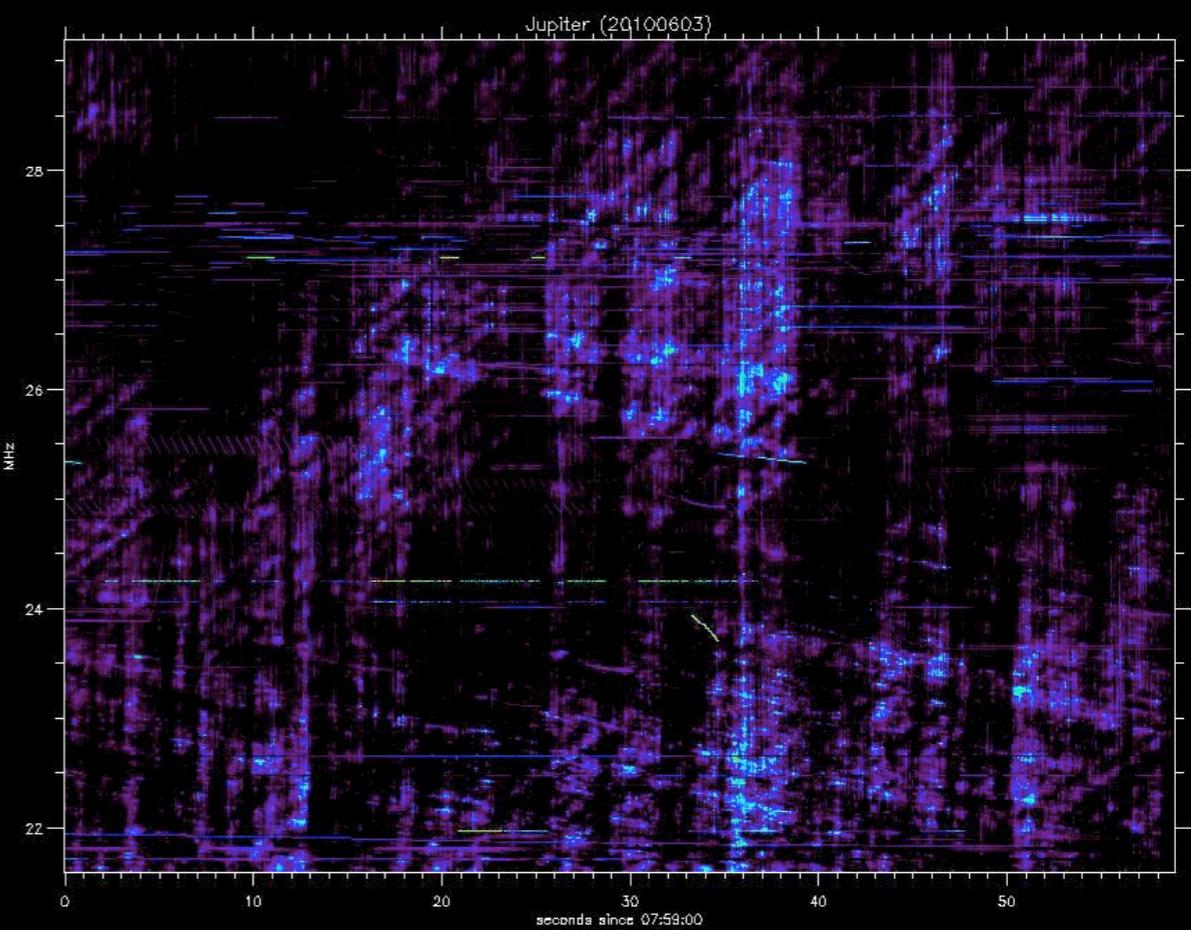
[www.blue-media.nl](http://www.blue-media.nl)

# Detection of Particle Showers from Cosmic Rays



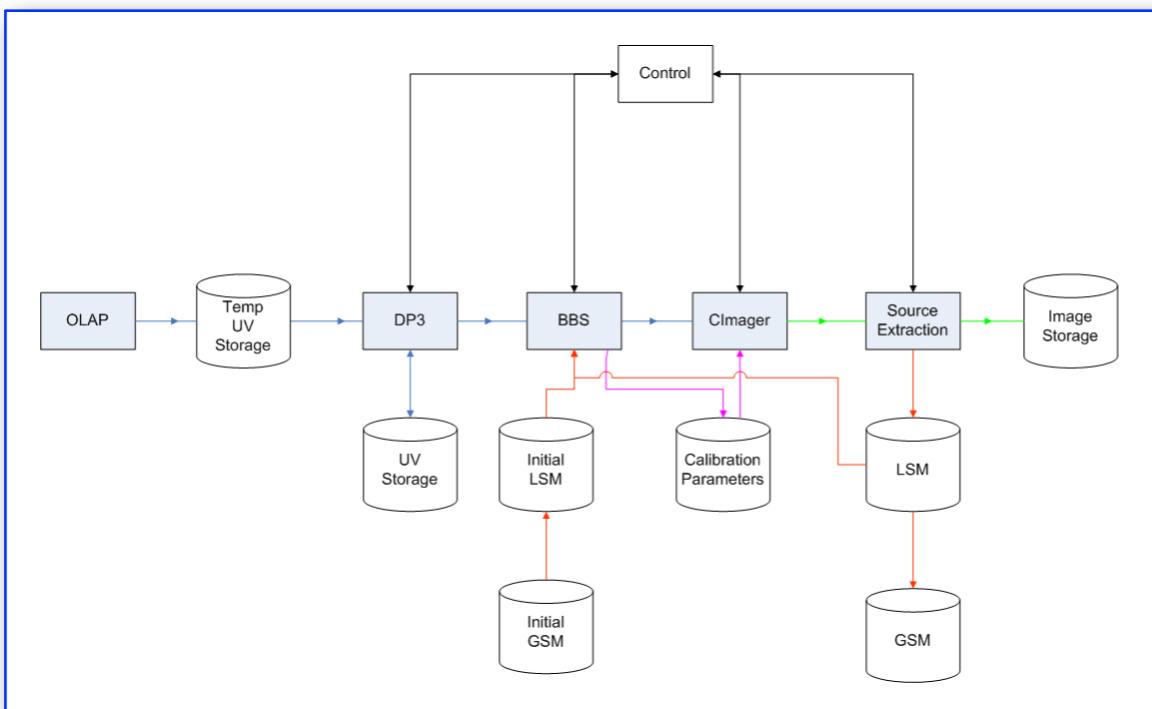
[www.blue-media.nl](http://www.blue-media.nl)

# Ultra-low Frequency Radio Bursts from Jupiter-Io System

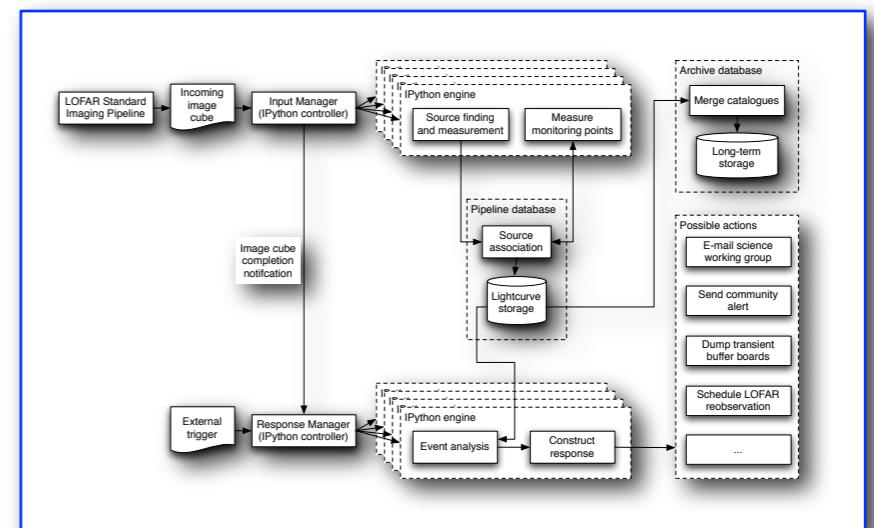


# Science Pipelines

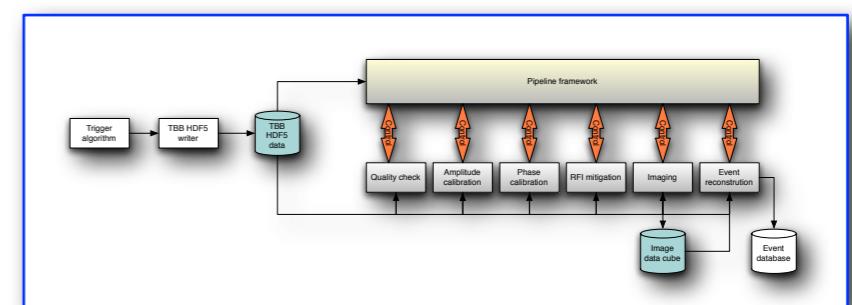
## Standard Imaging



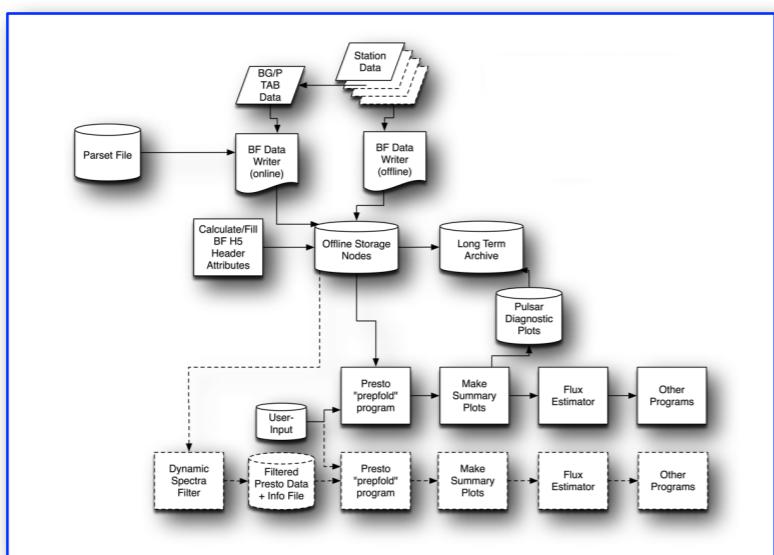
## Transient Detection



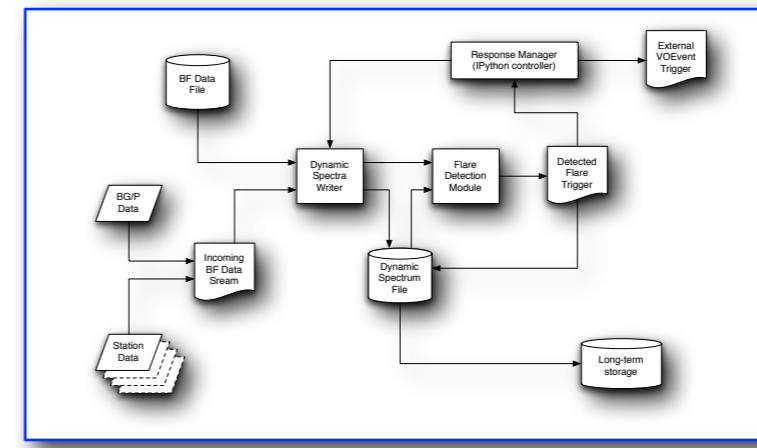
## VHECR



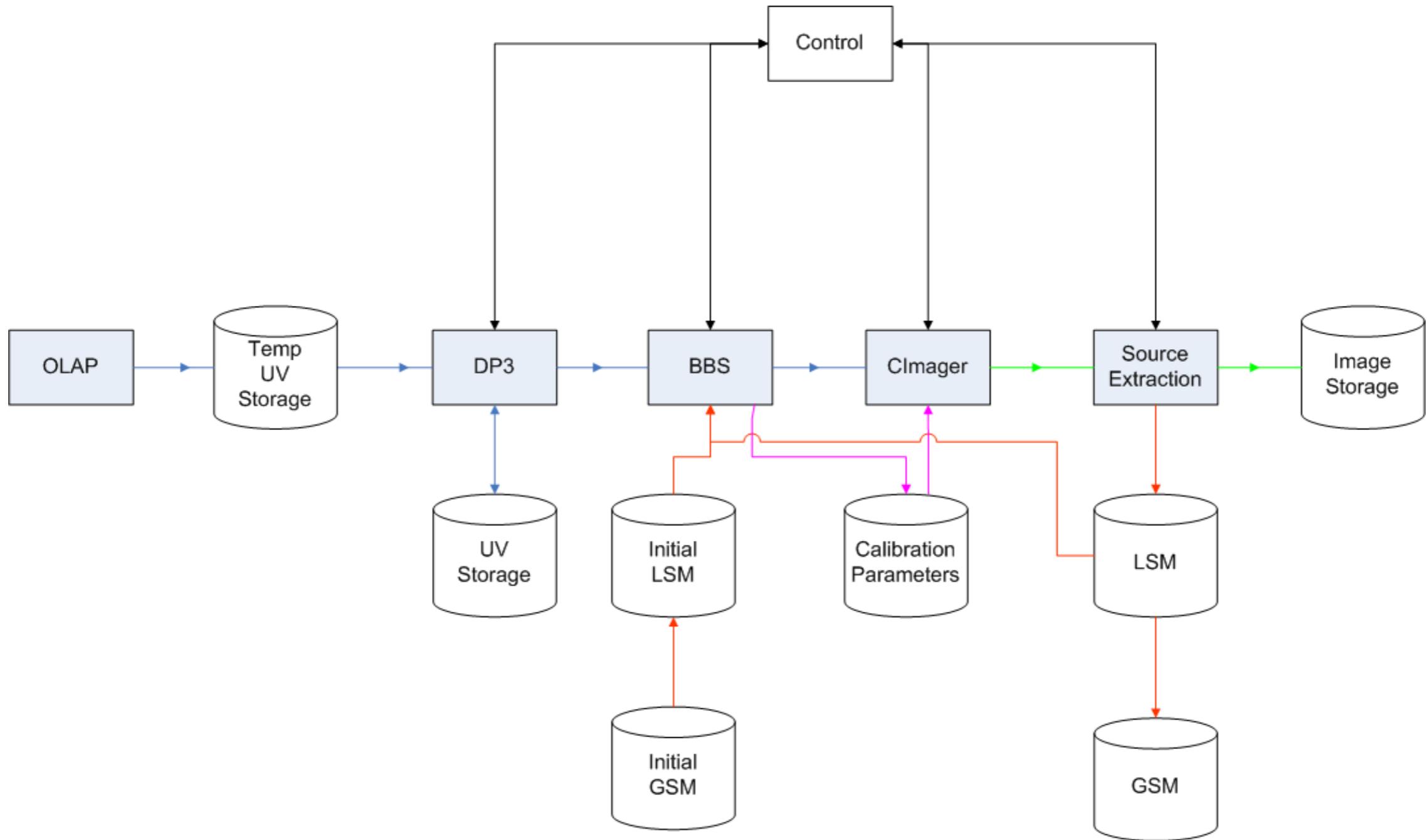
## Known Pulsars



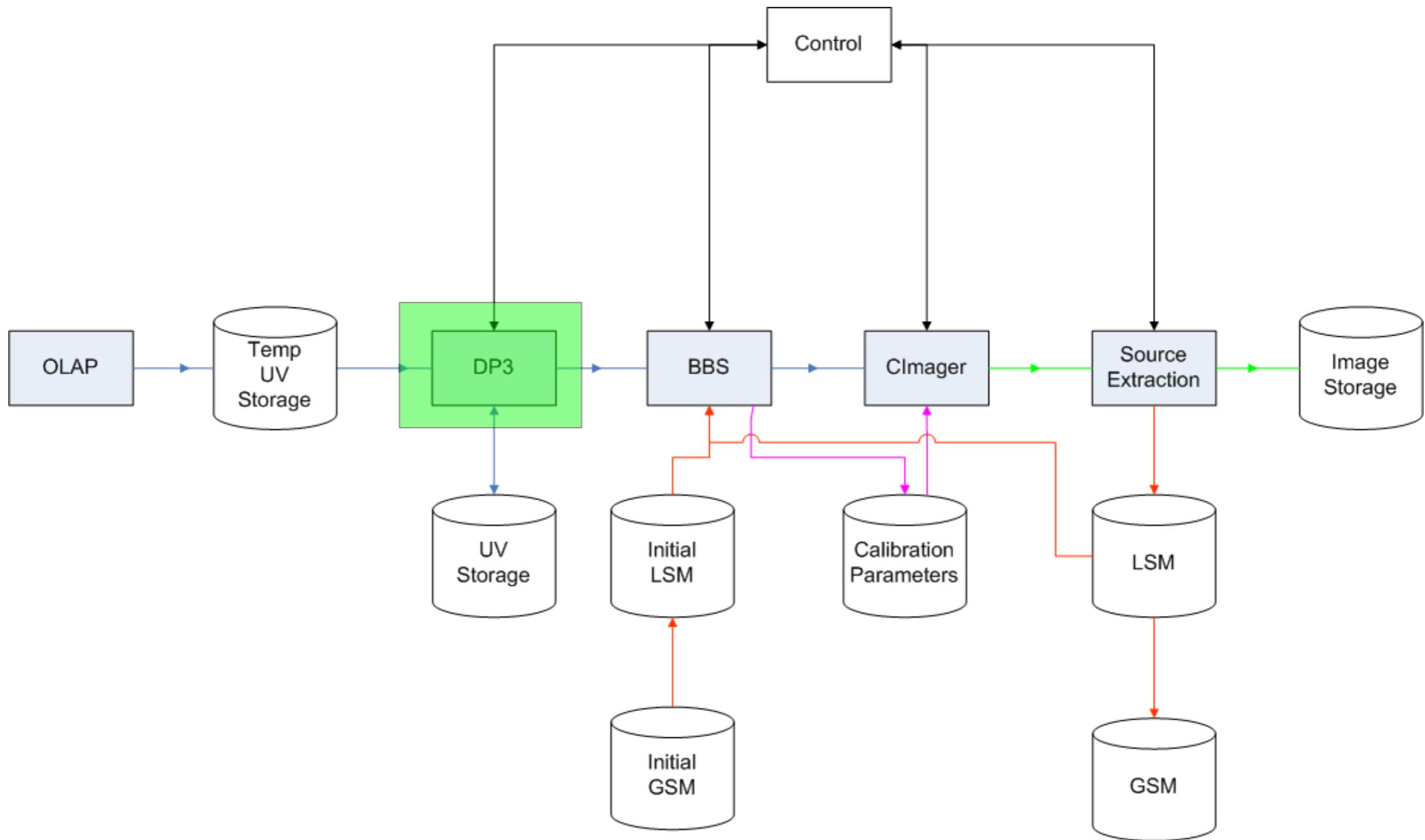
## Dynamic Spectra



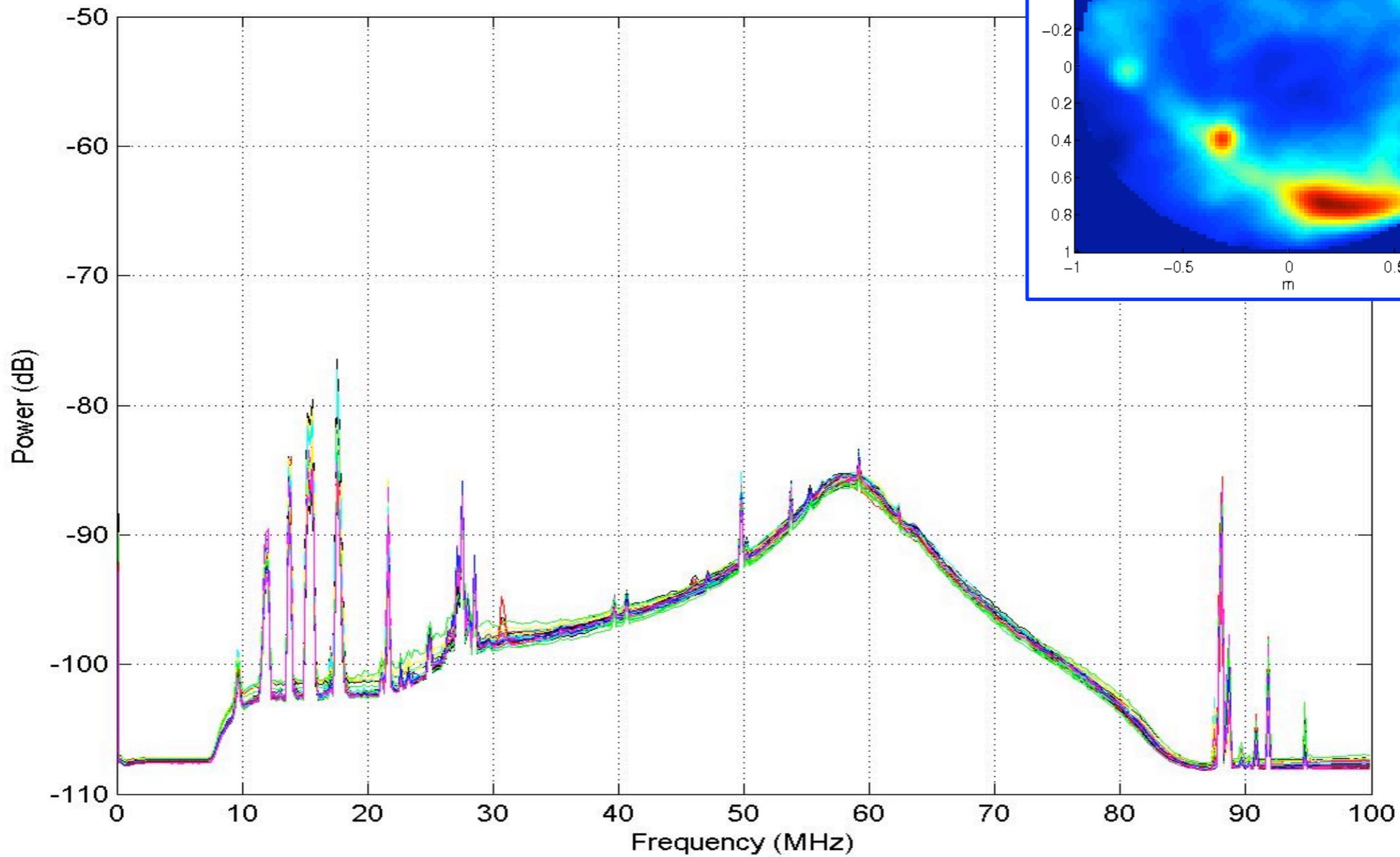
# Standard Imaging Pipeline



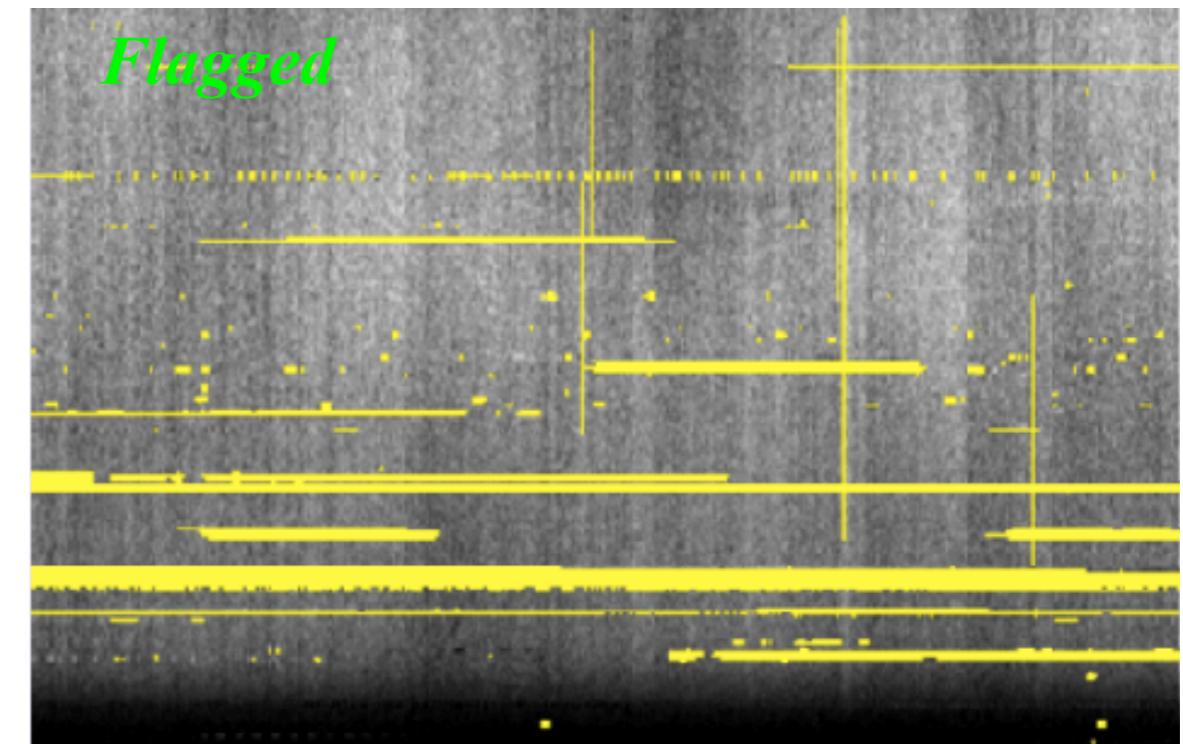
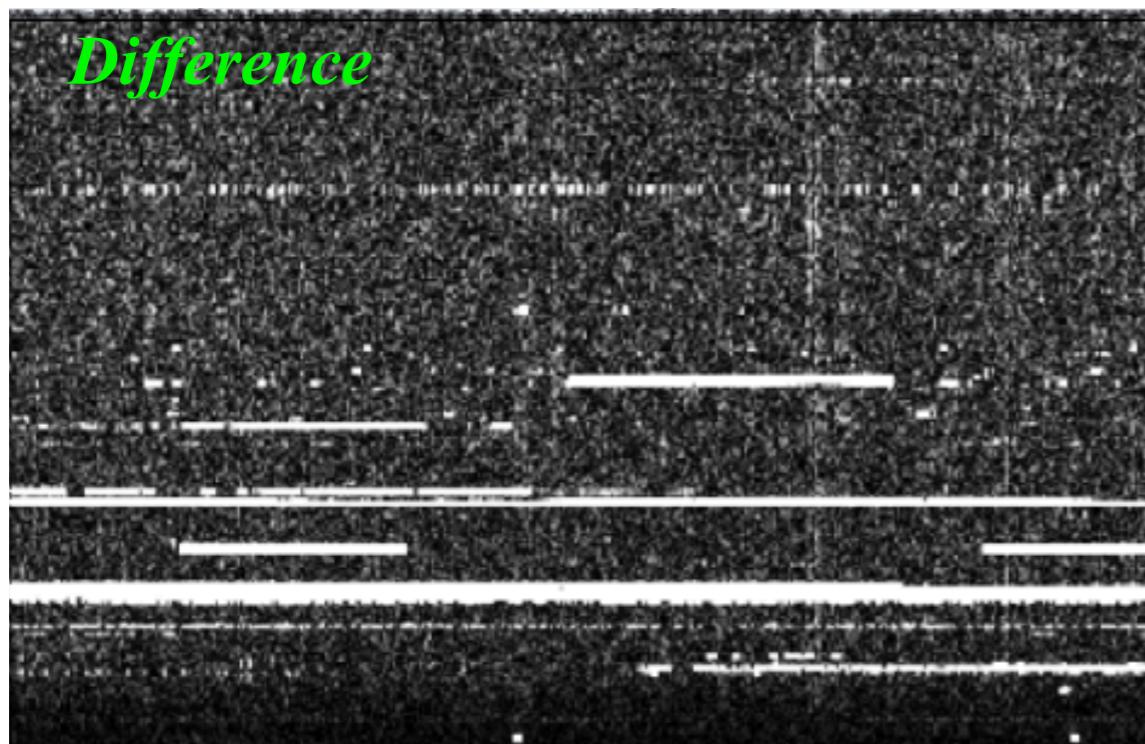
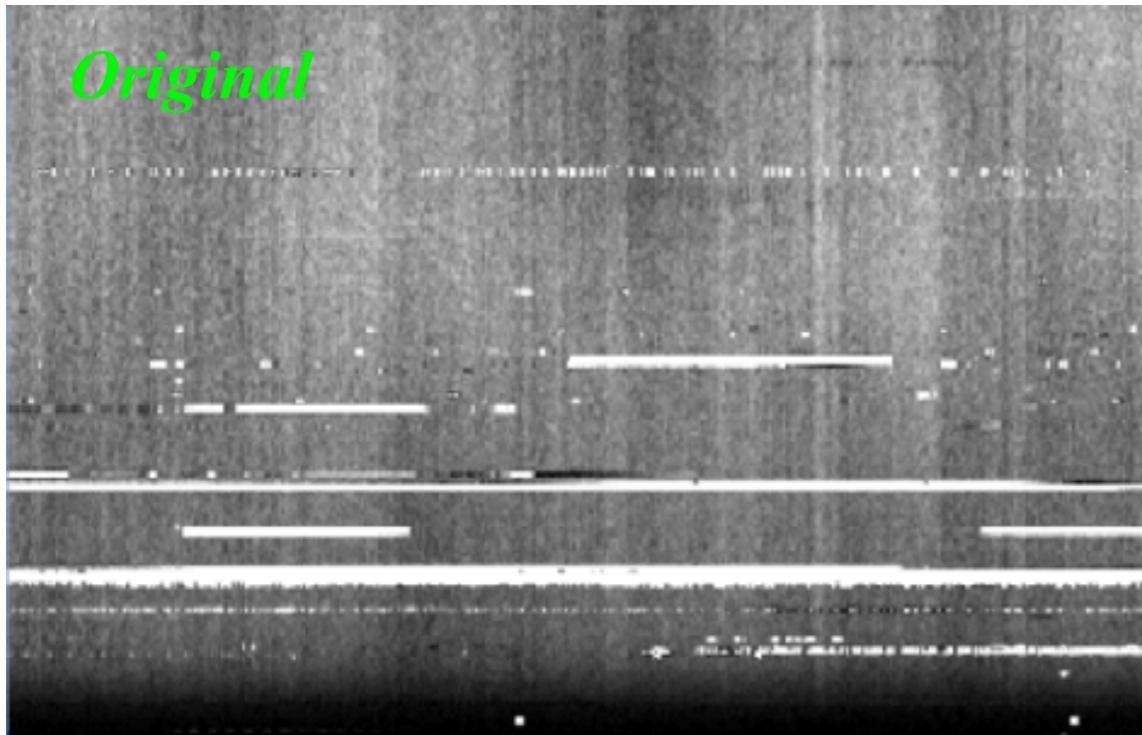
# Standard Imaging Pipeline



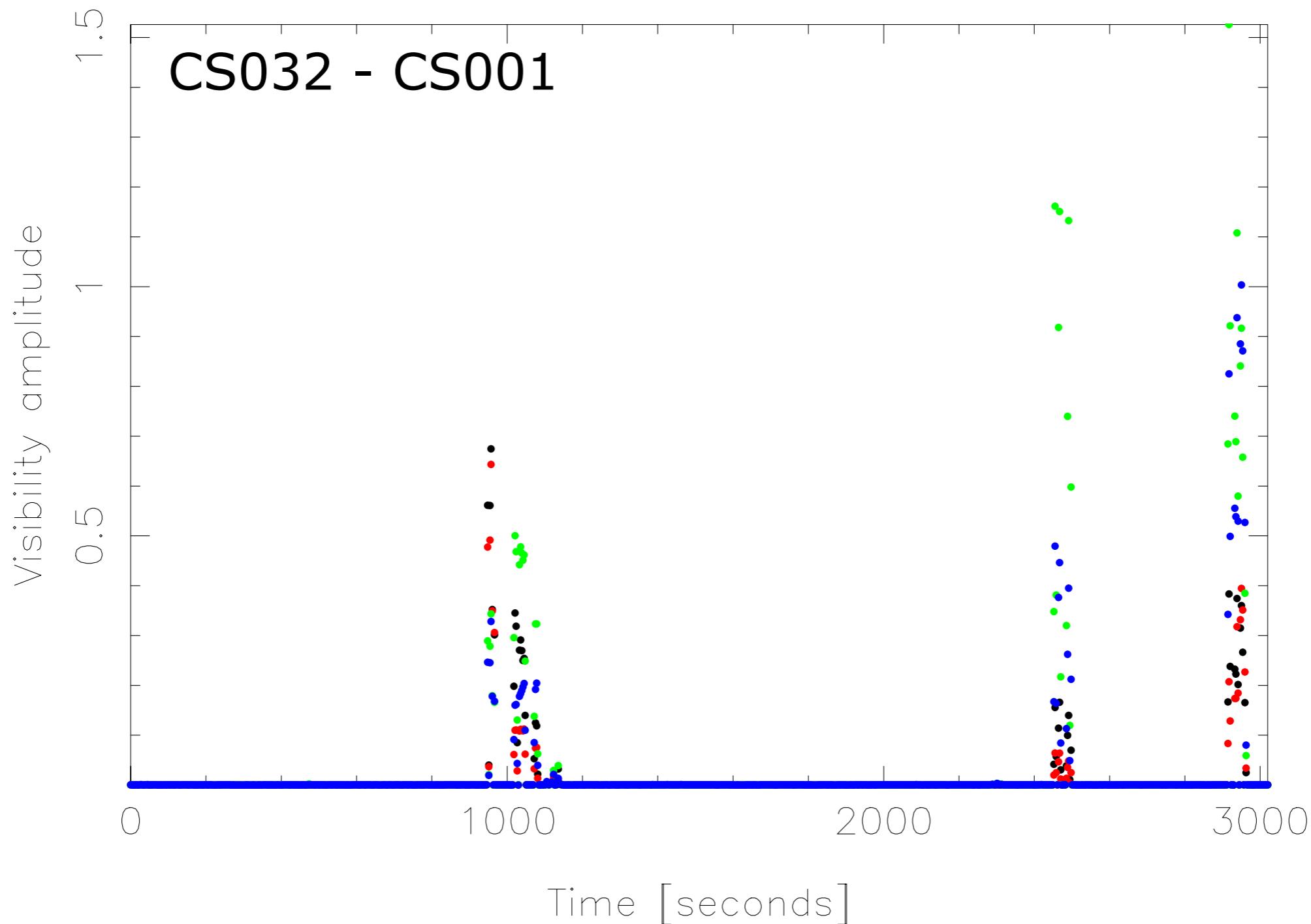
# Local RFI Environment



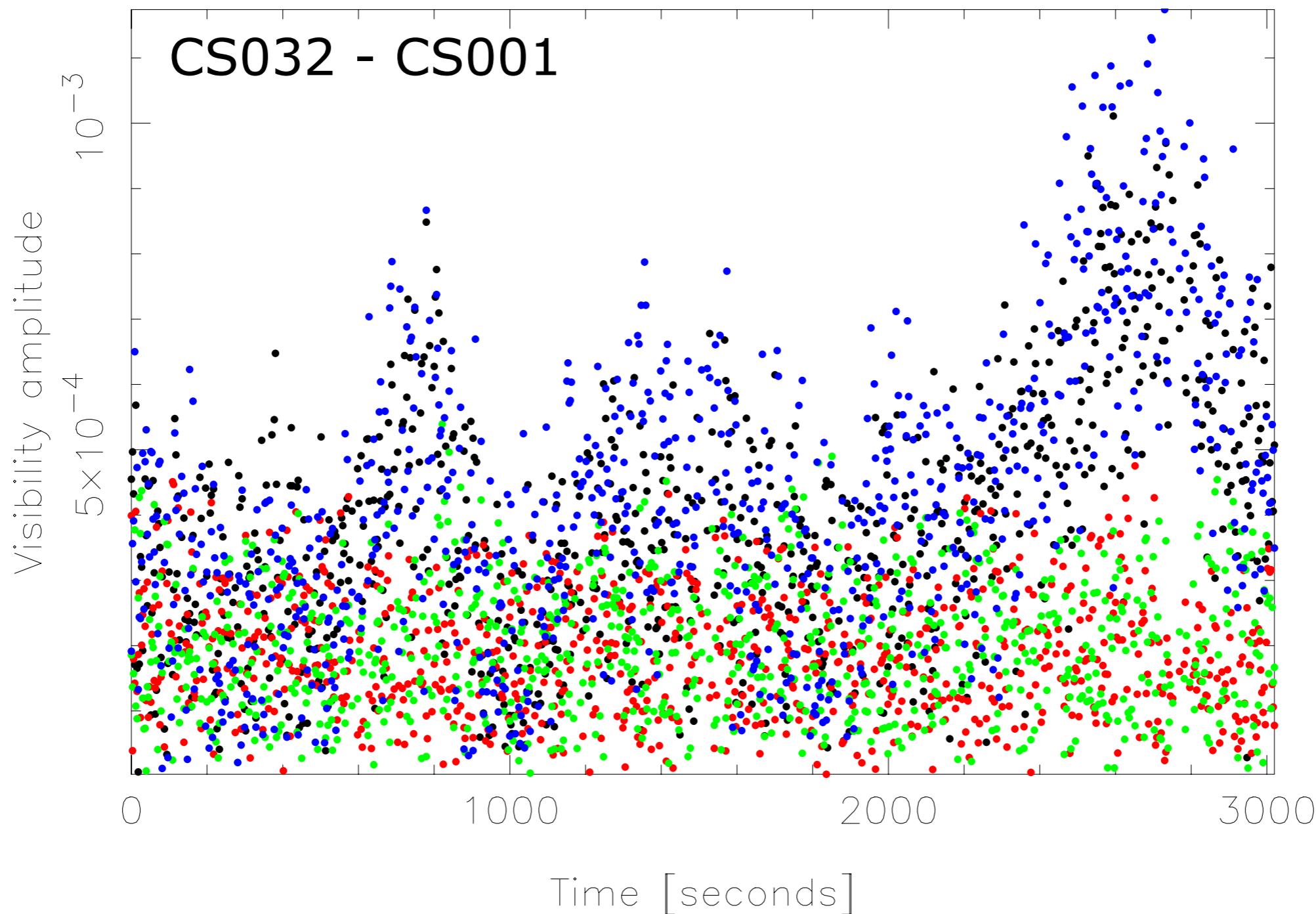
# Automated RFI Flagging



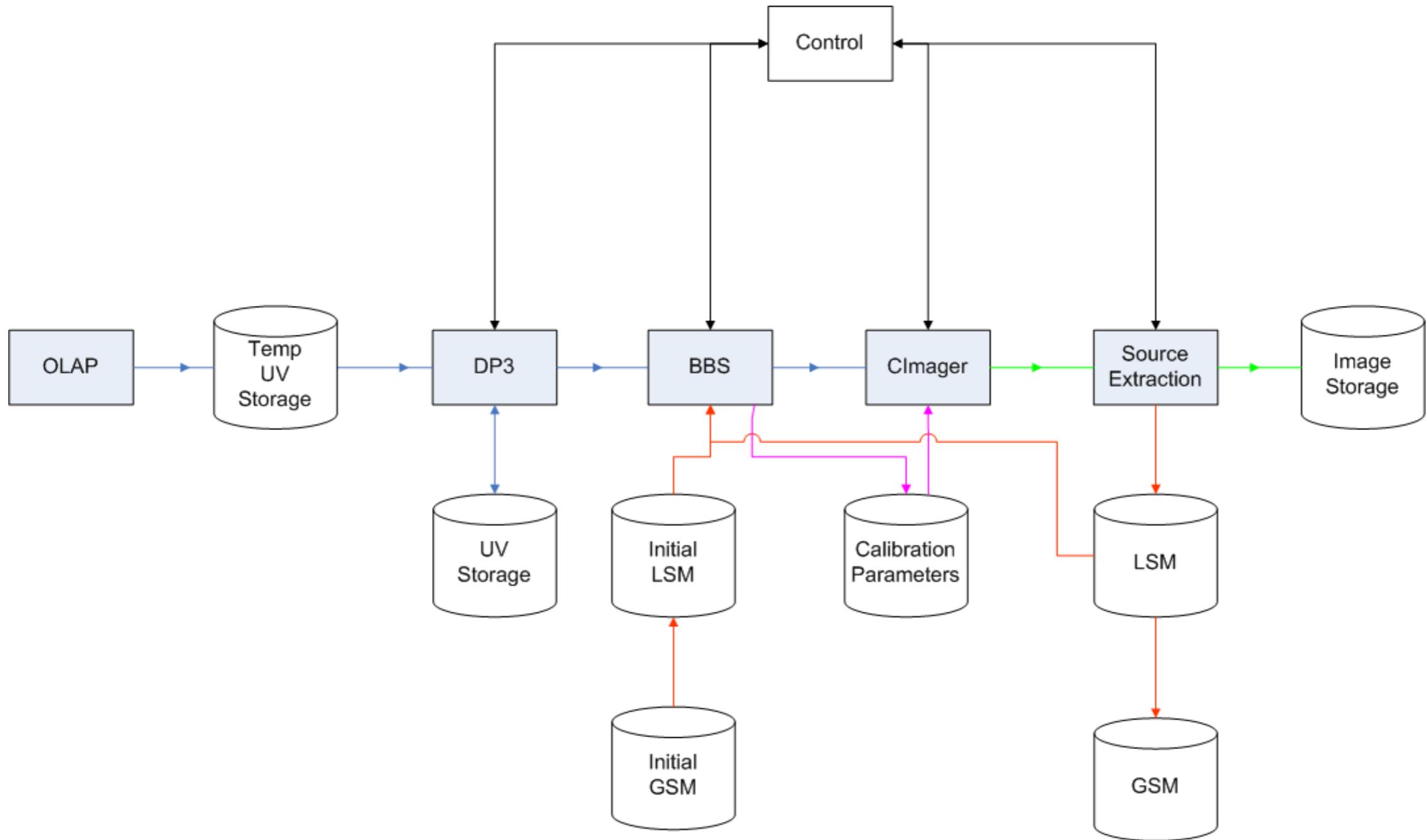
# Automated RFI Flagging



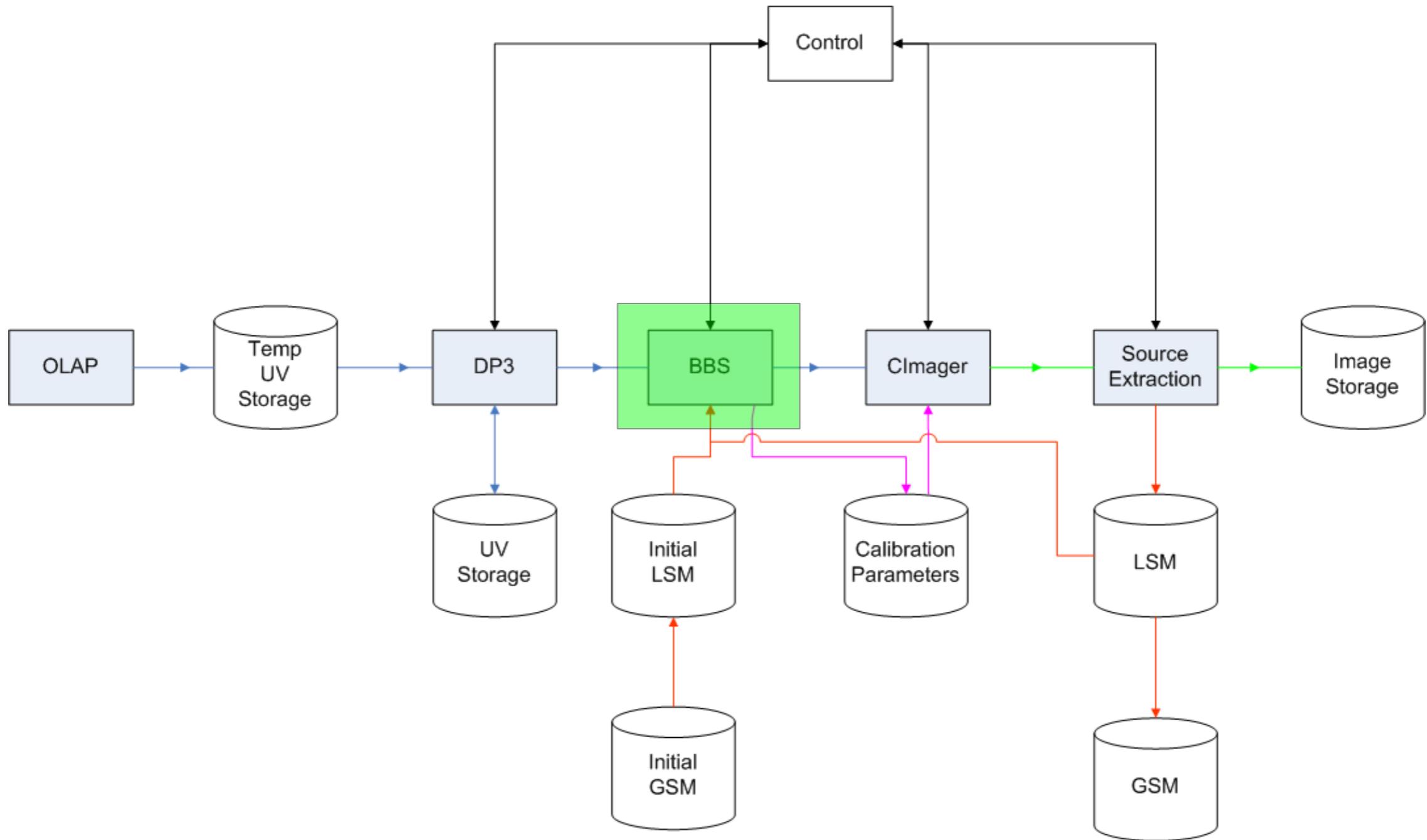
# Automated RFI Flagging



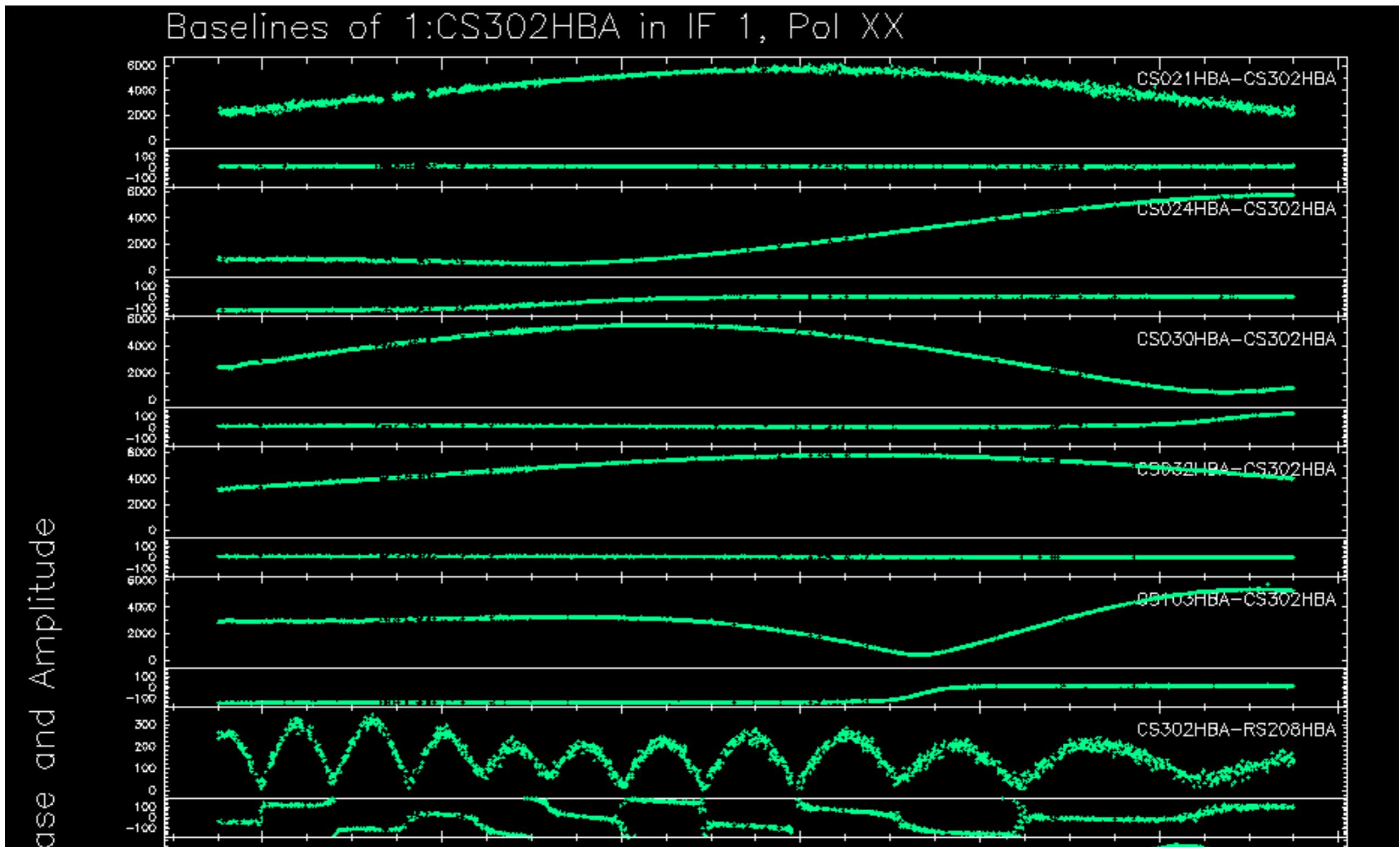
# Standard Imaging Pipeline



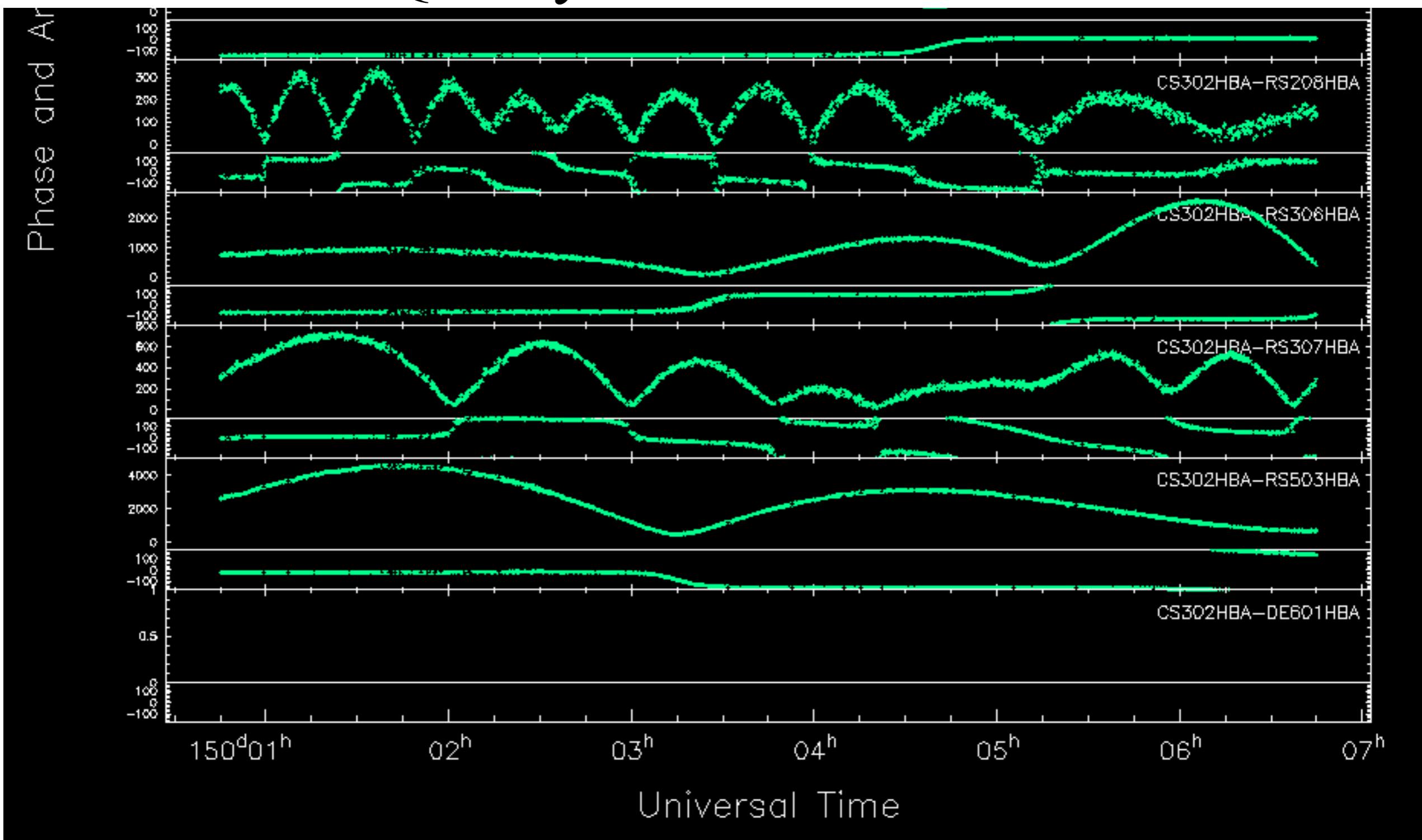
# Standard Imaging Pipeline



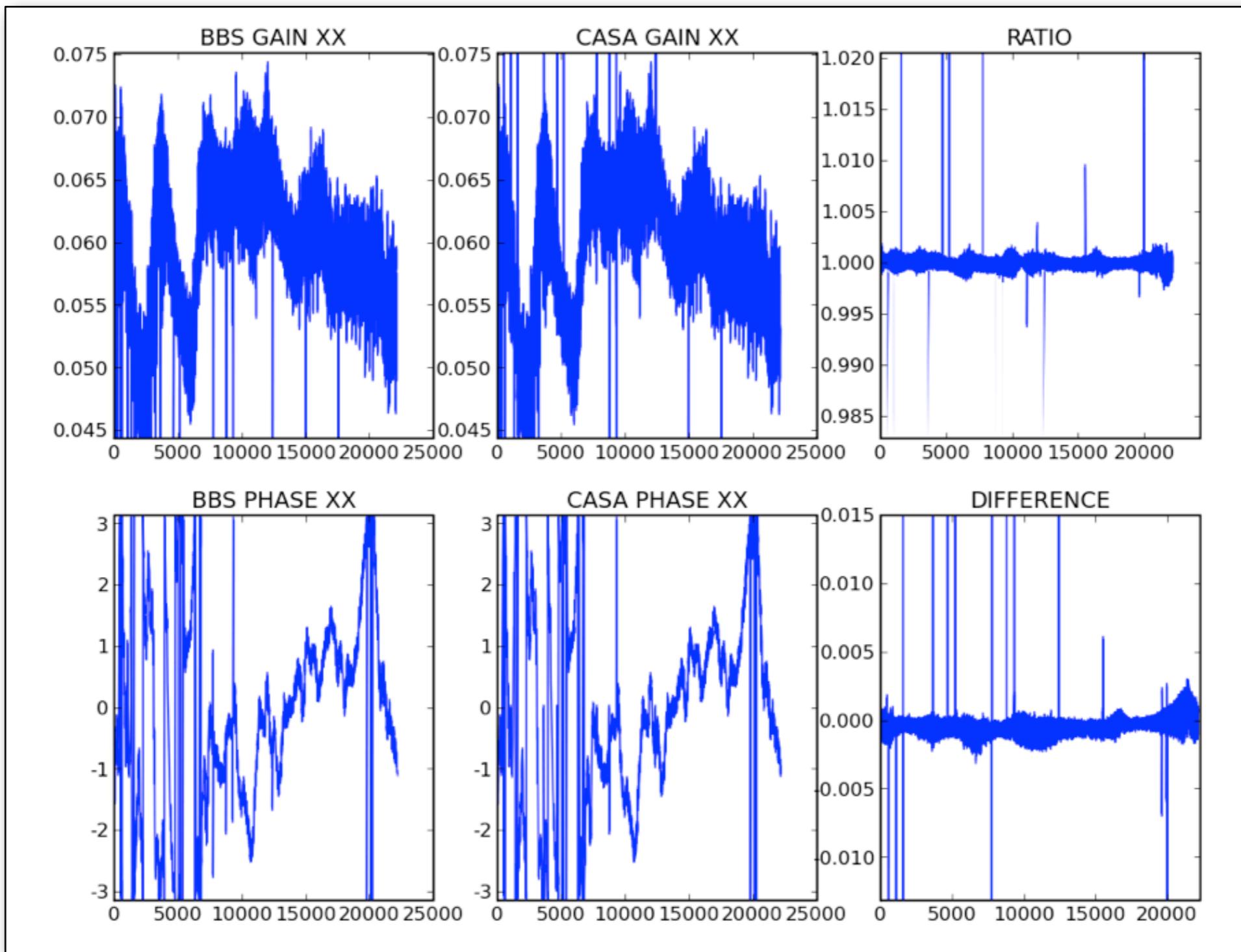
# Data Quality



# Data Quality

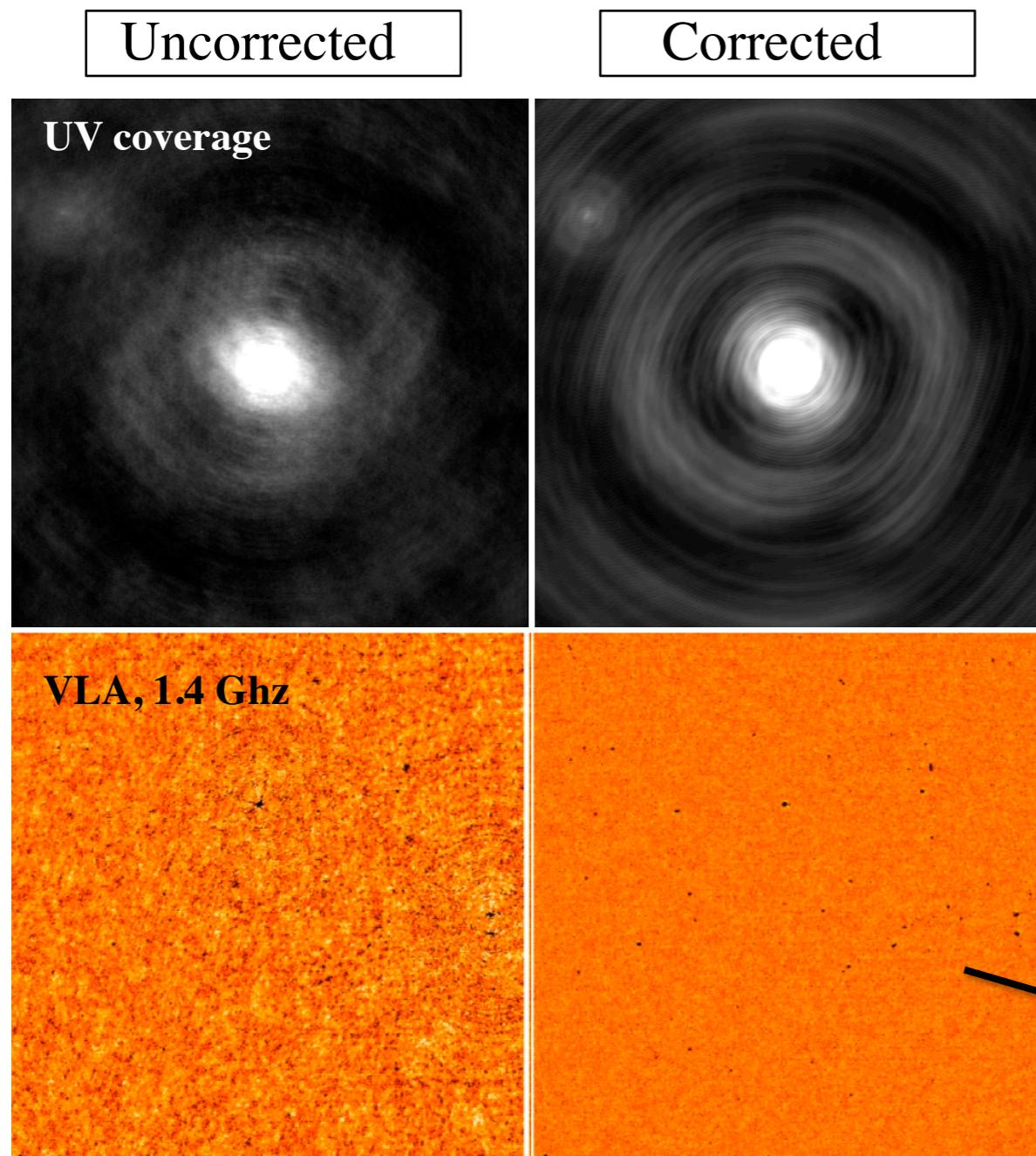


# Calibration Testing

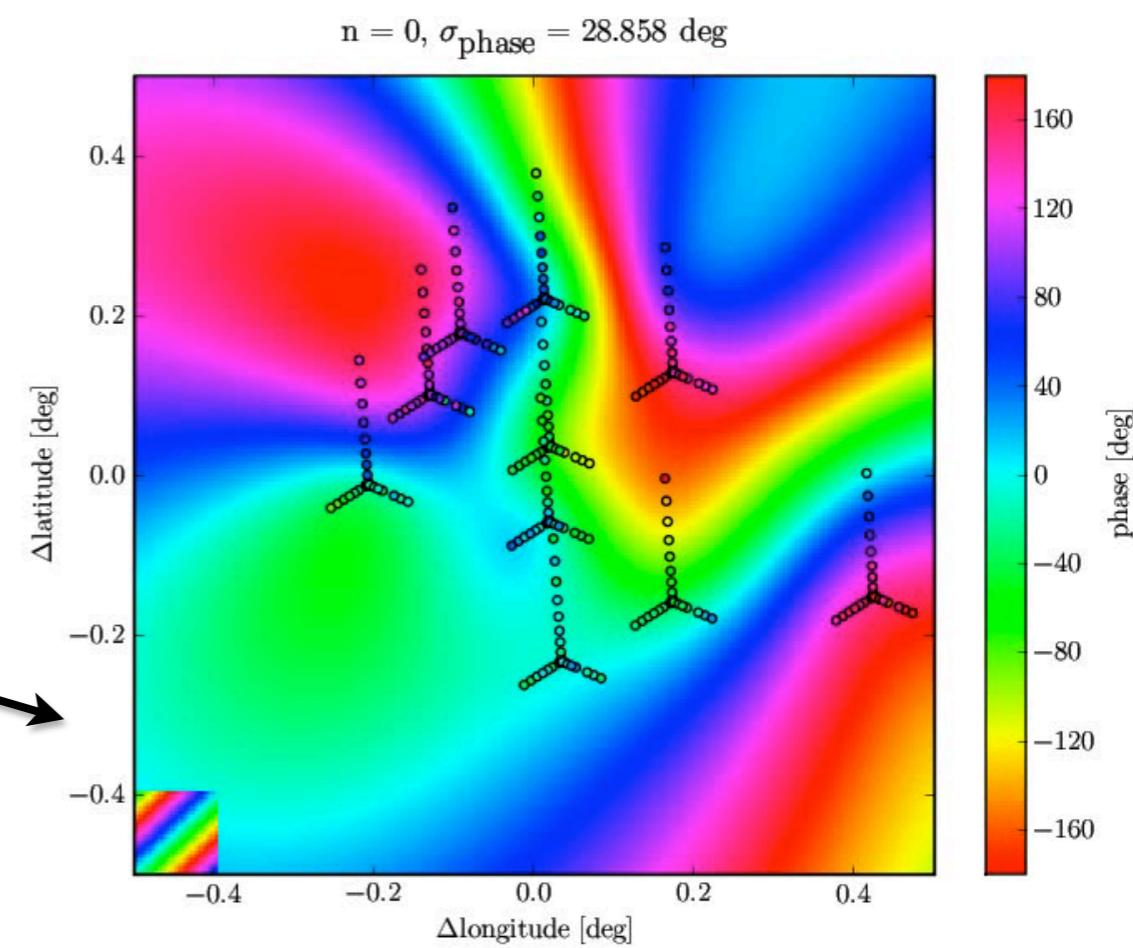
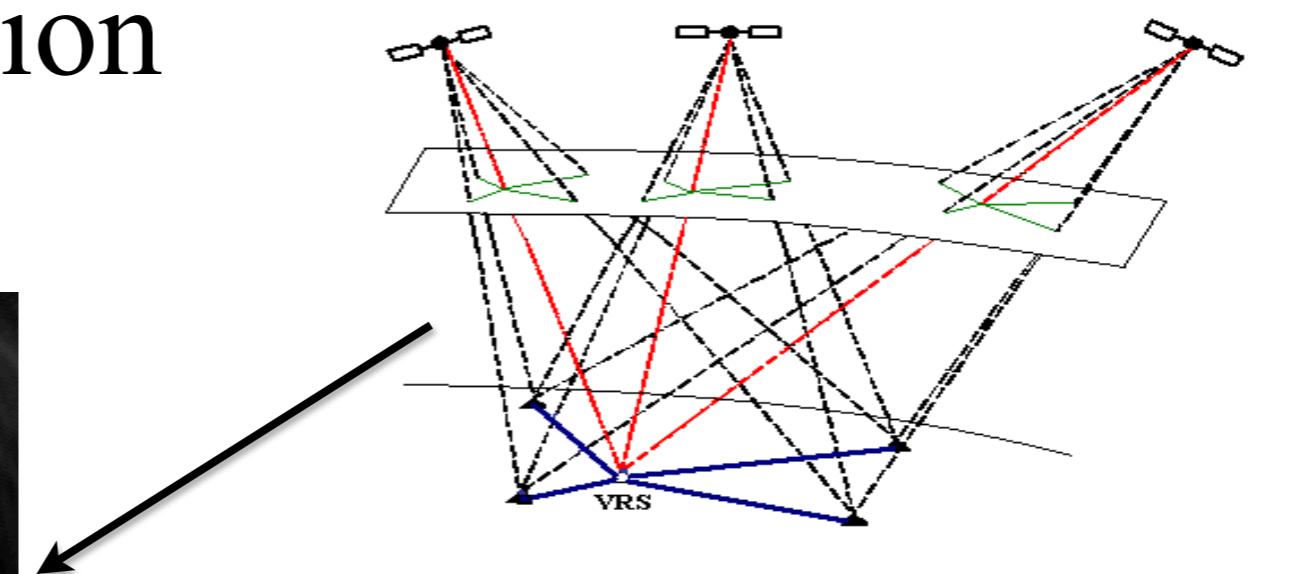


(courtesy J. van Zwieten)

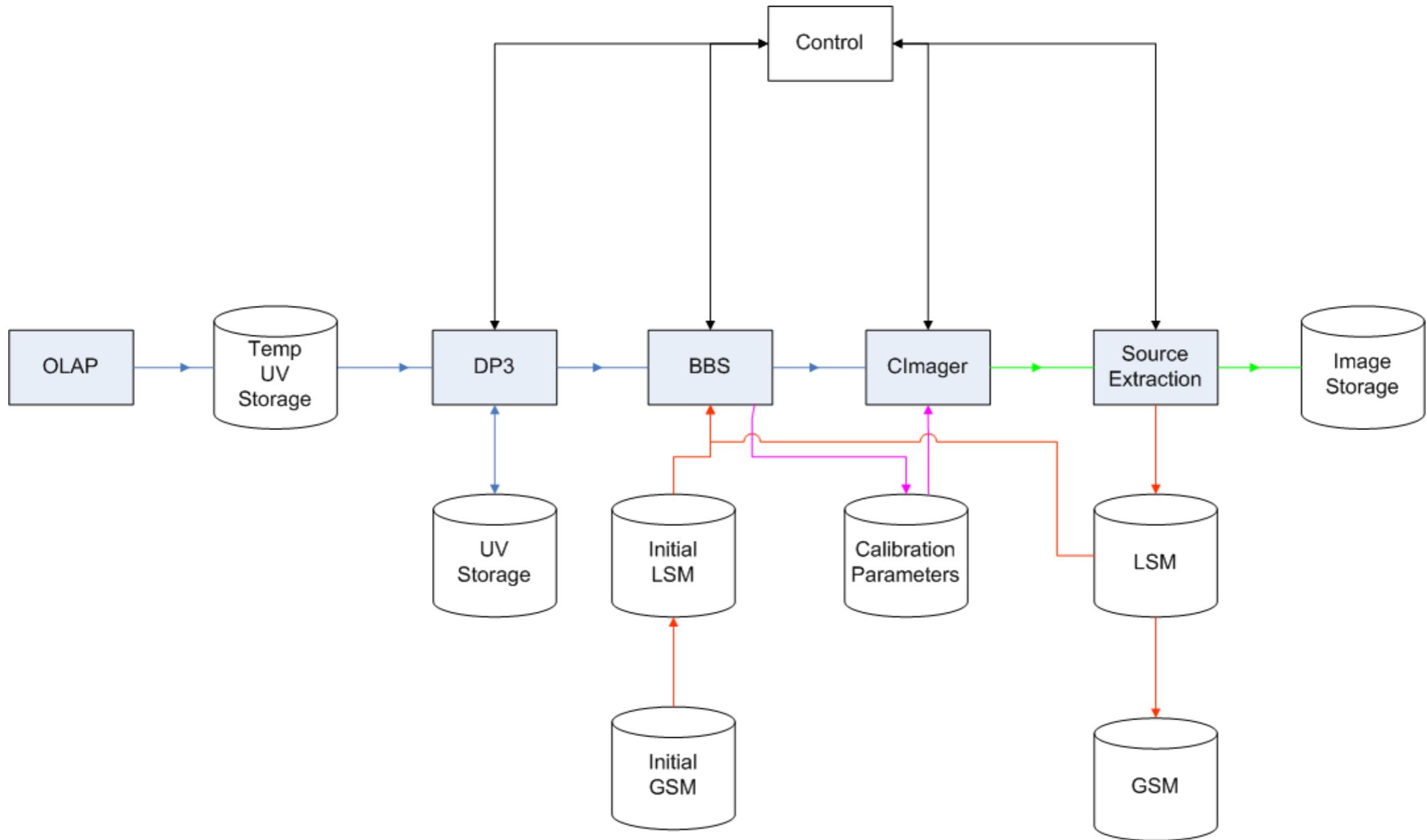
# Ionosphere Correction



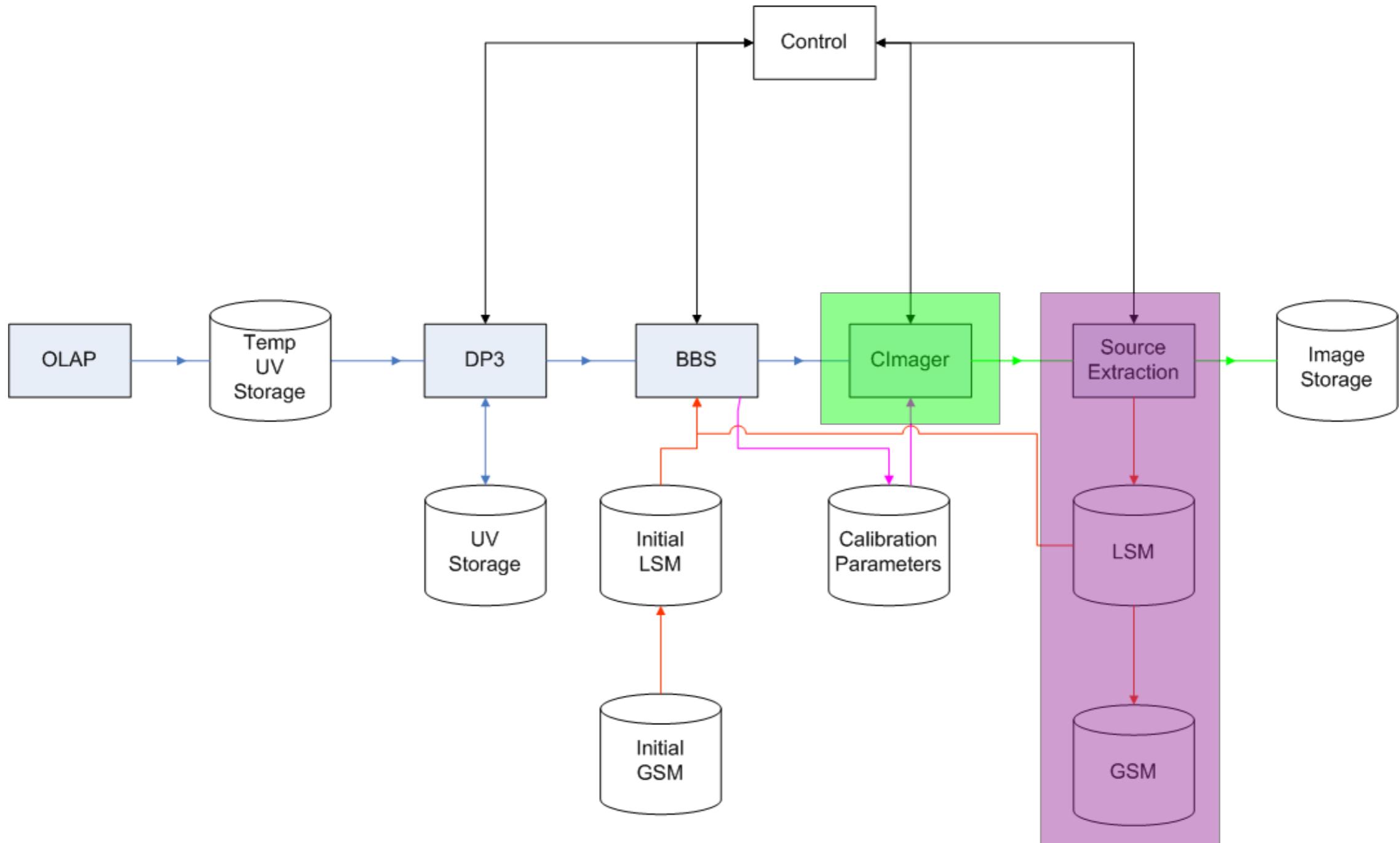
(courtesy H. Intema)



# Standard Imaging Pipeline



# Standard Imaging Pipeline



*3C 61.1*

*Wide-field imaging*

*HBA 115-185 MHz*

*8(x2)+ 4 stations*

*8 deg x 8 deg field*

*4 arcsec pixels*

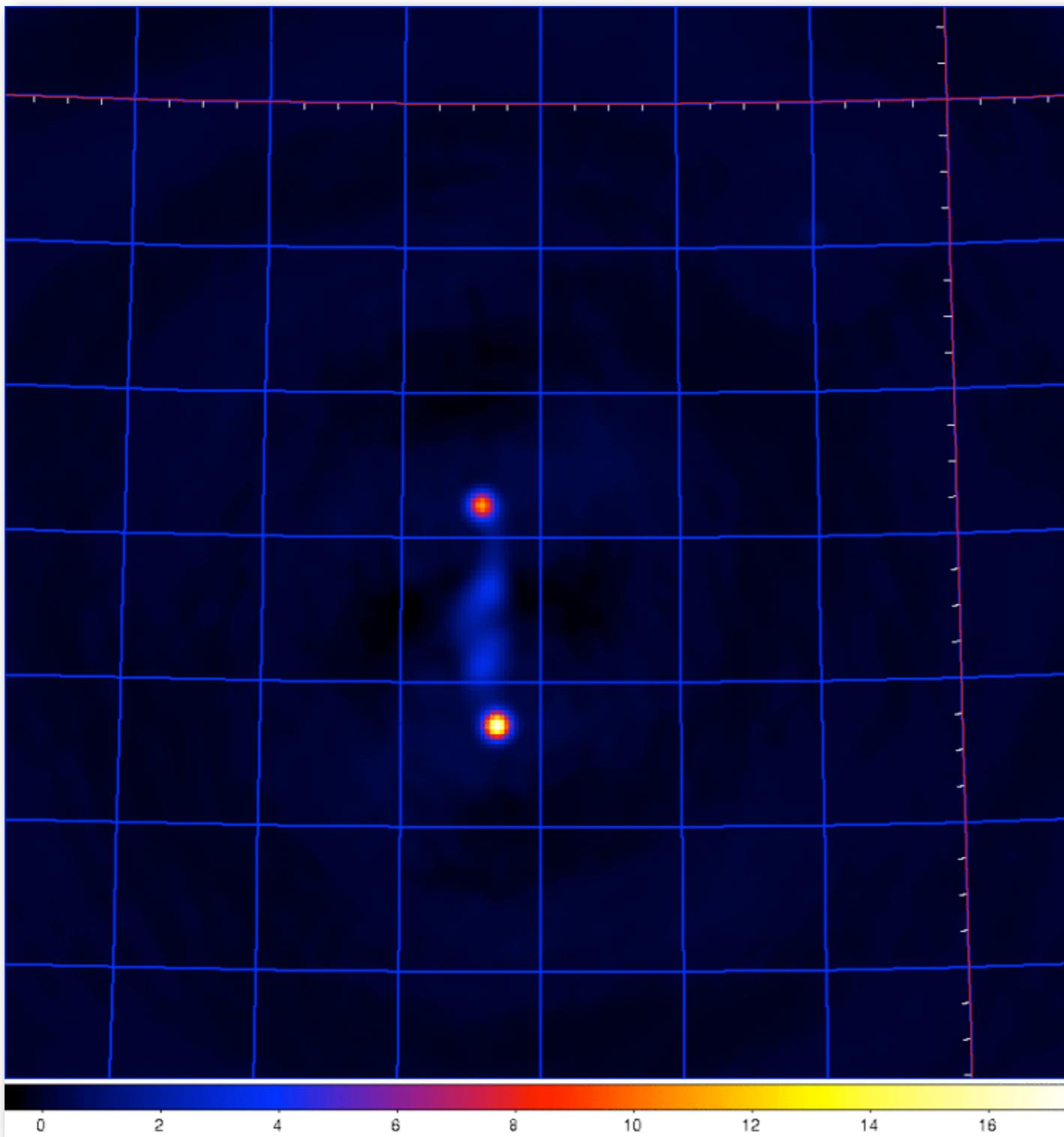
*$\sim 5.18 \times 10^7$  pixels*

*10 arcsec PSF*

*10 Jy peak*

*1 mJy noise*

(courtesy S. Yatawatta)

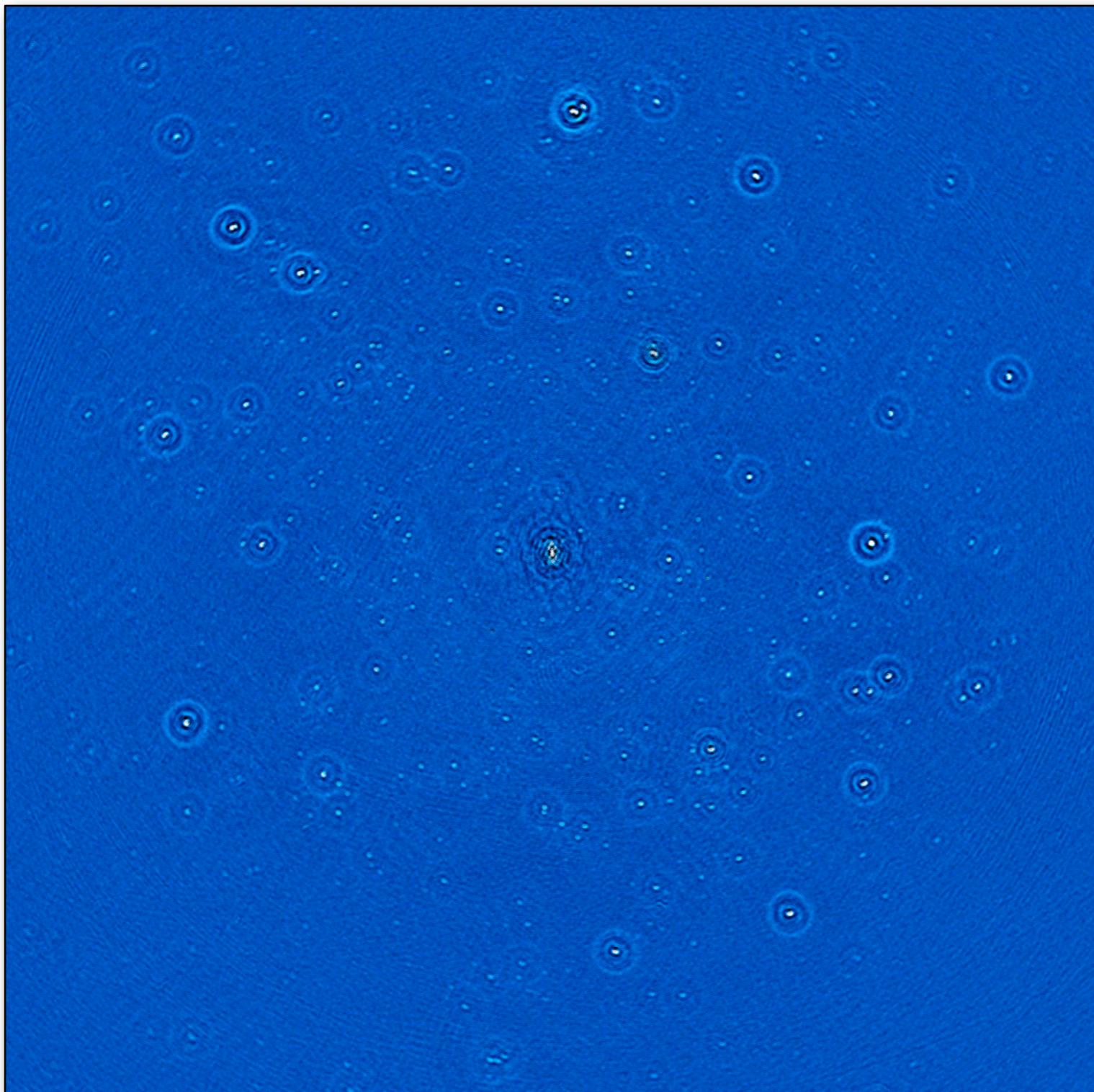


(courtesy S. Yatawatta)

*3C 61.1  
Wide-field imaging*

*HBA 115-185 MHz  
8(x2)+ 4 stations  
8 deg x 8 deg field  
4 arcsec pixels  
 $\sim 5.18 \times 10^7$  pixels  
10 arcsec PSF*

*10 Jy peak  
1 mJy noise*



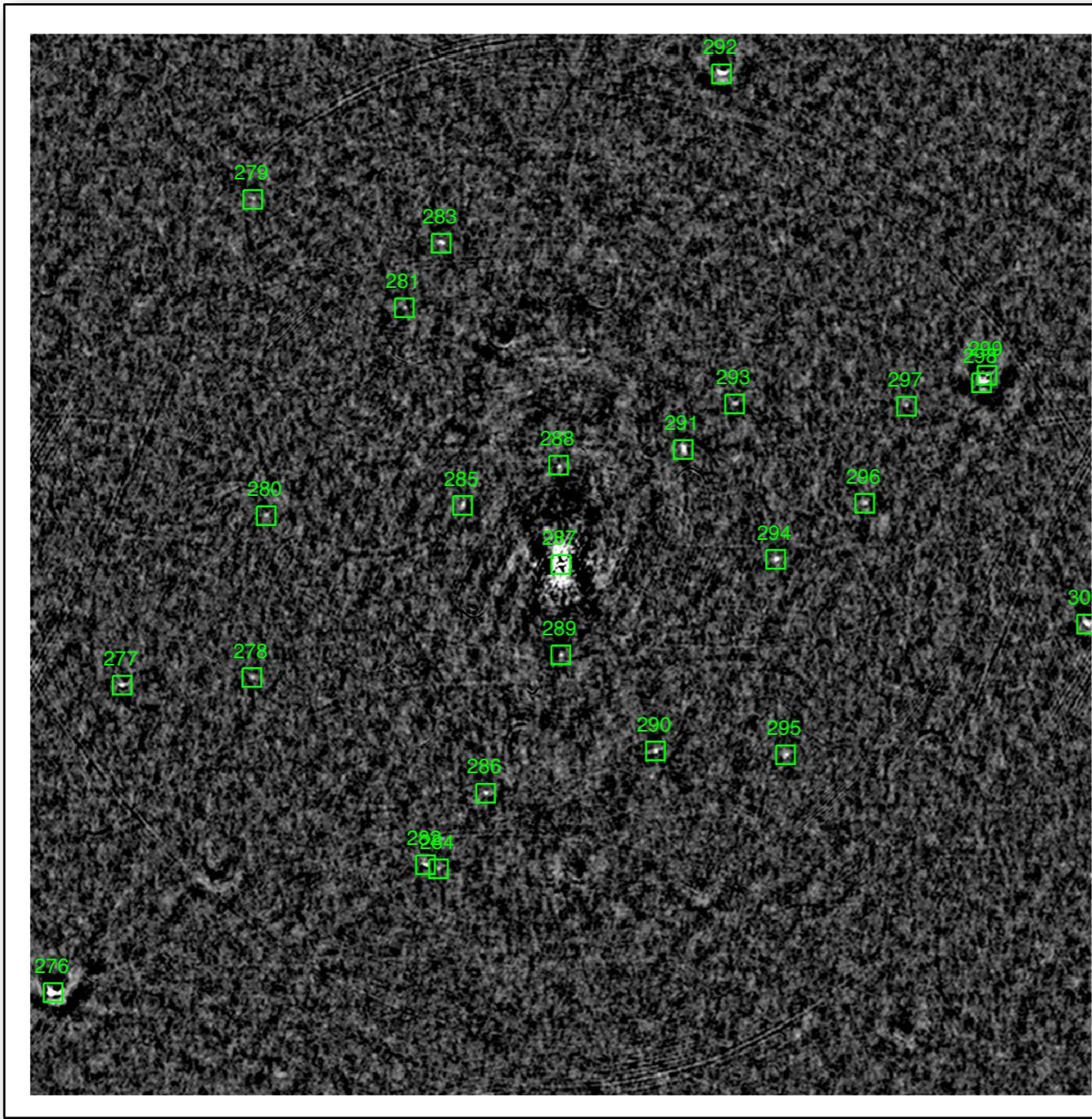
(courtesy S. Yatawatta)

## 3C 61.1 *Wide-field imaging*

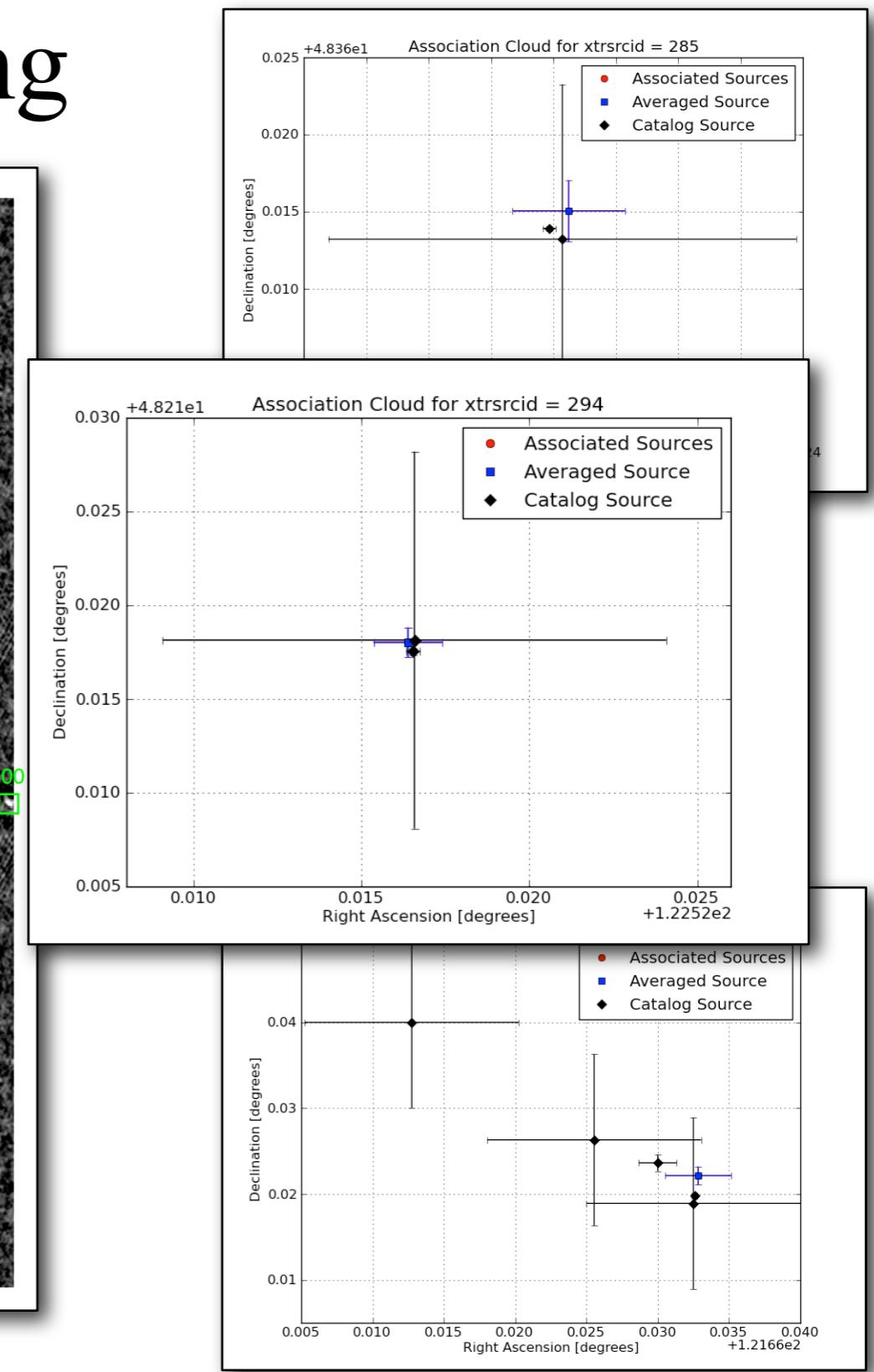
*HBA 115-185 MHz  
8(x2)+ 4 stations  
8 deg x 8 deg field  
4 arcsec pixels  
~ $5.18 \times 10^7$  pixels  
10 arcsec PSF*

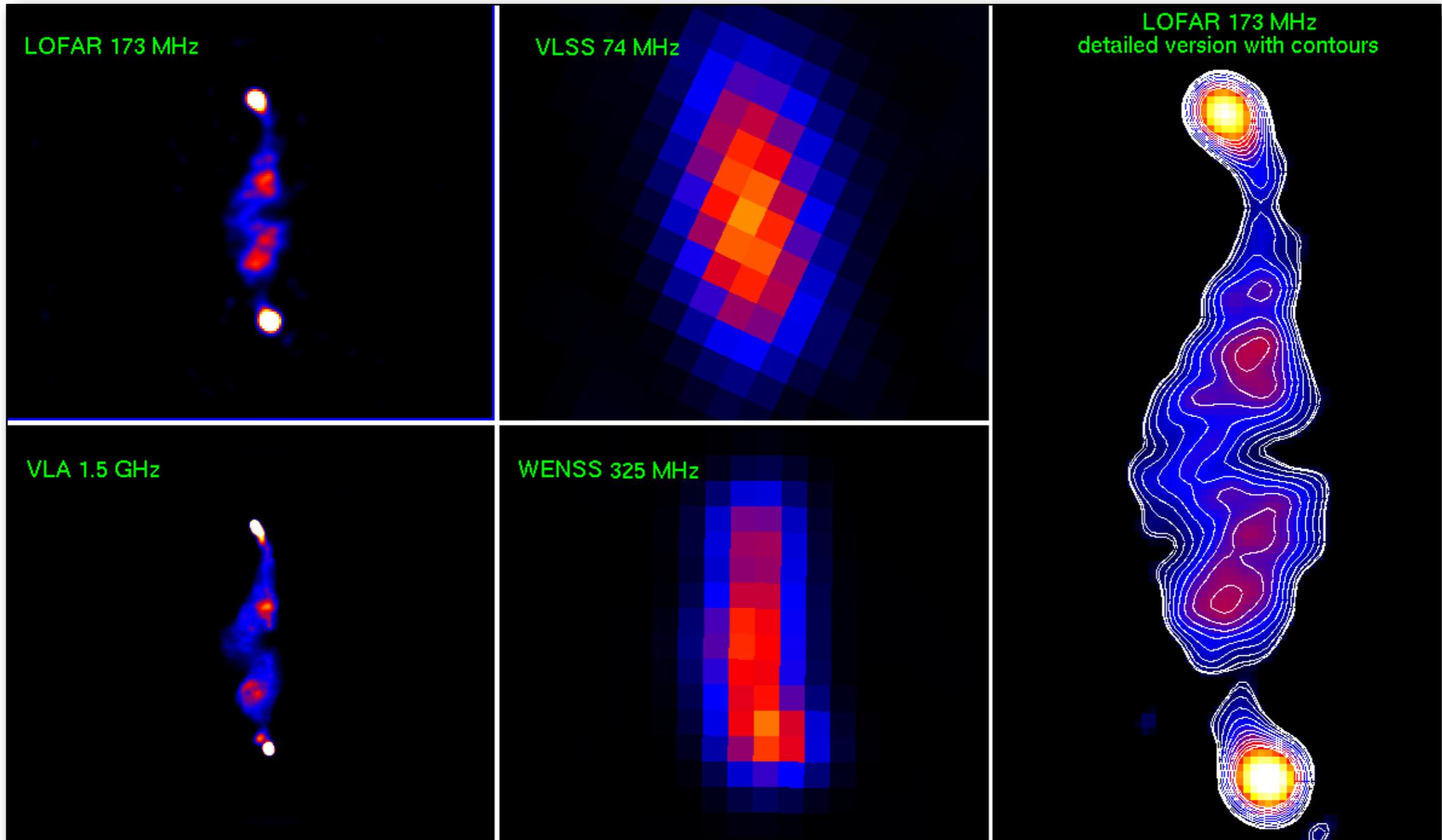
*10 Jy peak  
1 mJy noise*

# GSM and Source Finding



(courtesy B. Scheers, N. Mohan, J. Swinbank)





(courtesy R. van Weeren)

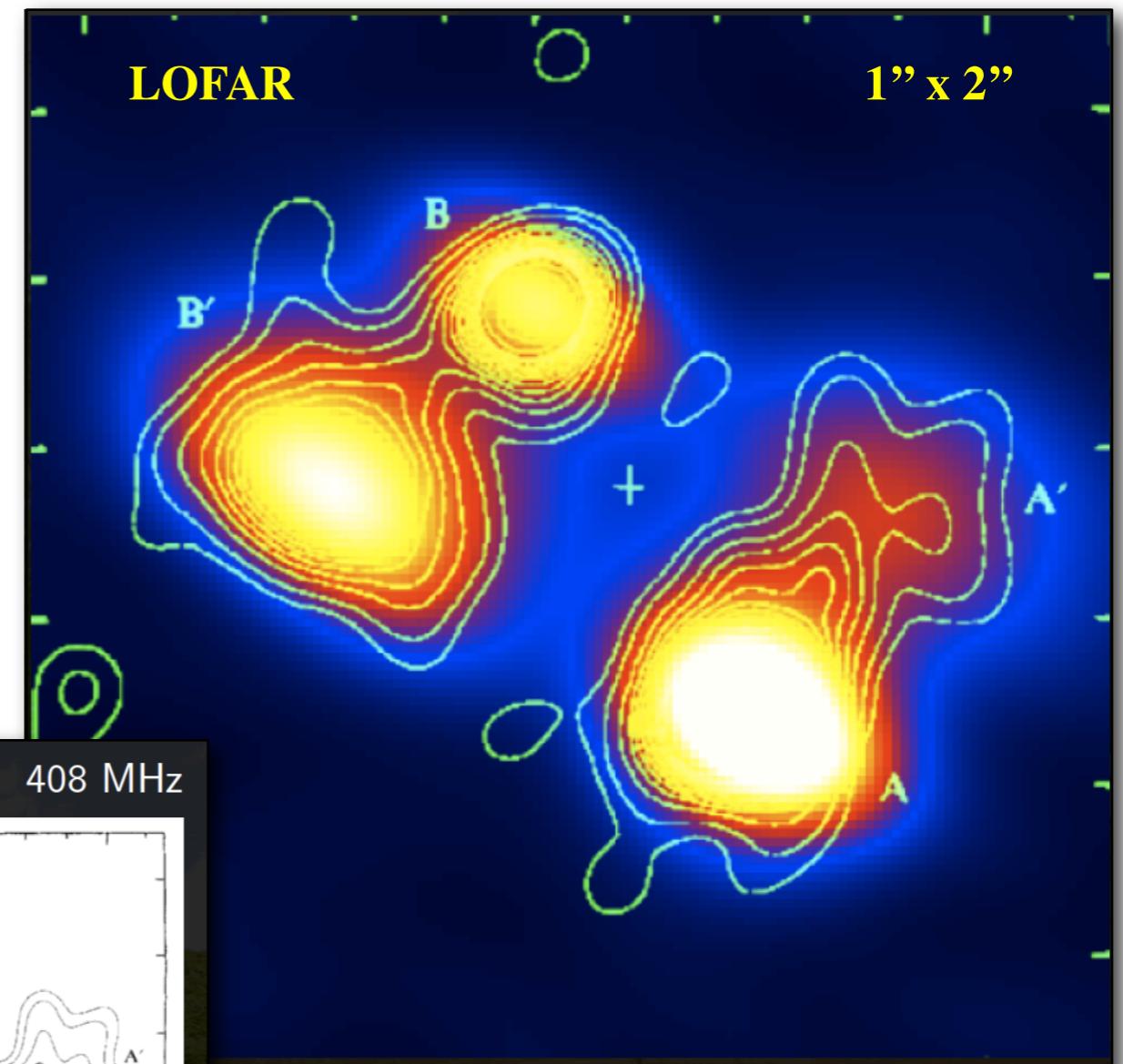
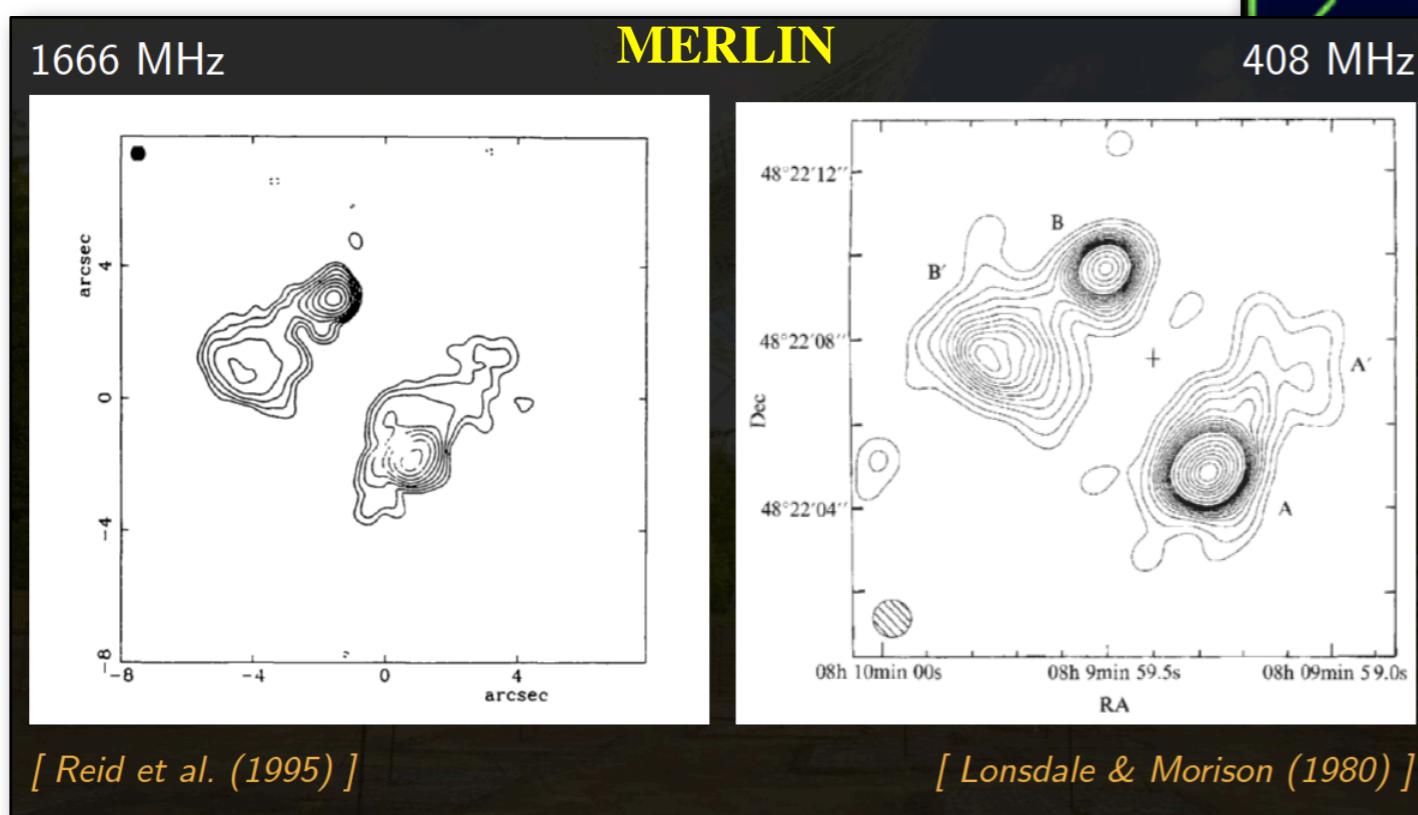
*3C 61.1, 60 hr, 20 HBA stations (16 split core + 4 remote)*

*1 sub-band, 9.7 by 9.4 arcsec resolution*

## 3C196 ( $\sim 140$ Jy)

*Morphology at 50 MHz  
consistent with structure in  
408 MHz Merlin maps*

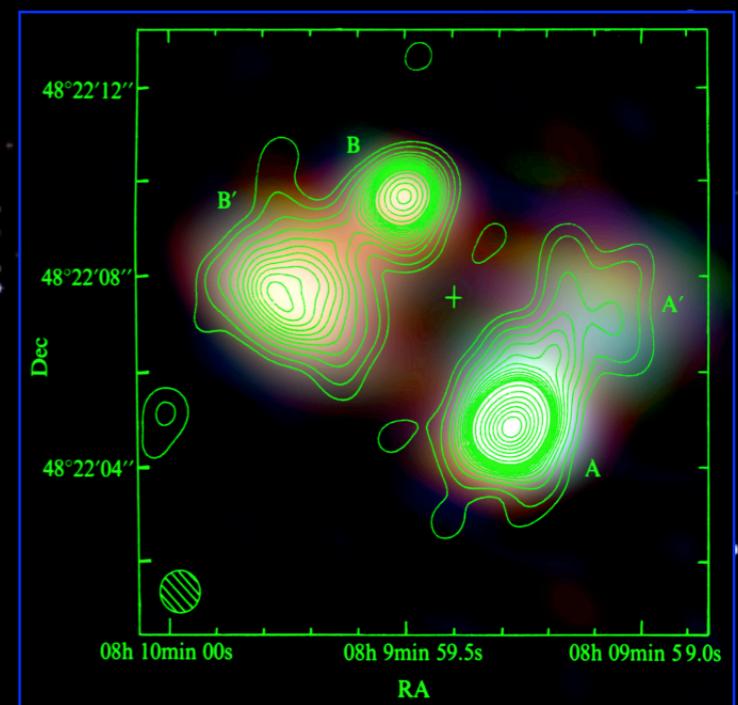
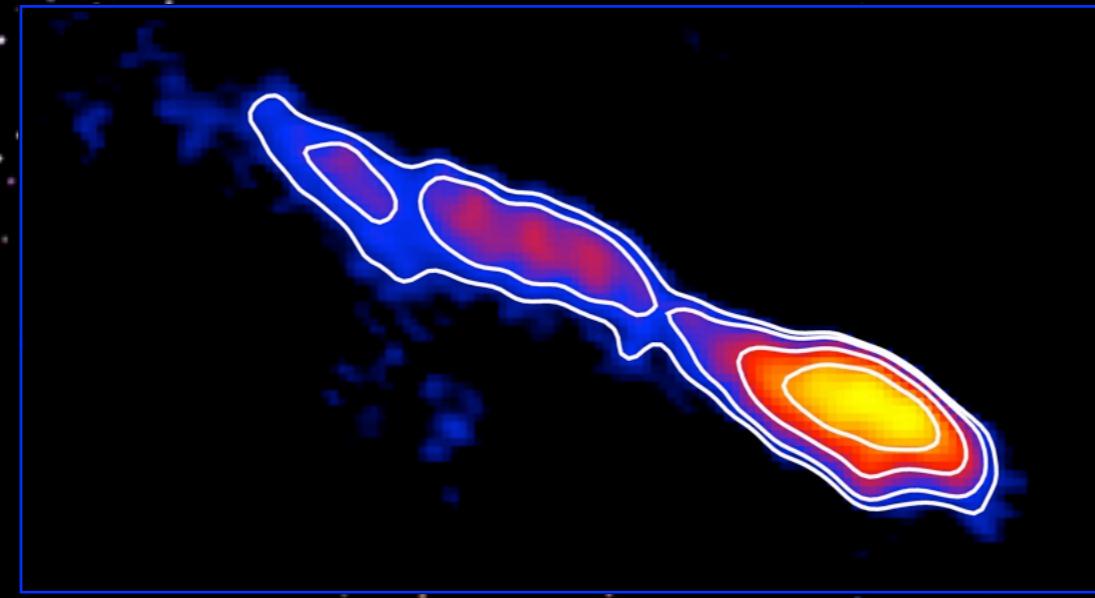
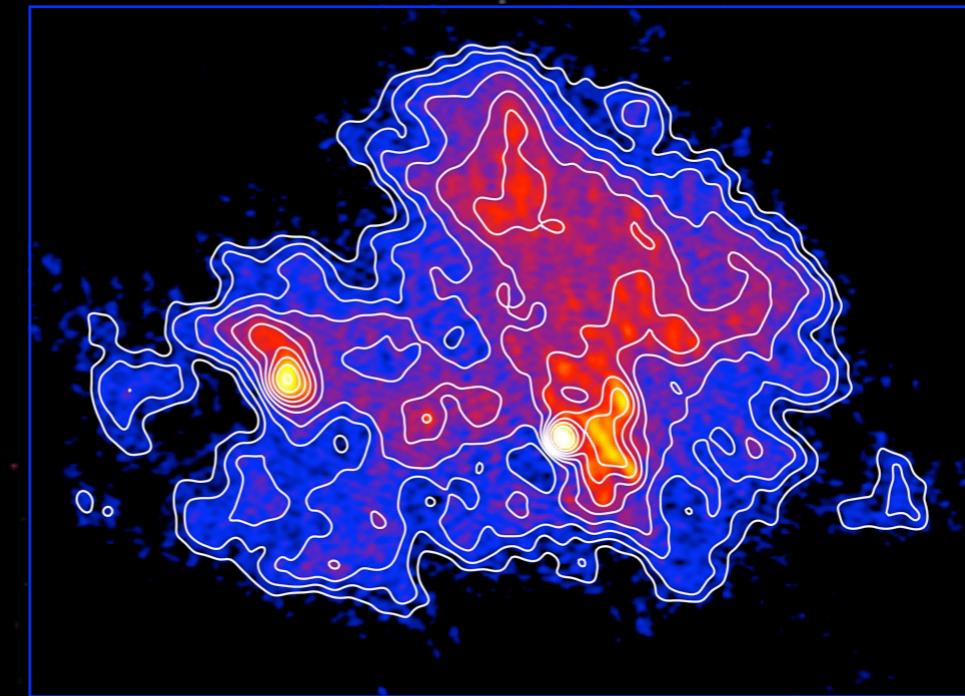
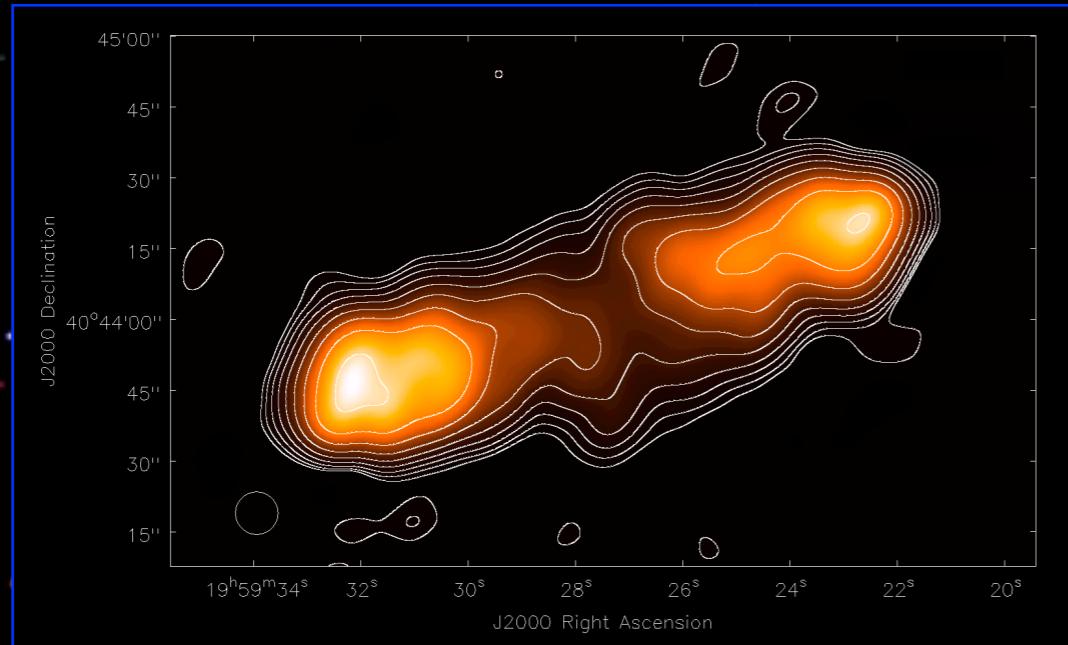
*Highest resolution image  
at 50 MHz to date!*



(courtesy: O. Wucknitz)

- LBA, 31 subbands, 44–59 MHz
- 6 hr on 12/13 Feb 2010
- 5 NL + 3 DE stations (Effelsberg, Unterweilenbach, Tautenburg)

# Some Recent Results





# LOFAR needs YOU!

The End