Status of LOFAR

Ronald Nijboer (ASTRON)

On behalf of the LOFAR team

ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)

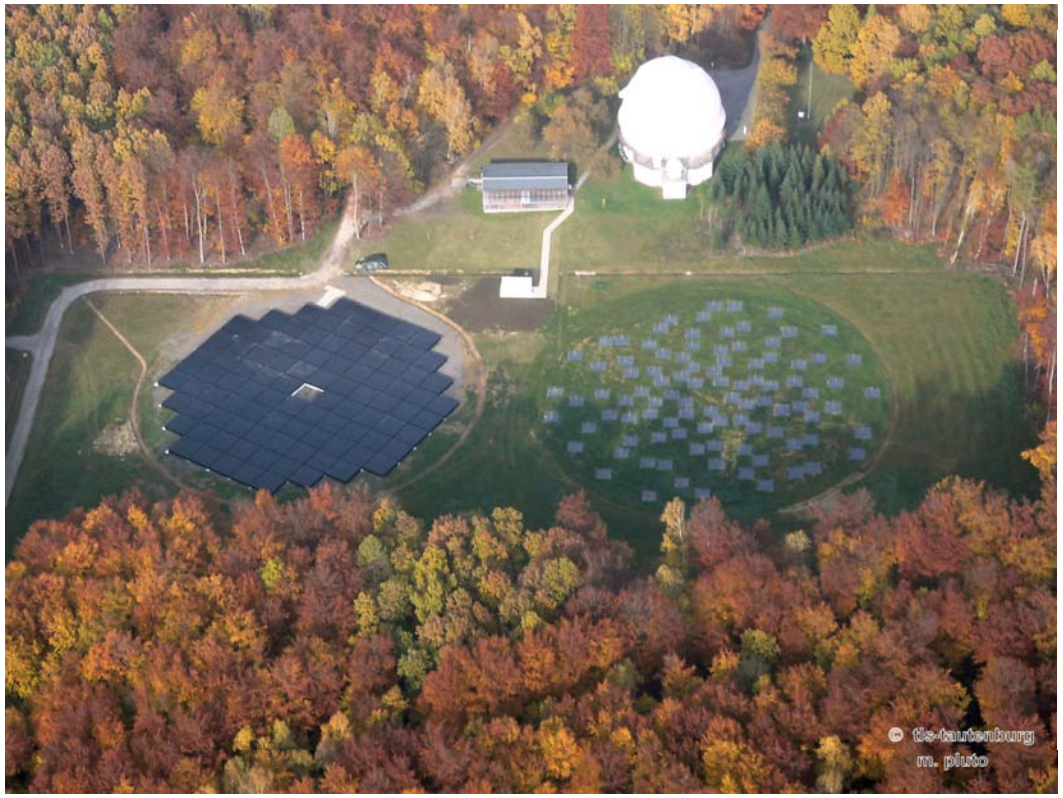
LOFAR: LOw Frequency ARray

- LBA: 10/30 – 80 MHz; HBA: 120 – 240 MHz
- 48 MHz BW
- AA Stations
  - Superterp: 6 stations, B ~ 350 m
    48 LBA dipoles (2 sets) + 2 x 24 HBA tiles; single clock
  - Core: + 18 stations, B ~ 3 km,
    48 LBA dipoles (2 sets) + 2 x 24 HBA tiles
  - NL Remote: + 16 stations, B ~ 80 km,
    48 LBA dipoles (2 sets) + 48 HBA tiles
  - EU Remote: + 8 stations , B ~ 1000 km,
    96 LBA dipoles + 96 HBA tiles

LOFAR Super Terp

LOFAR Core Station

International Stations



Tautenburg

Effelsberg

International Stations

Potsdam

Garching /
Unterweilenbach

International Stations

Onsala

Nancay

International Stations

Status LOFAR roll out

- Planned: 24 CS + 16 RS + 8 EU
  - Core: all rolled out
  - Dutch remote: 7 stations to be rolled out
  - EU: Onsala to be finished (est. Aug. 2011)
- Currently rolled out: 24 CS + 9 RS + 7 EU
  - Core: 20 stations validated
  - Dutch remote: 7 stations validated; 2 stations (80 km baselines) being validated right now
  - EU: 6 stations validated; 4 Germany, Nancay (FR), Chilbolton (UK); Juelich (DE) being validated right now
- Currently operational: 20 CS + 7 RS + 6 EU

» As of July 1st 2011.

LOFAR on the map

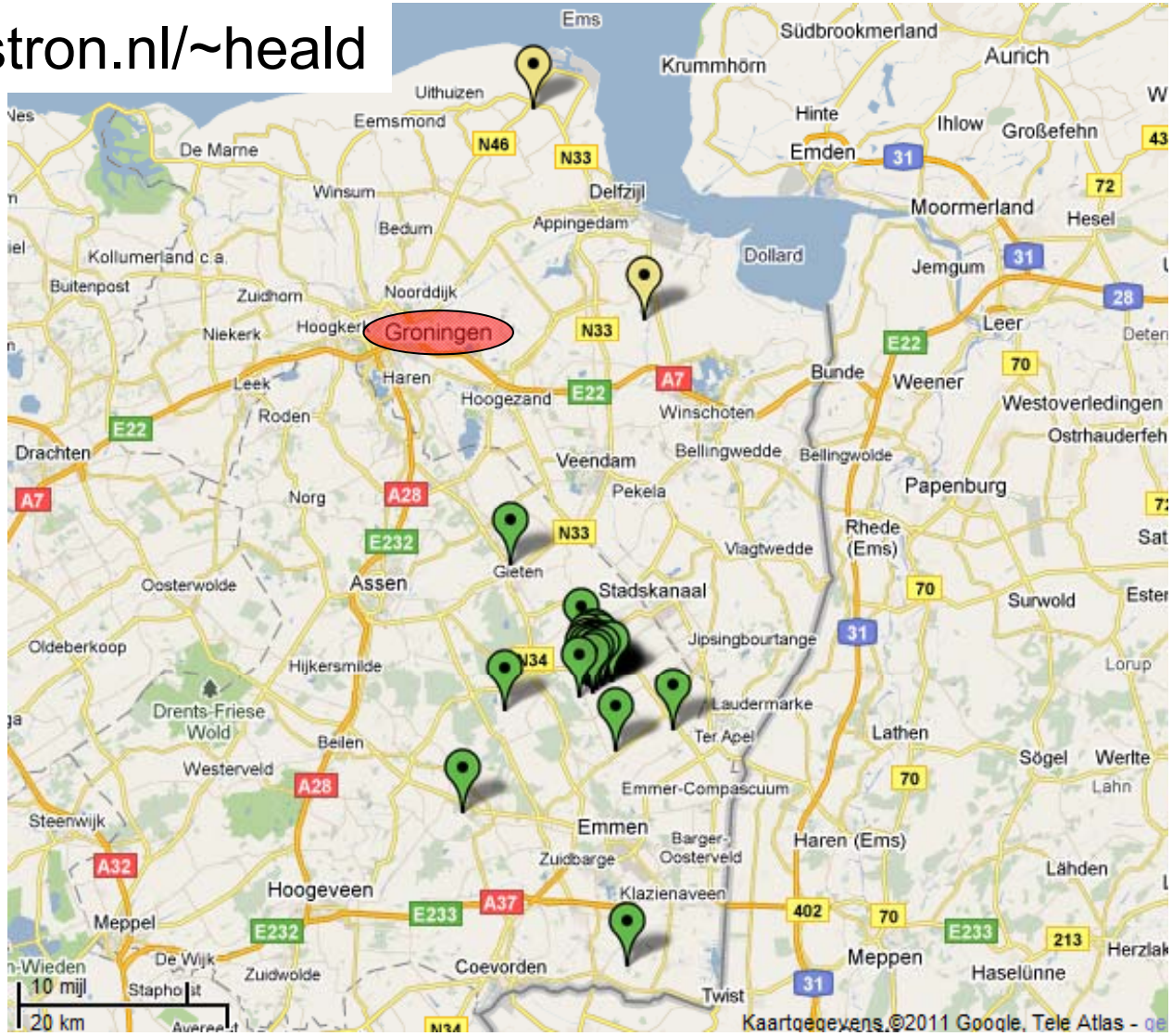
www.astron.nl/~heald

LOFAR on the map

www.astron.nl/~heald

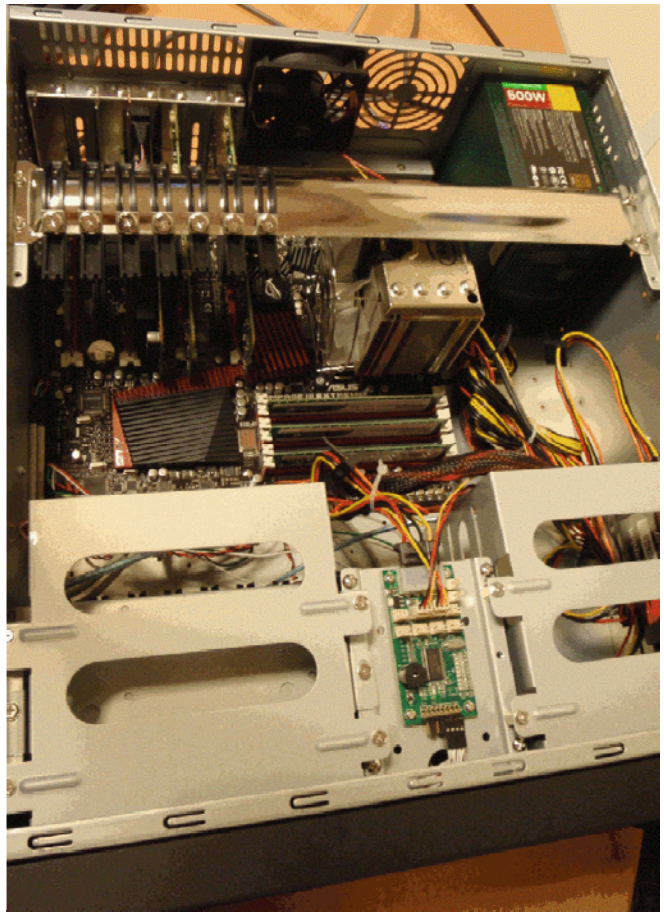
LOFAR on the map

www.astron.nl/~heald



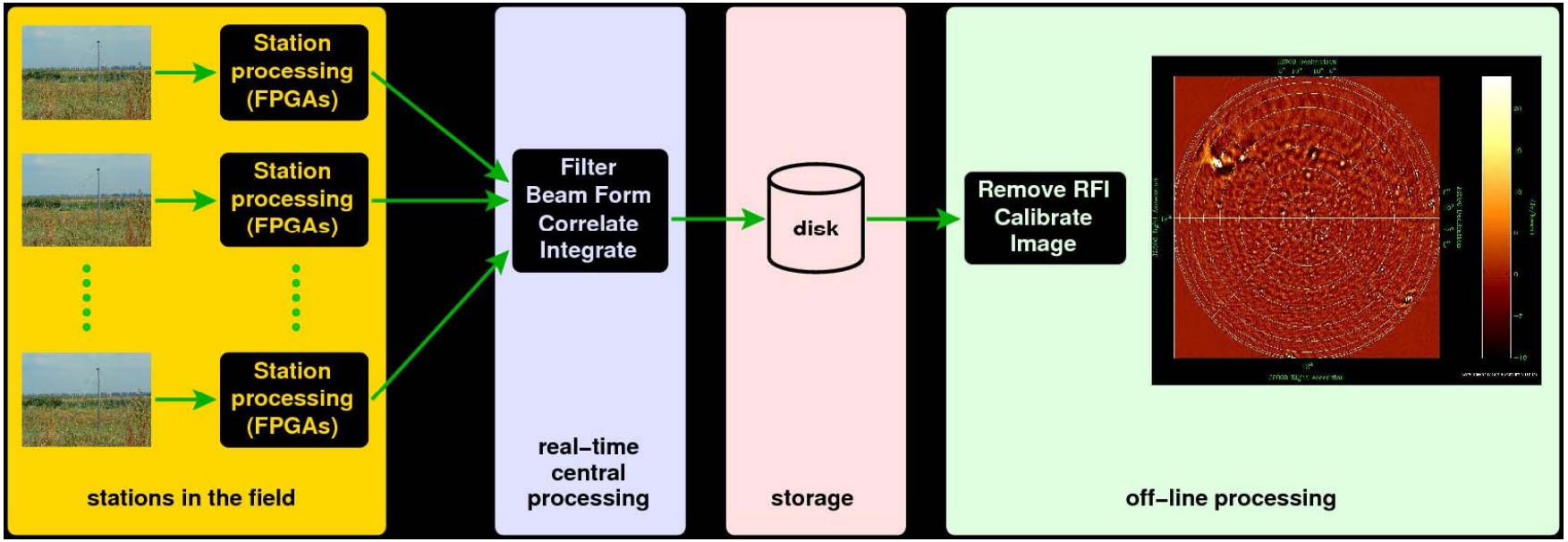
Phase 2 Processing Cluster

- Combined compute and storage cluster
  - 102 compute nodes
    - 100 nodes are also used for storage
  - 2 CPUs with each 12 cores (2.1 GHz)
  - 20 TByte storage per node
- Total capacity: 20 TFlop + 2 PByte
- For details see presentation by Chris Broekema



Compute capacity

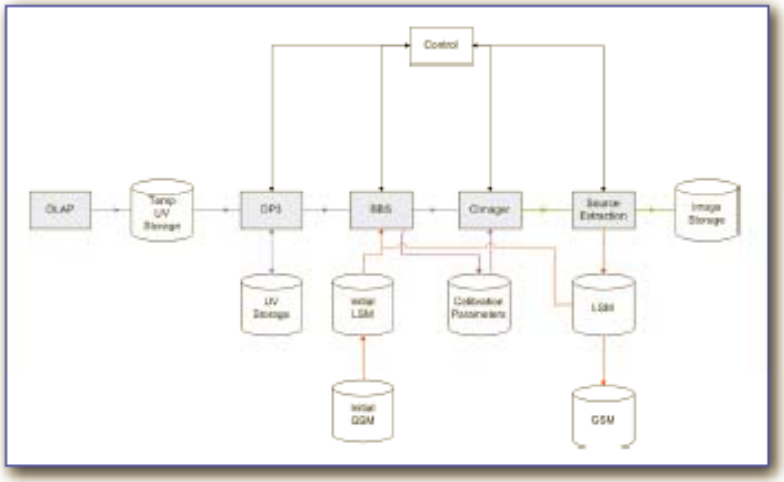
2 PByte



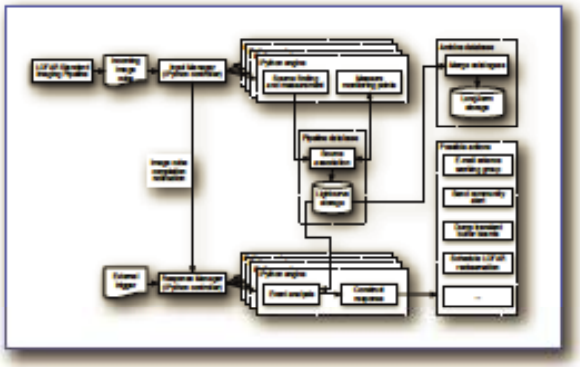
36 Tmul/s 14 Tflops 20 Tflops

Processing pipelines

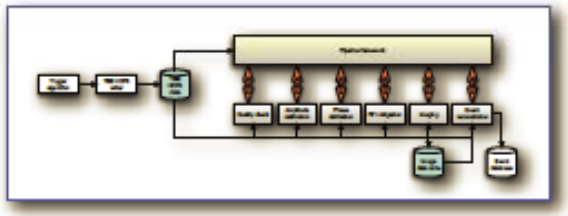
Standard Imaging



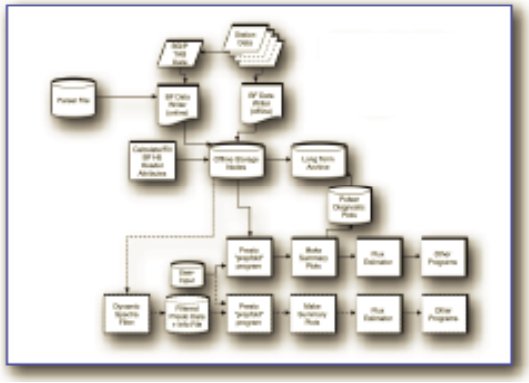
Transient Detection



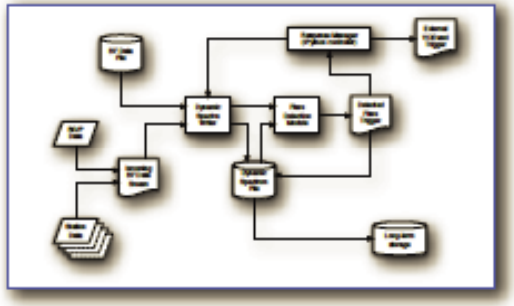
VHECR



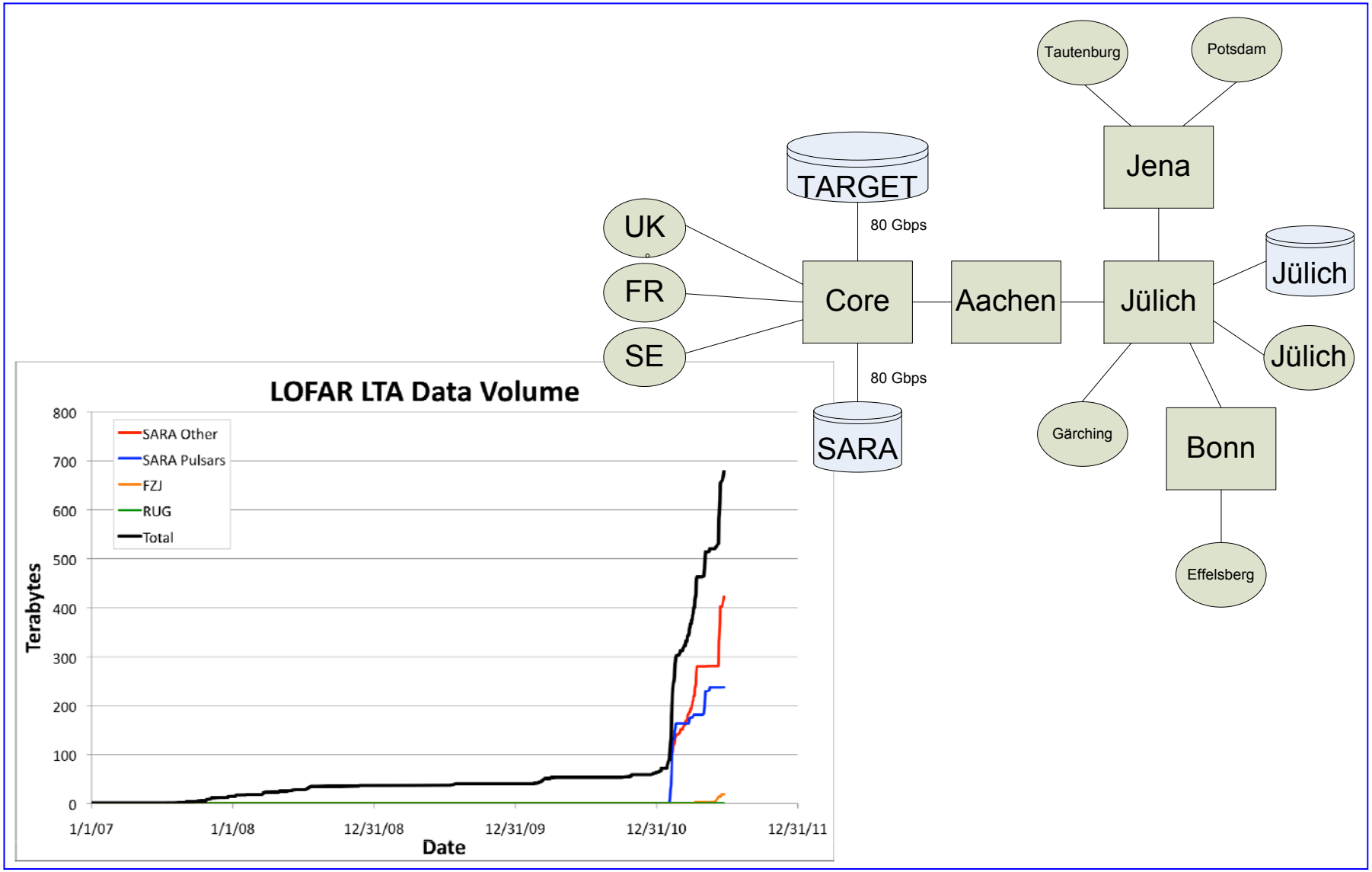
Known Pulsars



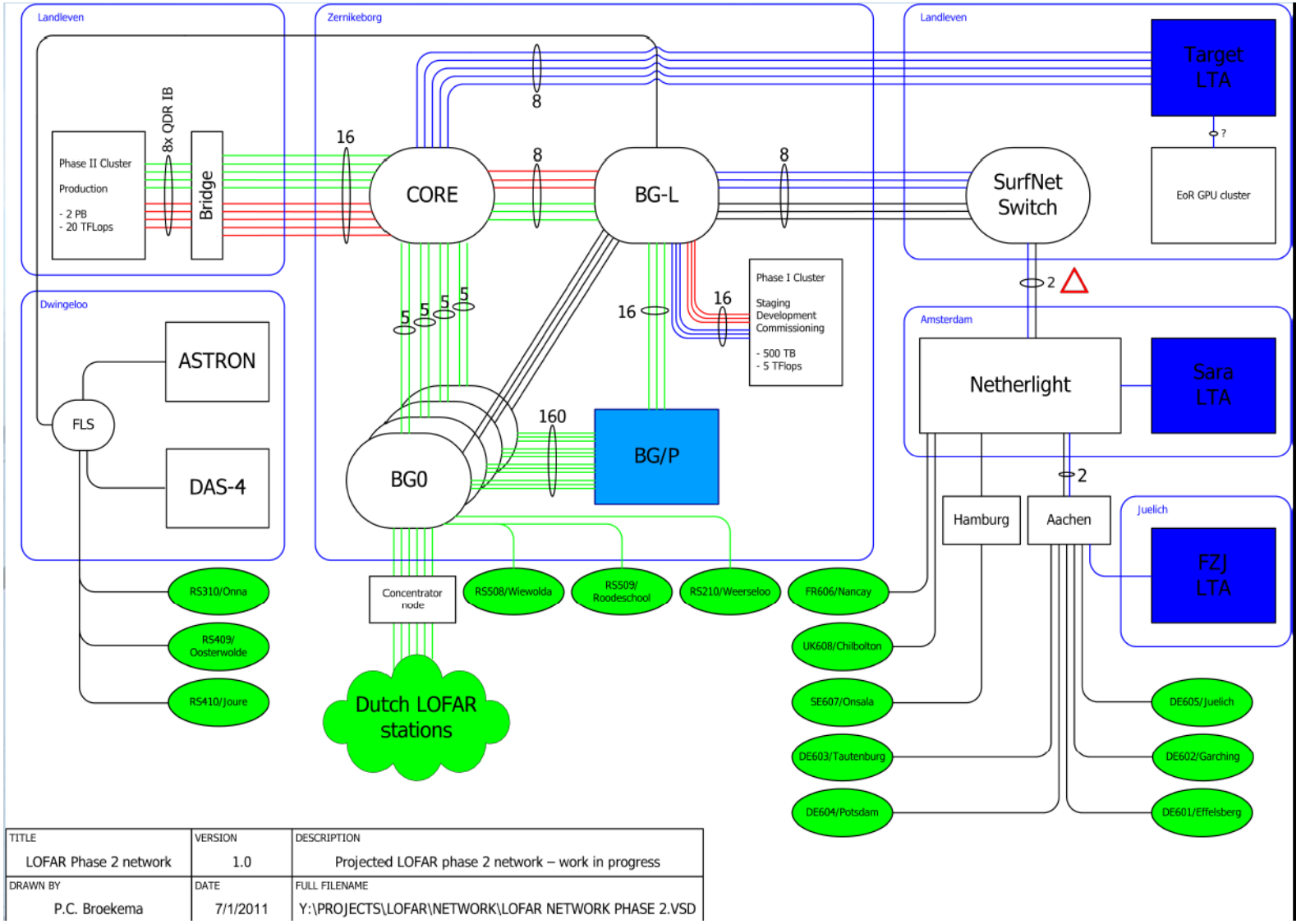
Dynamic Spectra



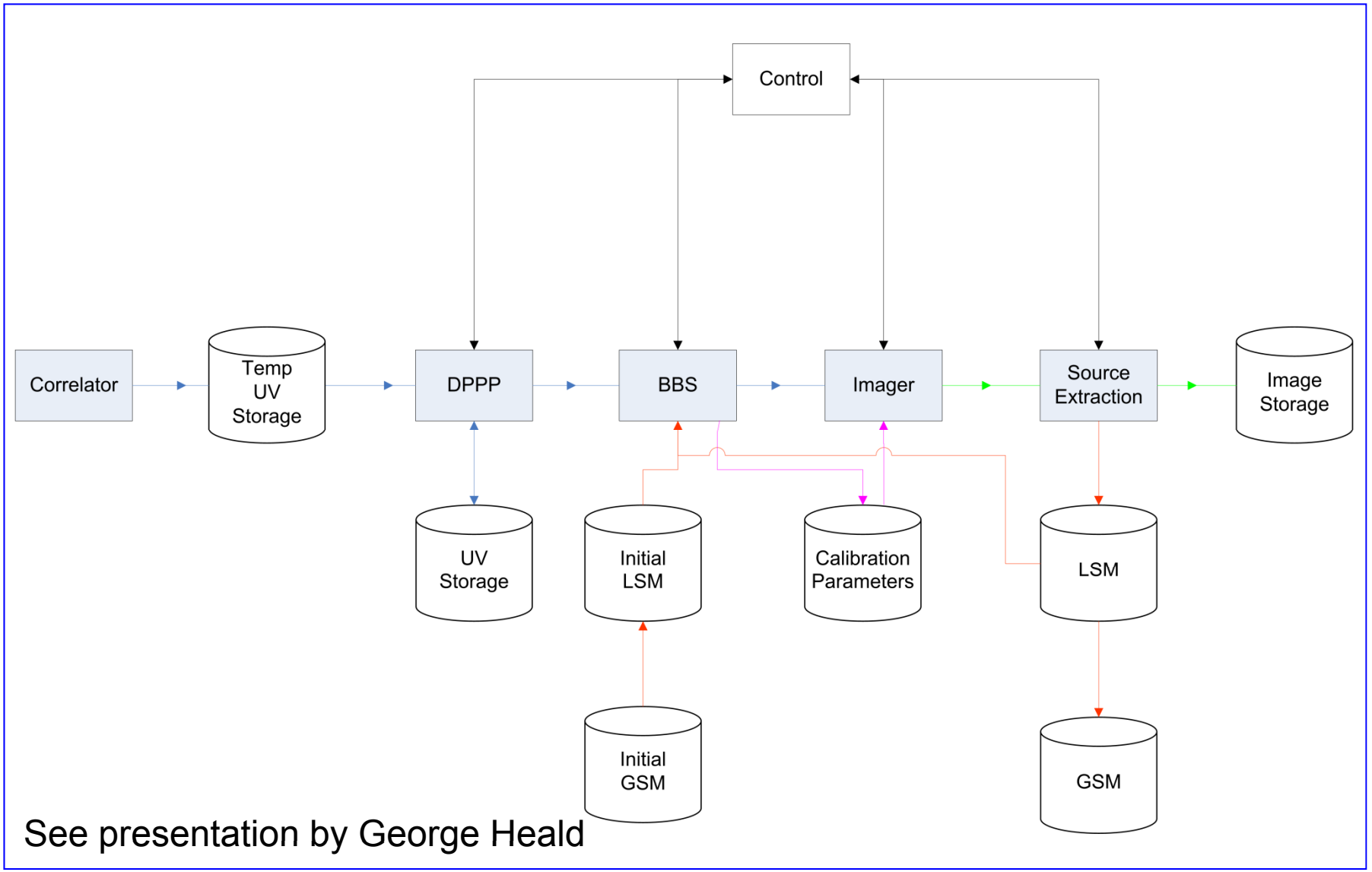
LOFAR Archive



Network

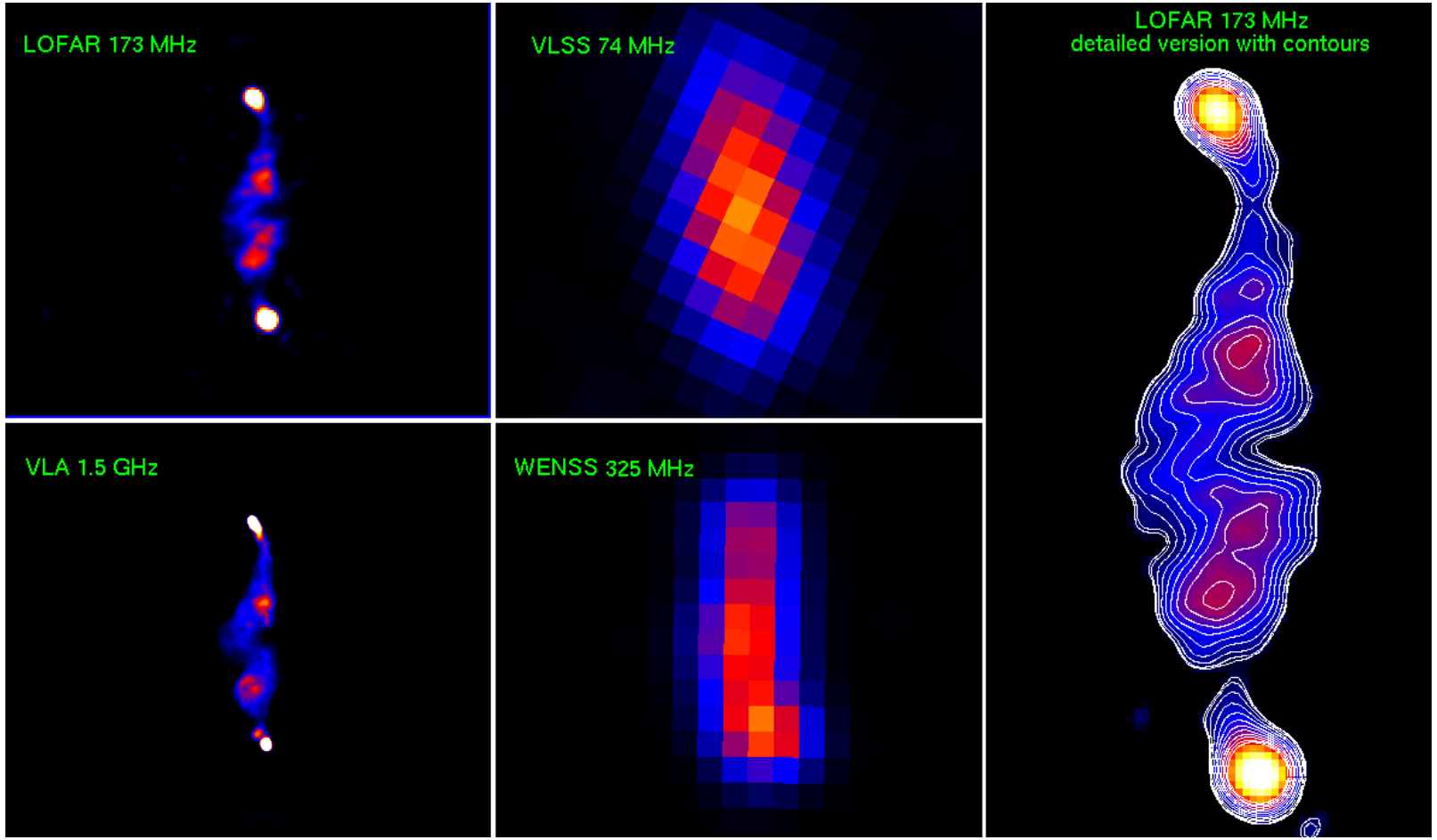

Landleven
Zernikeborg
Landleven
Target LTA
?
EoR GPU cluster
Phase II Cluster
Production
- 2 PB
- 20 TFLops
8x QDR IB
Bridge
16
CORE
8
BG-L
SurfNet Switch
Phase I Cluster
Staging
Development
Commissioning
- 500 TB
- 5 TFlops
Dwingeloo
ASTRON
FLS
DAS-4
5 5 5 5
16
160
BG0
BG/P
2
Amsterdam
Netherlight
Sara LTA
Hamburg
Aachen
Juelich
FZJ LTA
RS310/Onna
RS409/ Oosterwolde
RS410/Joure
Concentrator node
RS508/Wiewolda
RS509/ Roodeschool
RS210/Weerseloo
FR606/Nancay
UK608/Chilbolton
SE607/Onsala
DE603/Tautenburg
DE604/Potsdam
DE605/Juelich
DE602/Garching
DE601/Effelsberg
Dutch LOFAR stations
TITLE
LOFAR Phase 2 network
VERSION
1.0
DESCRIPTION
Projected LOFAR phase 2 network – work in progress
DRAWN BY
P.C. Broekema
DATE
7/1/2011
FULL FILENAME
Y:\PROJECTS\LOFAR\NETWORK\LOFAR NETWORK PHASE 2.VSD

Standard Imaging Pipeline



See presentation by George Heald

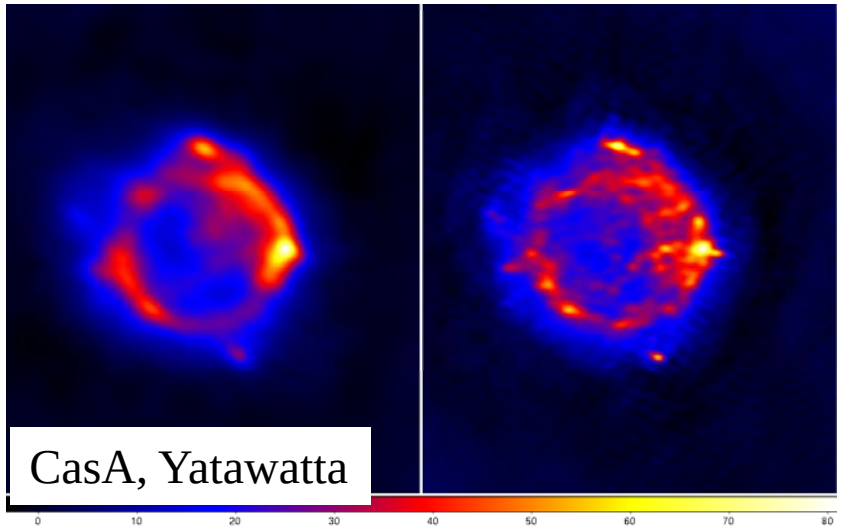
3C61.1



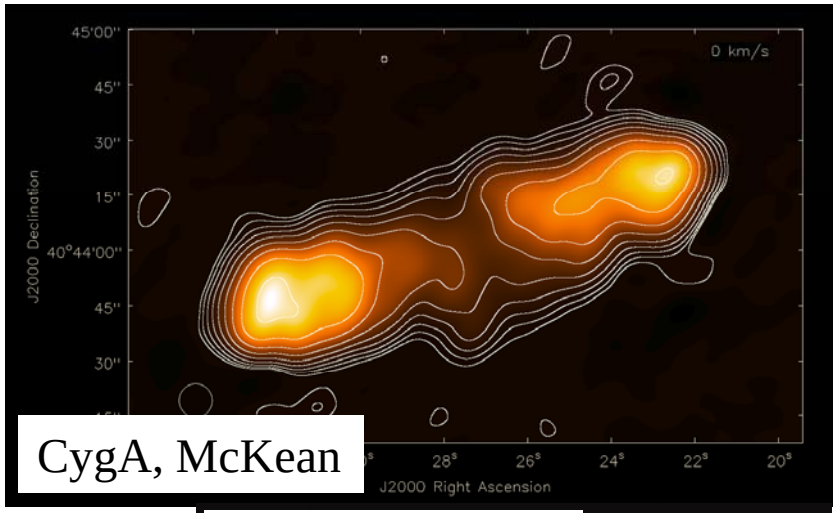
Reinout van Weeren (feb. 2010)

173 MHz; 0.2 MHz BW
20 stations: 16 CS + 4 RS
9.7 arcsec x 9.4 arcsec

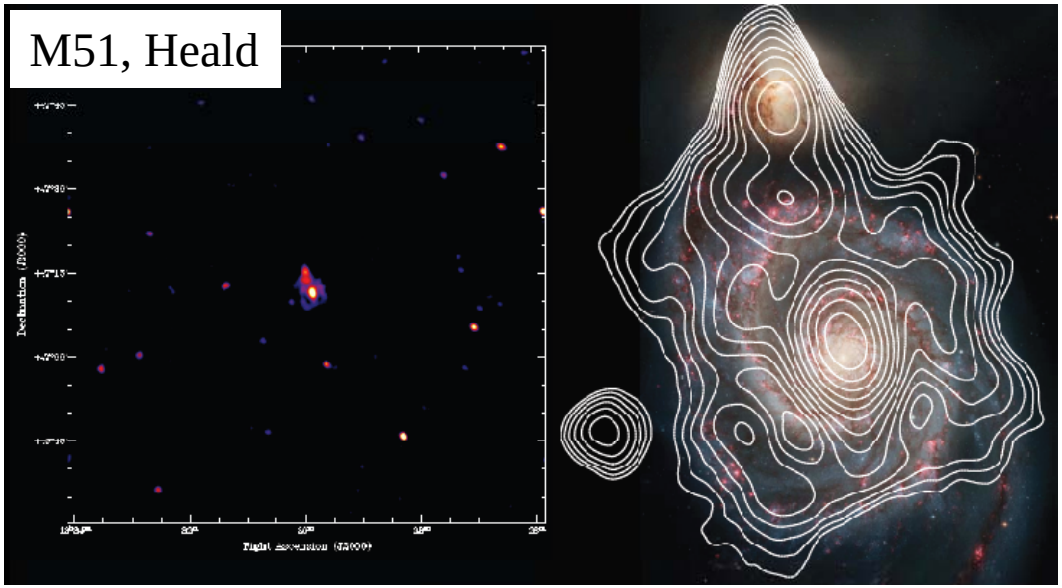
Various Images



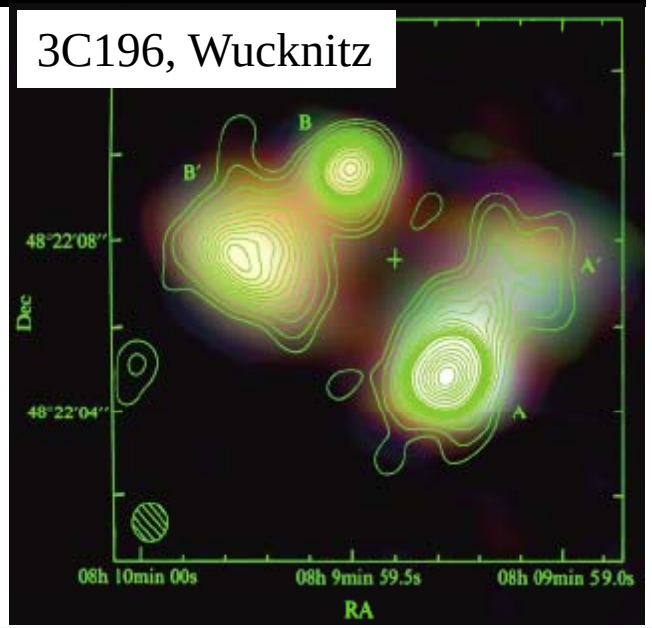
CasA, Yatawatta



CygA, McKean

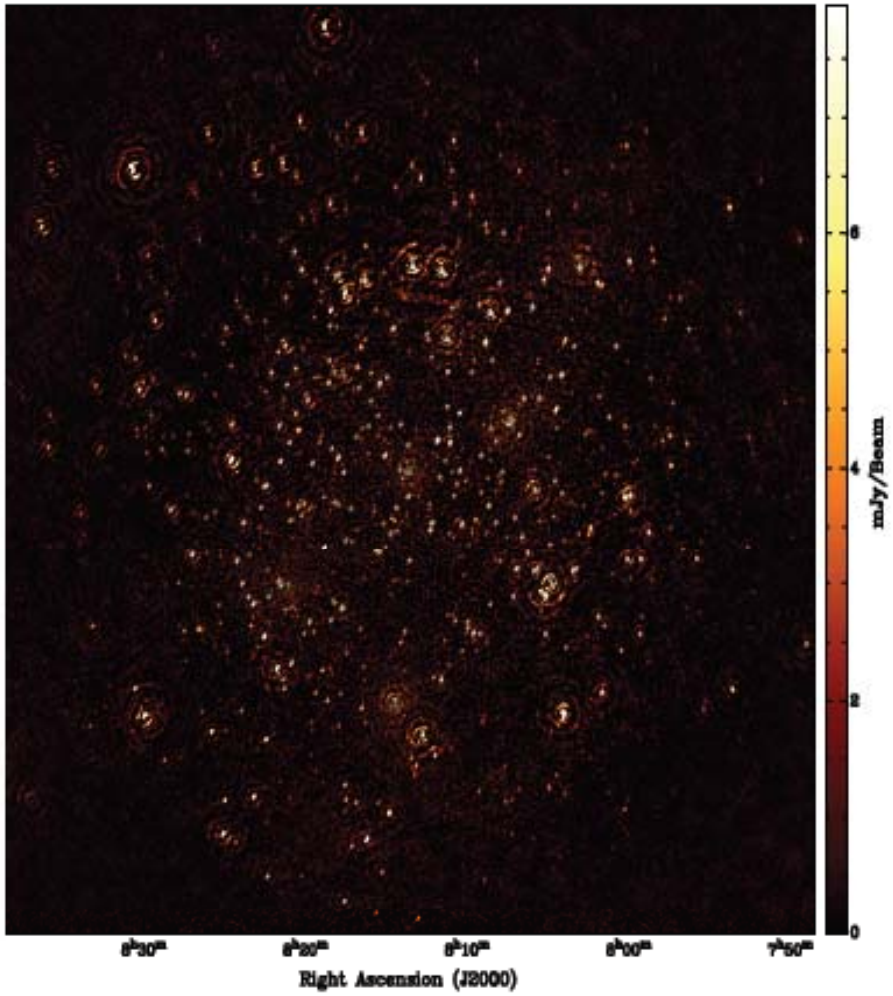


M51, Heald



3C196, Wucknitz

EoR: LOFAR Deep Field 3C196



See presentation by Panos Labroupolous

LOFAR (2011)
47 stations, DR 250000:1

Panos Labroupolous

Status Imaging Pipeline

- Currently being automated / integrated
- DPPP
  - Flags data, removes A-team, compresses data
- BBS
  - DD Calibration
  - Beam model
  - Ionospheric calibration in progress
- Imager
  - AWProjection for LOFAR beams implemented; needs testing
- Source Finder
  - Two in-house packages
- Sky database
  - Based on VLSS, WENSS, NVSS

AWProjection (1)

- **JAWS: the Joint AW Spheroidal Imager**
- Cyril Tasse, Bas van der Tol, Ger van Diepen, Joris van Zwieten, Sanjay Bhatnagar, Urvashi Rau, Kumar Golap

JAWS: the theory

Beam (4*4)

W term (scalar)

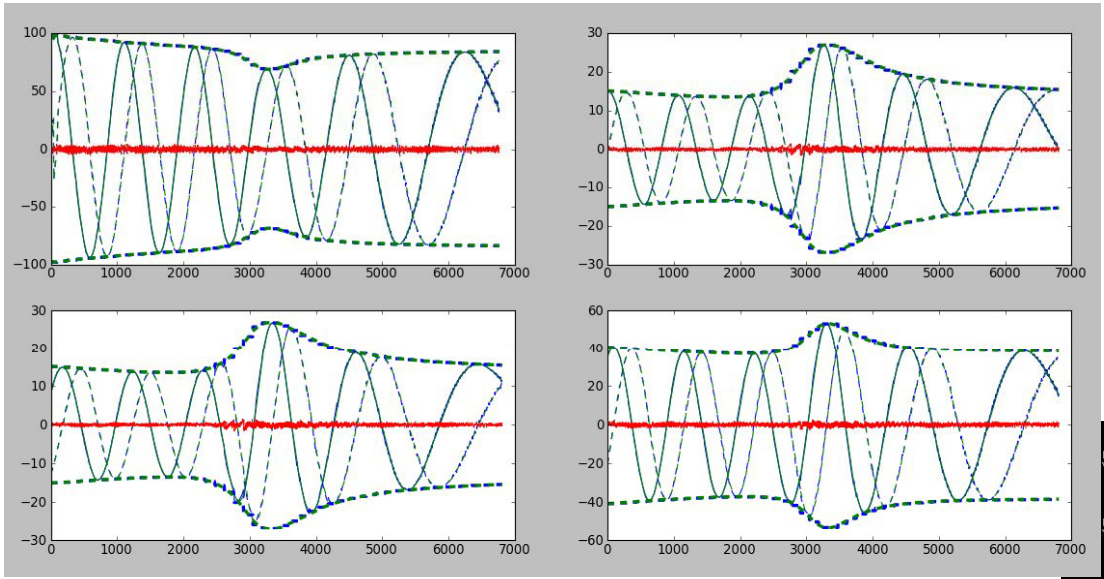
$$\mathrm{Vec}(V_{pq}) = (G_q^* \otimes G_p)\mathrm{FT}\left[\left(E_{q,\vec{s}}^* \otimes E_{p,\vec{s}}.\exp\left(-2\pi i w_{pq}.\left(\sqrt{1-l^2-m^2}-1\right)\right)\right)\right]$$

Convolution → $\circledast_S \int \mathrm{Vec}(X_{\vec{s}}).\exp\left(-2\pi i(u_{pq}l + v_{pq}m)\right)dl.dm$

This is an EXACT map from sky plane to the Visibilities in the UVW space!

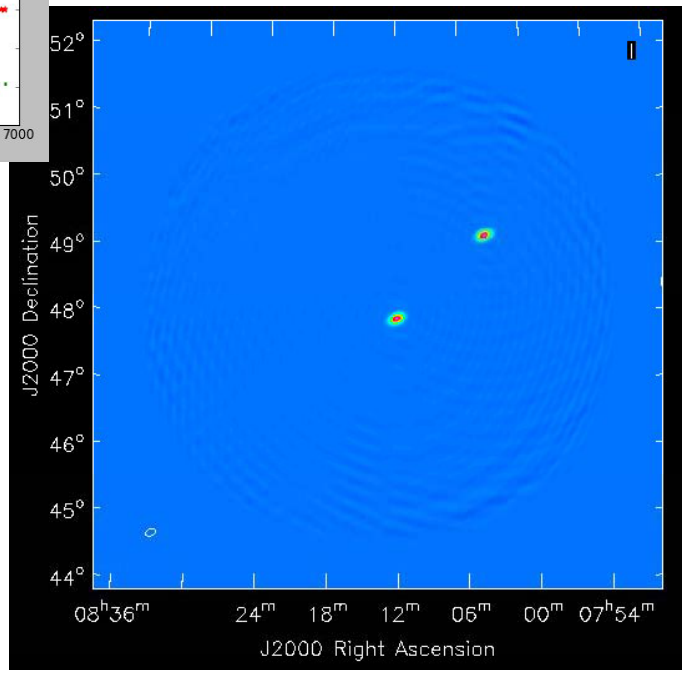
BUT: The inverse map is approximative! (based on pseudo-inverse)

AWProjection (3)

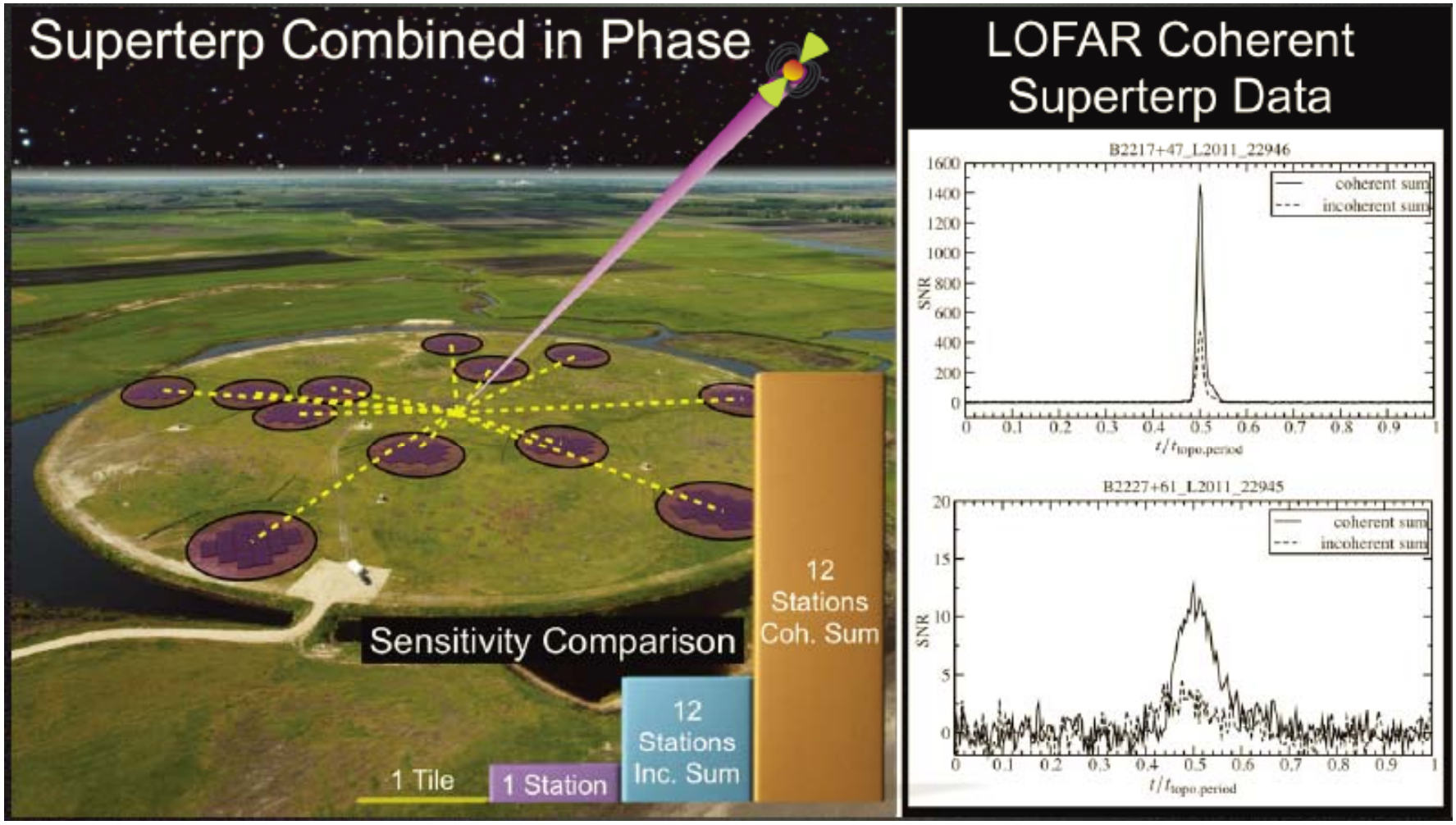


BBS predict (DFT) vs. AW degridding

Recovered IQUV fluxes to better than 1%

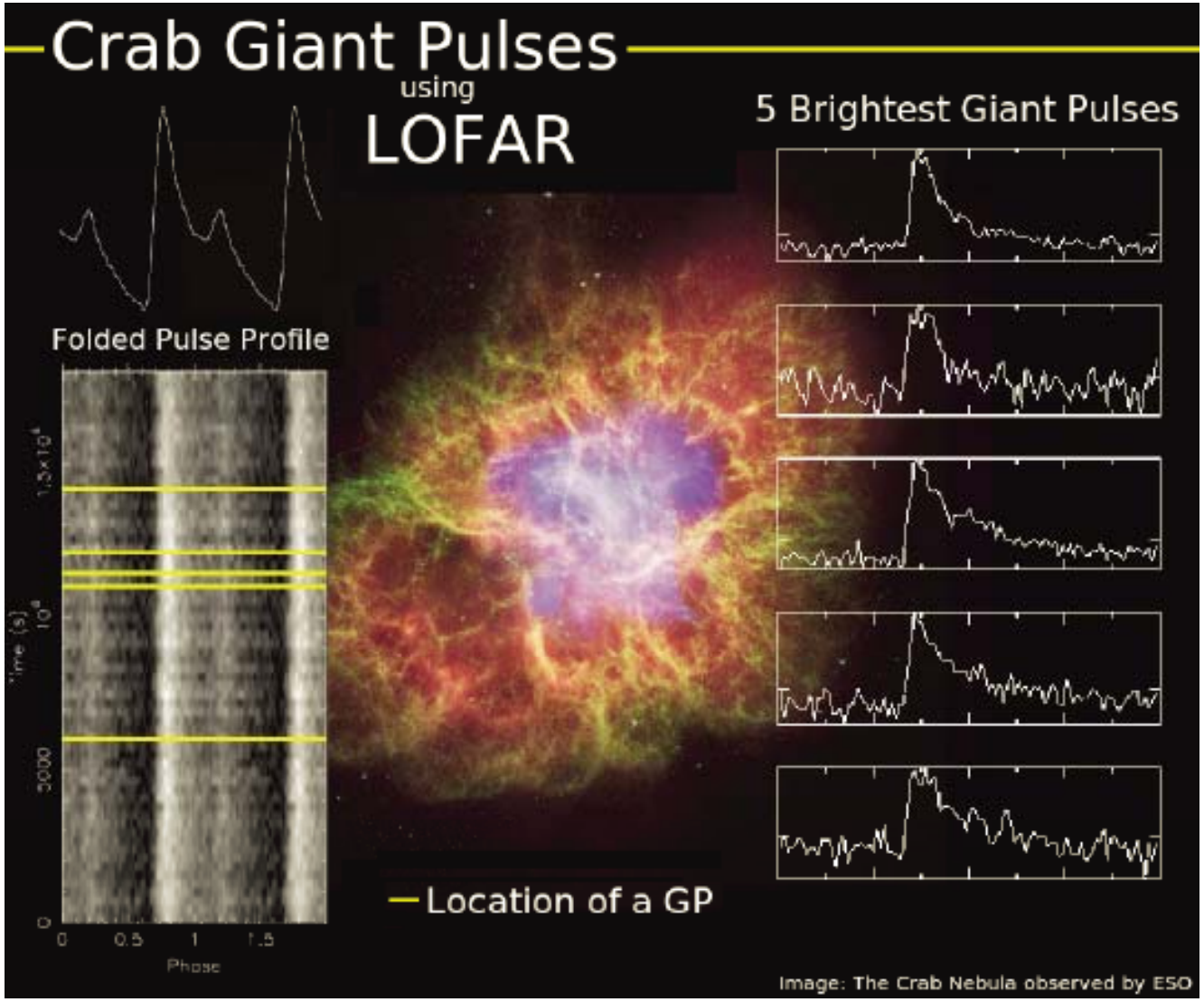


Pulsar observations



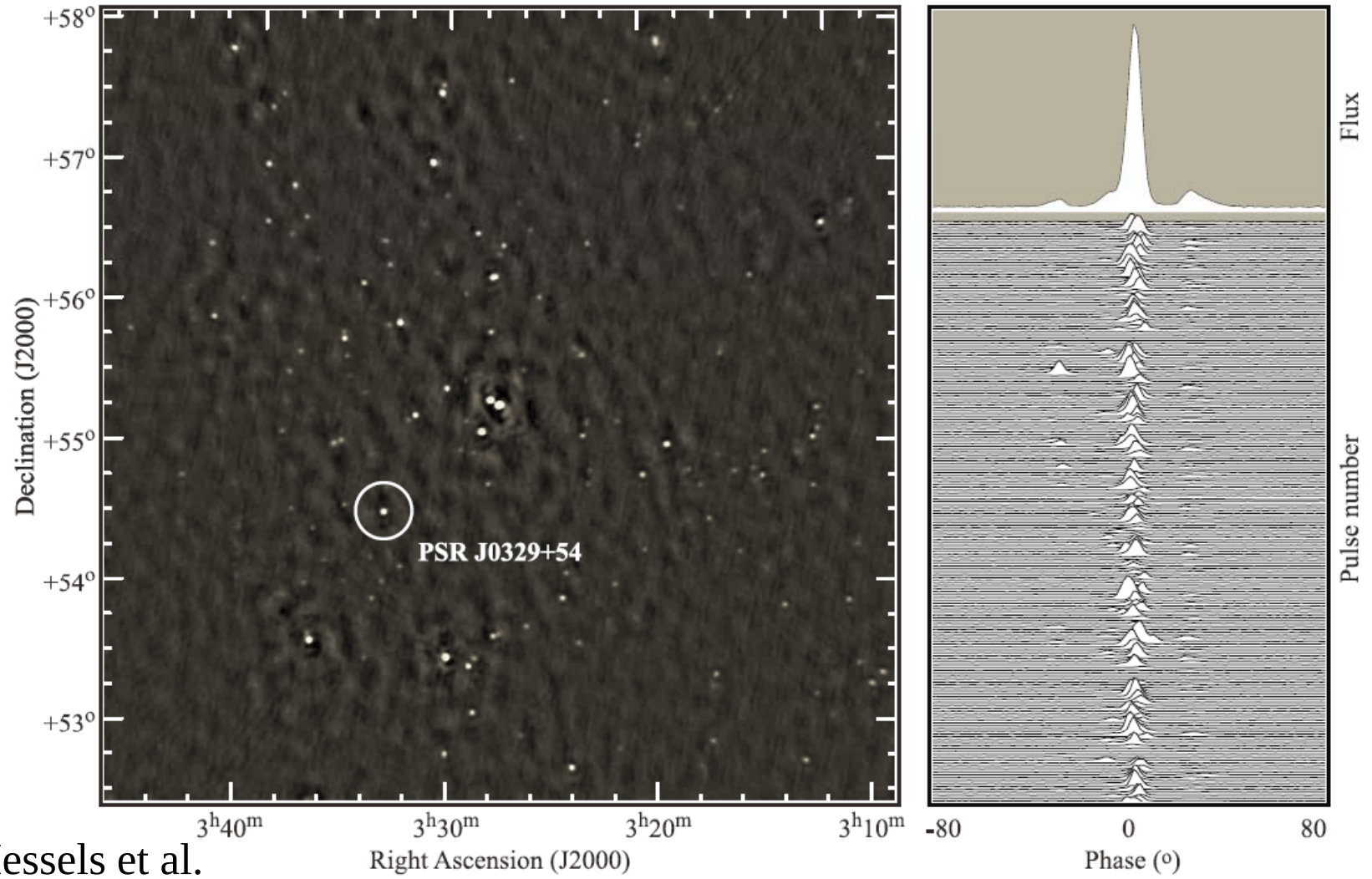
Hessels et al.

Crab Pulsar



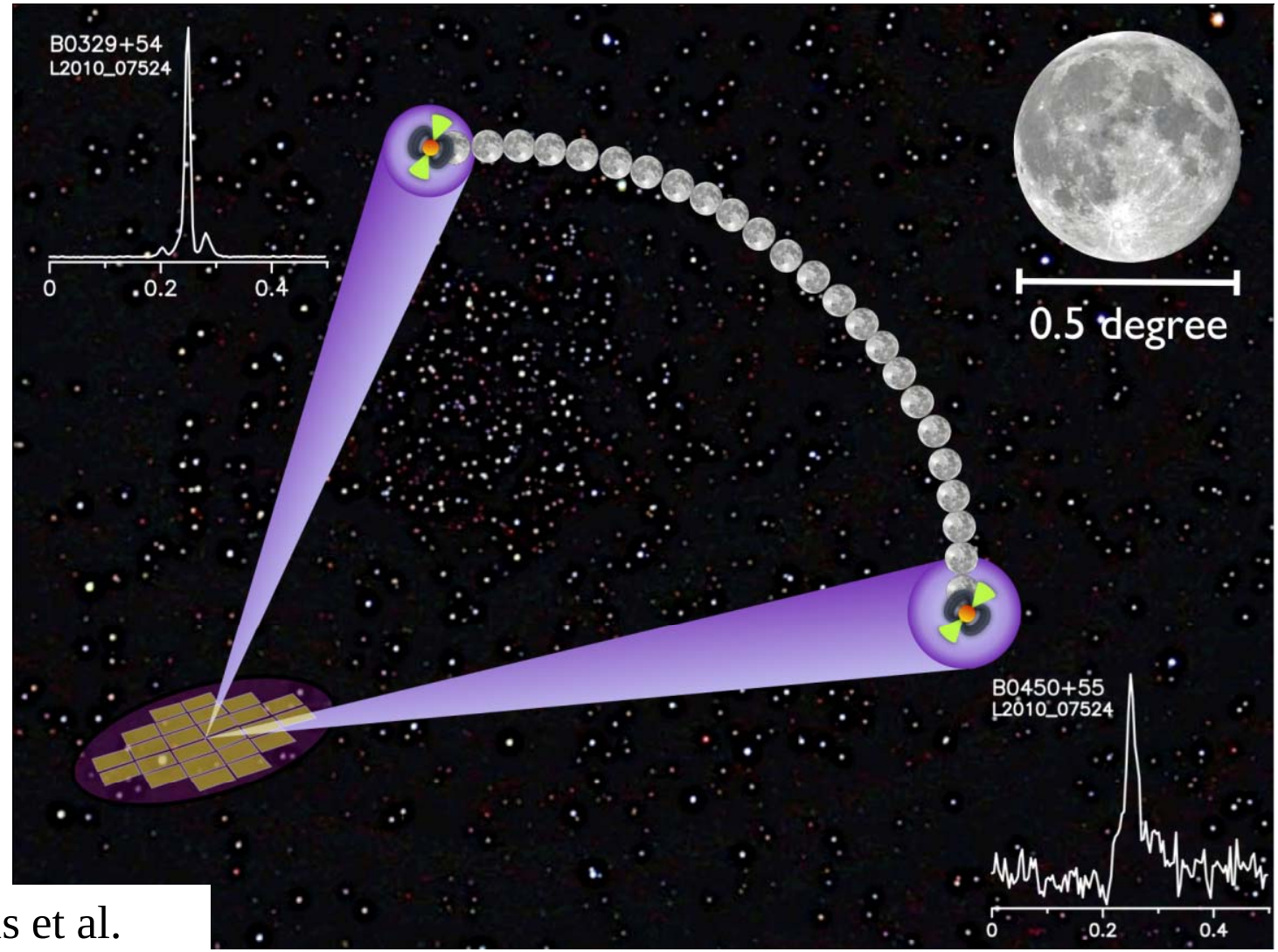
Hessels et al.

PSR J0329+54: Imaging + tied array



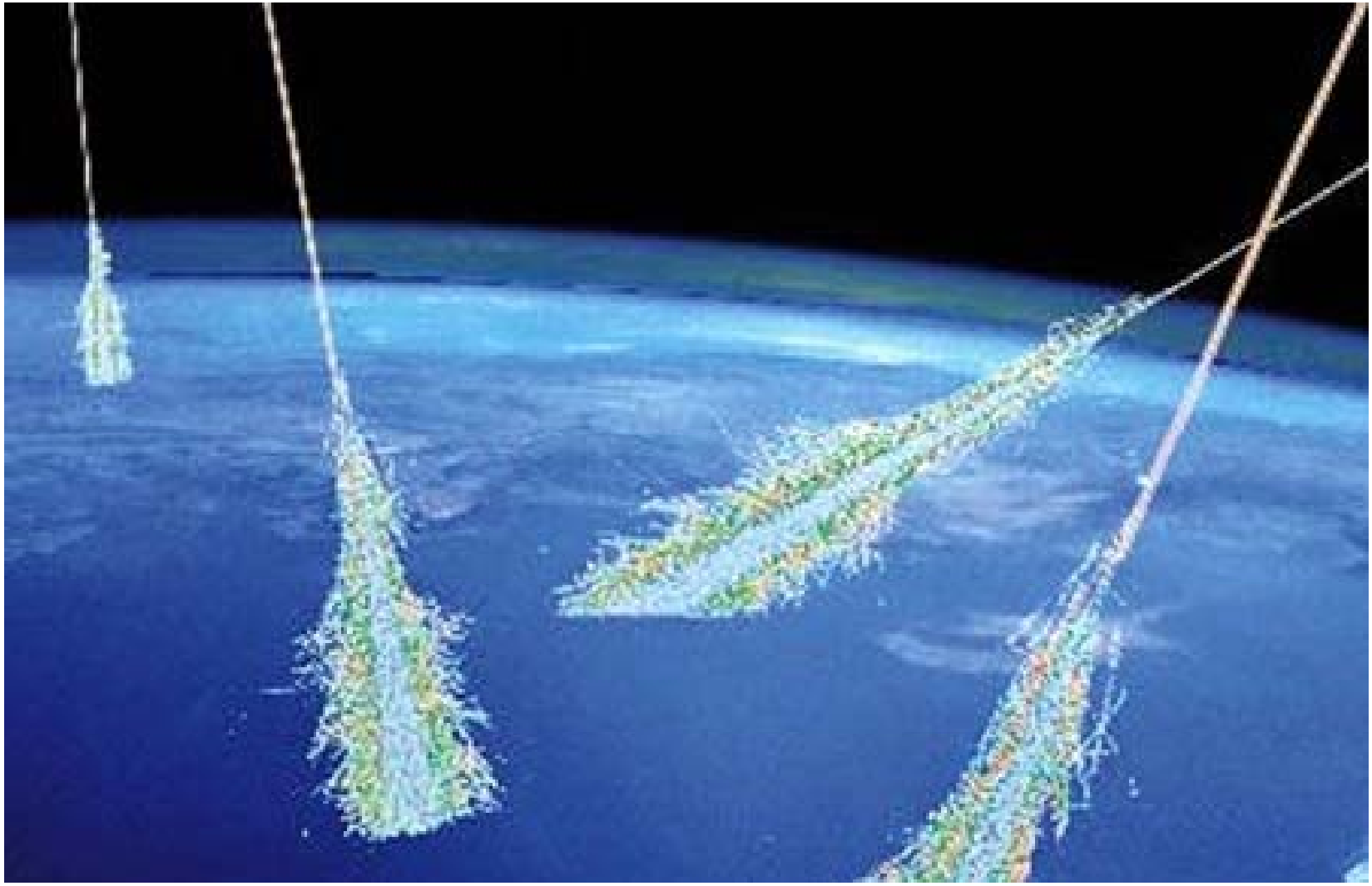
Hessels et al.

Multi-beam observations

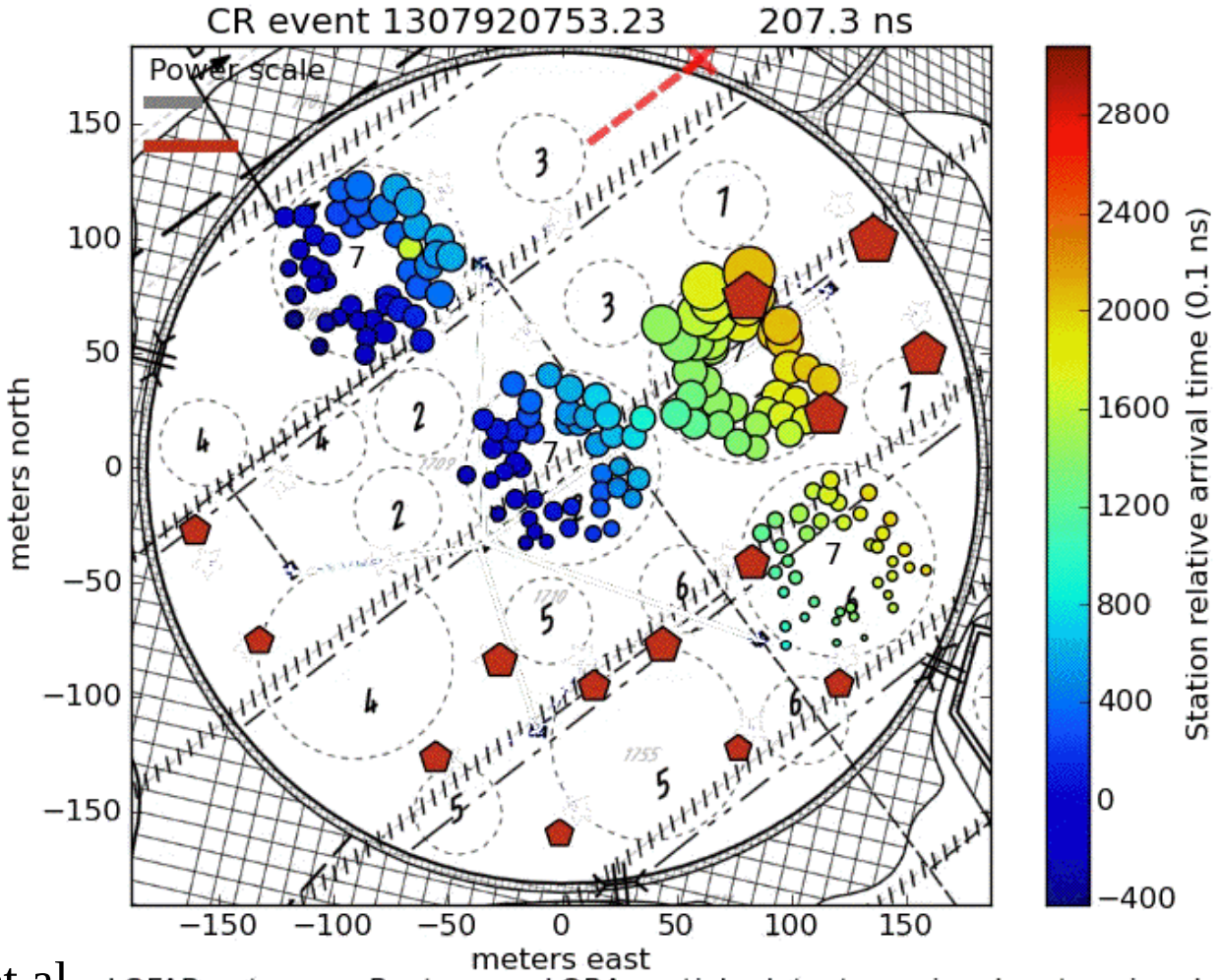


Hessels et al.

Cosmic Rays



Cosmic Ray detection



Ter Veen et al. LOFAR antennas, Pentagons: LORA particle detectors, size denotes signal strength

LOFAR Commissioning Survey

- A.k.a. MSSS (Million Source Shallow Survey)
- Key roles:
  - Fill the initial GSM for calibration of arbitrary fields at arbitrary frequency in LOFAR bands
  - Guide development of, and exercise:
    - observatory operations
    - processing software
    - imaging pipeline
    - (piggyback applications?)

Draft Specification

- MSSS-LBA
  - Array configuration: 24 CS + 11 RS (LBA_INNER)
    - Up to 10 km baselines
    - 1.5 – 2 arcmin resolution
  - Bandwidth: 16 MHz over 30-78 MHz [coverage TBD]
  - Number of independent beams: 3
  - Time per field: 90 minutes (9x10 minutes; δHA~0.5h)
  - Resulting sensitivity (approximate): ~15 mJy
  - Required number of fields: 619 (covering 2π sr)
  - Required on-source observing time for full survey: 619/3x90min = 309.5 hr

Draft Specification

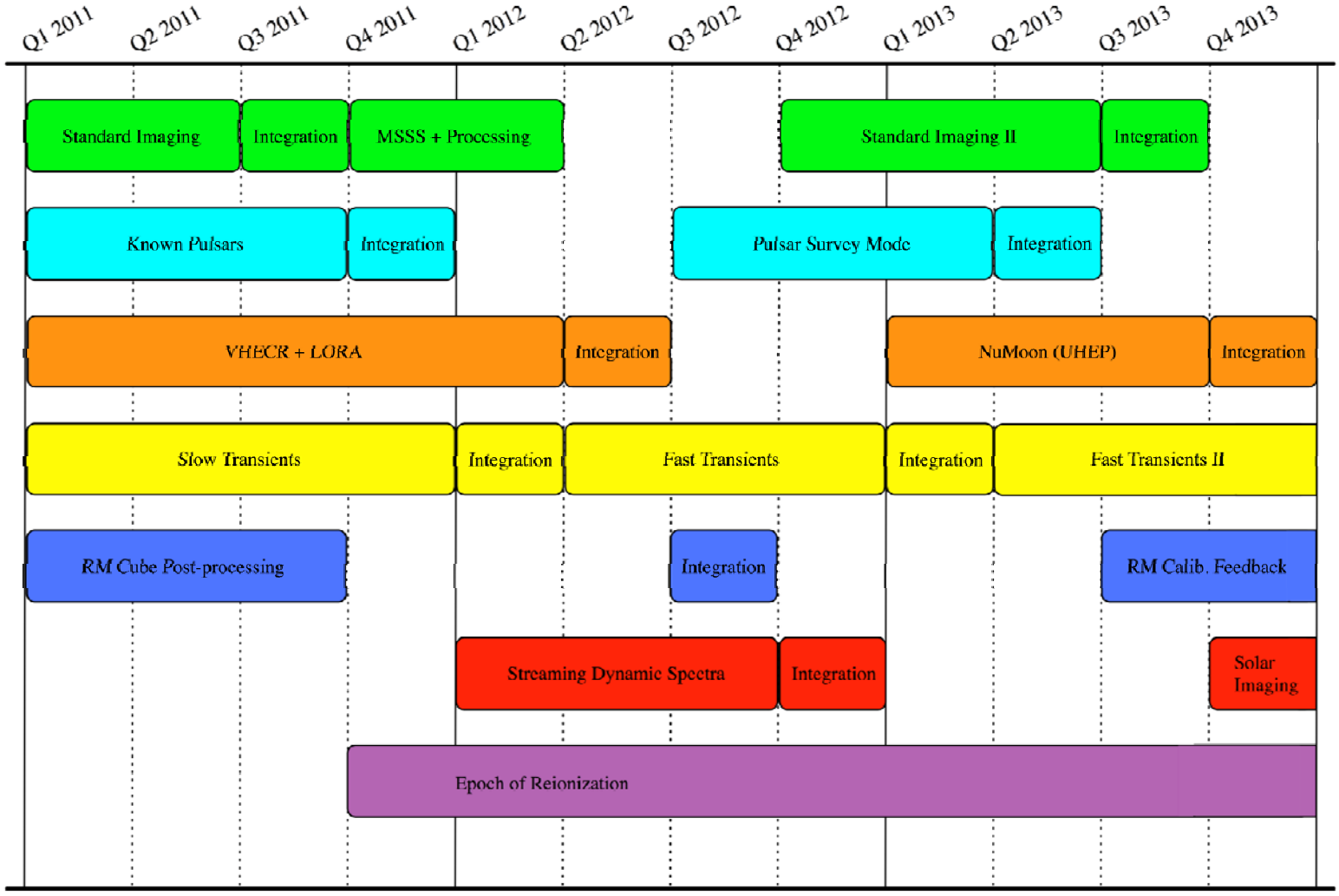
- MSSS-HBA
  - Array configuration: 24 CS (HBA_DUAL?)
    - Up to 3 km baselines
    - 1.5 – 2 arcmin resolution
  - Bandwidth: 16 MHz over 120-168 MHz [coverage TBD]
  - Number of independent beams: 3
  - Time per field: 15 minutes
  - Resulting sensitivity (approximate): ~5 mJy
  - Required number of fields: 3522 (covering 2π sr)
  - Required on-source observing time for full survey: 3522/3x15min = 293.5 hr

Comparing relevant Surveys

Survey	Frequency	Sensitivity	Resolution	Sky coverage
MSSS-LBA (core only)	~30-78 MHz	15 mJy/beam	100”	20,000 square deg (dec > 0)
VLSS	74 MHz	100 mJy/beam	80”	30,000 square deg (dec > -30)
MSSS-HBA (core only)	~120-170 MHz	5 mJy/beam	120”	20,000 square deg (dec > 0)
TGSS	140-156 MHz	7-9 mJy/beam	20”	(2100 of) 32,000 square deg (dec > -30)
WENSS	330 MHz	3.6 mJy/beam	54”	10,000 square deg (dec > 30)
NVSS	1400 MHz	0.45 mJy/beam	45”	35,000 square deg (dec > -40)

- **AARTFAAC: Amsterdam—ASTRON Radio Transients Facility and Analysis Centre**
  - Univ. of Amsterdam, ASTRON, Univ. of Oxford
- 24 / 7 all sky monitor
  - Correlate all 288 LBA dipoles in the superterp
  - Real time data processing and transient detection
  - Trigger
  - Follow up with full array or other instrument

Planning


Q1 2011
Q2 2011
Q3 2011
Q4 2011
Q1 2012
Q2 2012
Q3 2012
Q4 2012
Q1 2013
Q2 2013
Q3 2013
Q4 2013
Standard Imaging
Integration
MSSS + Processing
Standard Imaging II
Integration
Known Pulsars
Integration
Pulsar Survey Mode
Integration
VHECR + LORA
Integration
NuMoon (UHEP)
Integration
Slow Transients
Integration
Fast Transients
Integration
Fast Transients II
RM Cube Post-processing
Integration
RM Calib. Feedback
Streaming Dynamic Spectra
Integration
Solar Imaging
Epoch of Reionization

Summary

- LOFAR hardware roll-out is nearing completion
  - Last stations: end 2011 / begin 2012
  - Roll out compute hardware completed
  - Archive under development
- Data taking at ~50% efficiency
- Commissioning is in full swing
- LOFAR software under continued development
  - Operates the on-line chain from station to correlation / beamforming
  - Data processing pipelines are being automated
    - Imaging pipeline being first