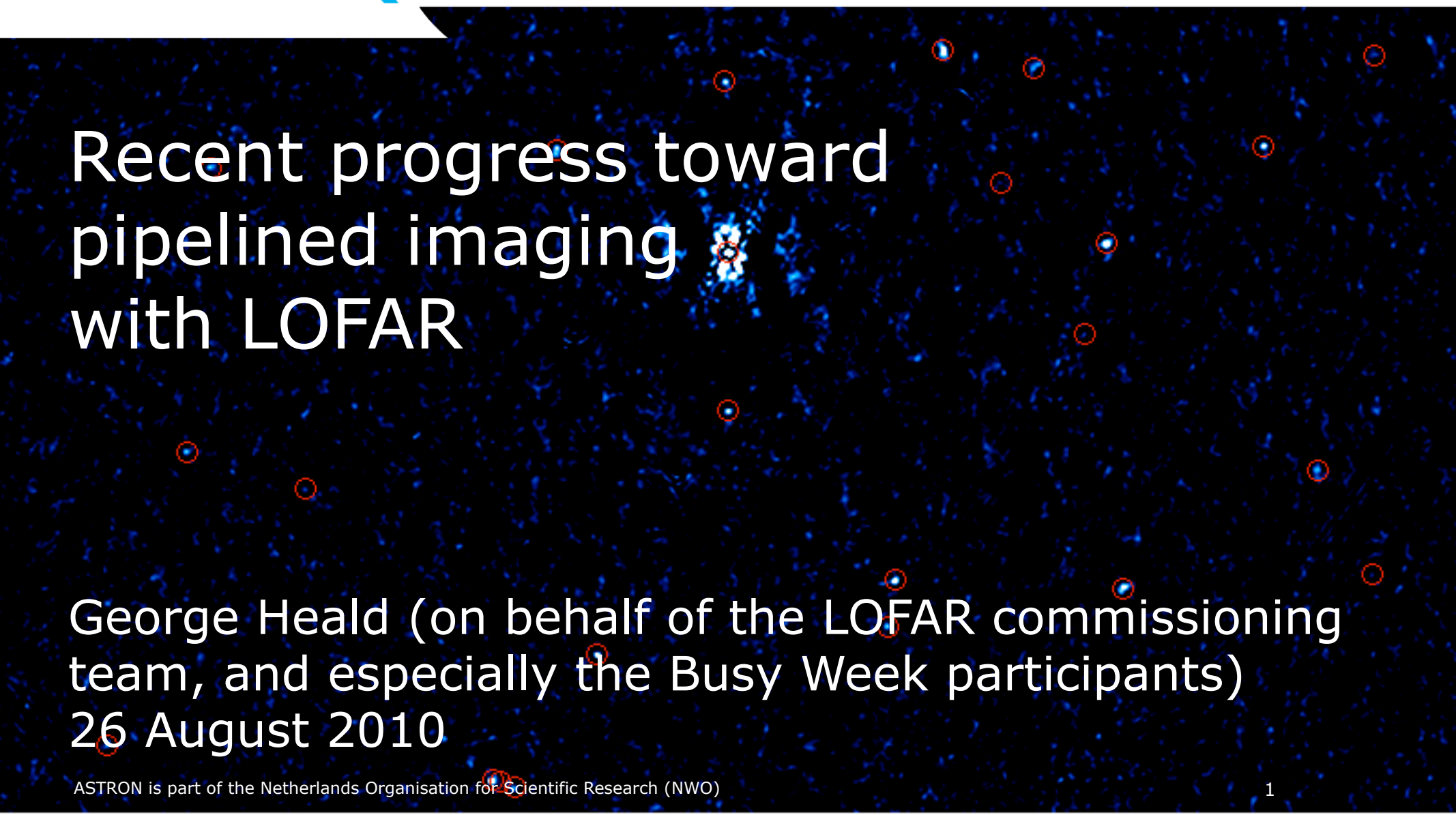
ASTRON

Netherlands Institute for Radio Astronomy



Recent progress toward pipelined imaging with LOFAR

George Heald (on behalf of the LOFAR commissioning team, and especially the Busy Week participants)

26 August 2010

Outline

- The LOFAR array ca. August 2010
- LOFAR Imaging Pipeline
- Calibration examples
- First imaging results and recent progress toward normal operations

- Along the way, we are developing the LOFAR Imaging Cookbook: http://www.mpa-garching.mpg.de/~fdg/LOFAR_cookbook/ (courtesy of Roberto Pizzo & Francesco de Gasperin)

The LOFAR Imaging Cookbook:
Manual data reduction with the imaging pipeline

Written by Timothy Garn (and updated by Roberto Francesco Pizzo, with contributions from Vishambhar Nath Pandey, Evert Rol, Anna Scaife, and John Swinbank, on behalf of the LOFAR commissioning teams)*

Version 3.0 - 22 July 2010

This cookbook describes the process of manually reducing a Measurement Set with the LOFAR imaging pipeline. It is intended to speed up the learning process for future commissioning, by collating various tips, tricks, and solutions in a single place. The LOFAR wiki[1] contains much more information on each stage of data reduction, but might be out of date in many places. The LOFAR forum[2] should also be helpful for commissioning. The contents of this cookbook are an approximation to the correct way of reducing LOFAR data – use with caution.
The softwares that have been designed for LOFAR data reduction are still in development. Sometimes, quicker results might be obtained with other data reduction packages (such as CASA). However, to test and improve the quality of the new software, we strongly encourage the users to follow the proposed way of the cookbook, post results or problems in the LOFAR forum, and talk to the software developers.

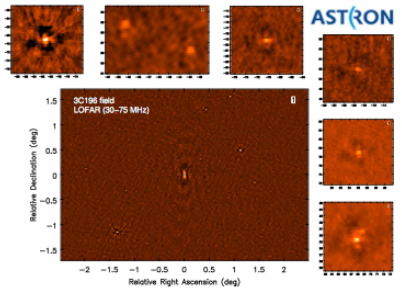
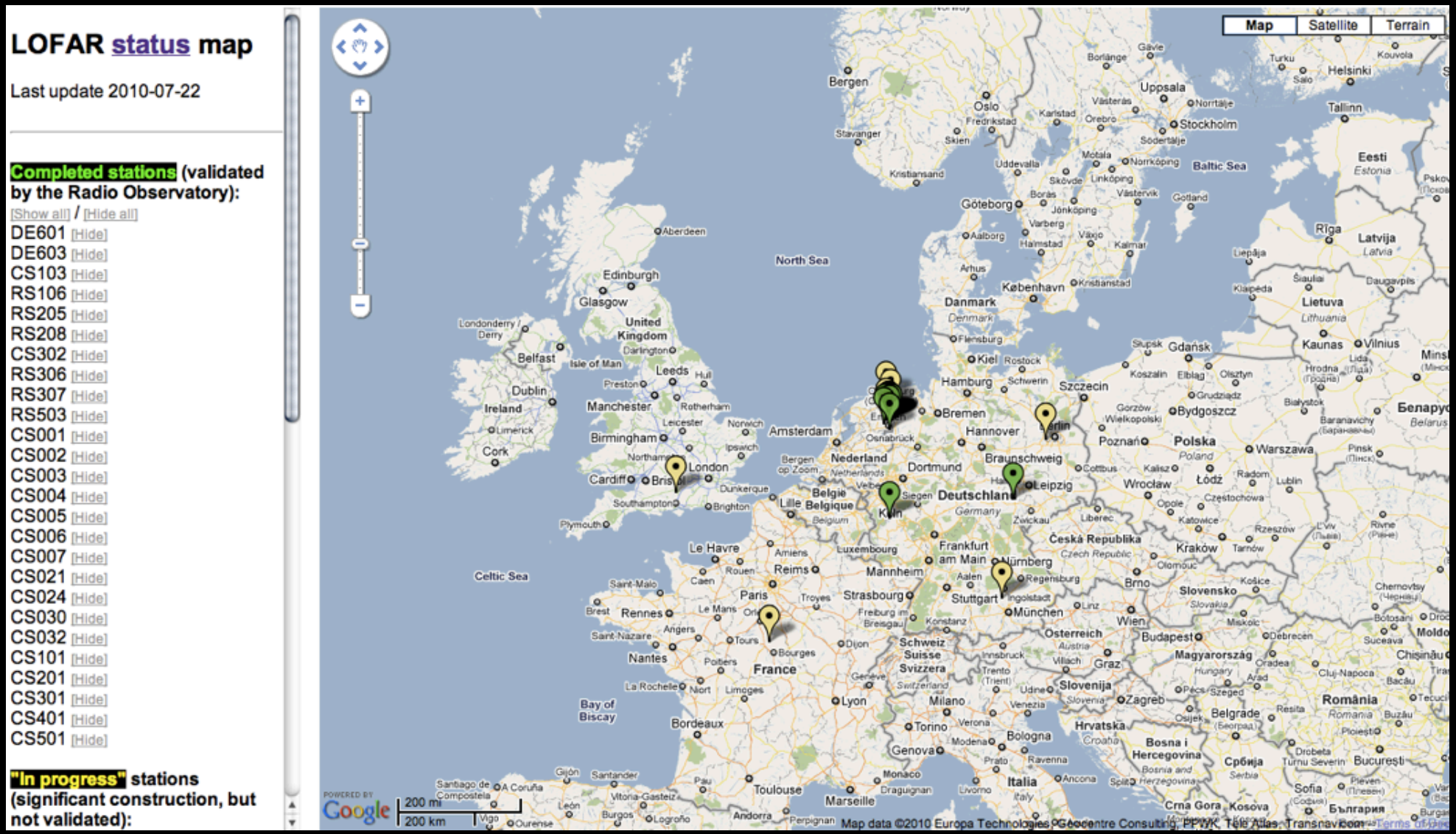


Figure 1: You too can make images like this with LOFAR

*for any suggestions and comments, please contact Roberto Francesco Pizzo, pizzo@astron.nl
[1] http://www.lofar.org/operations/doku.php?id=software:standard_imaging_pipeline
[2] http://usg.lofar.org/forum/

LOFAR as it is now: international

- 18 (24) core stations + 6 (9) remote + 2 (6) international
  http://www.astron.nl/~heald/lofarStatusMap.html



LOFAR as it is now: NL

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LOFAR as it is now: core area

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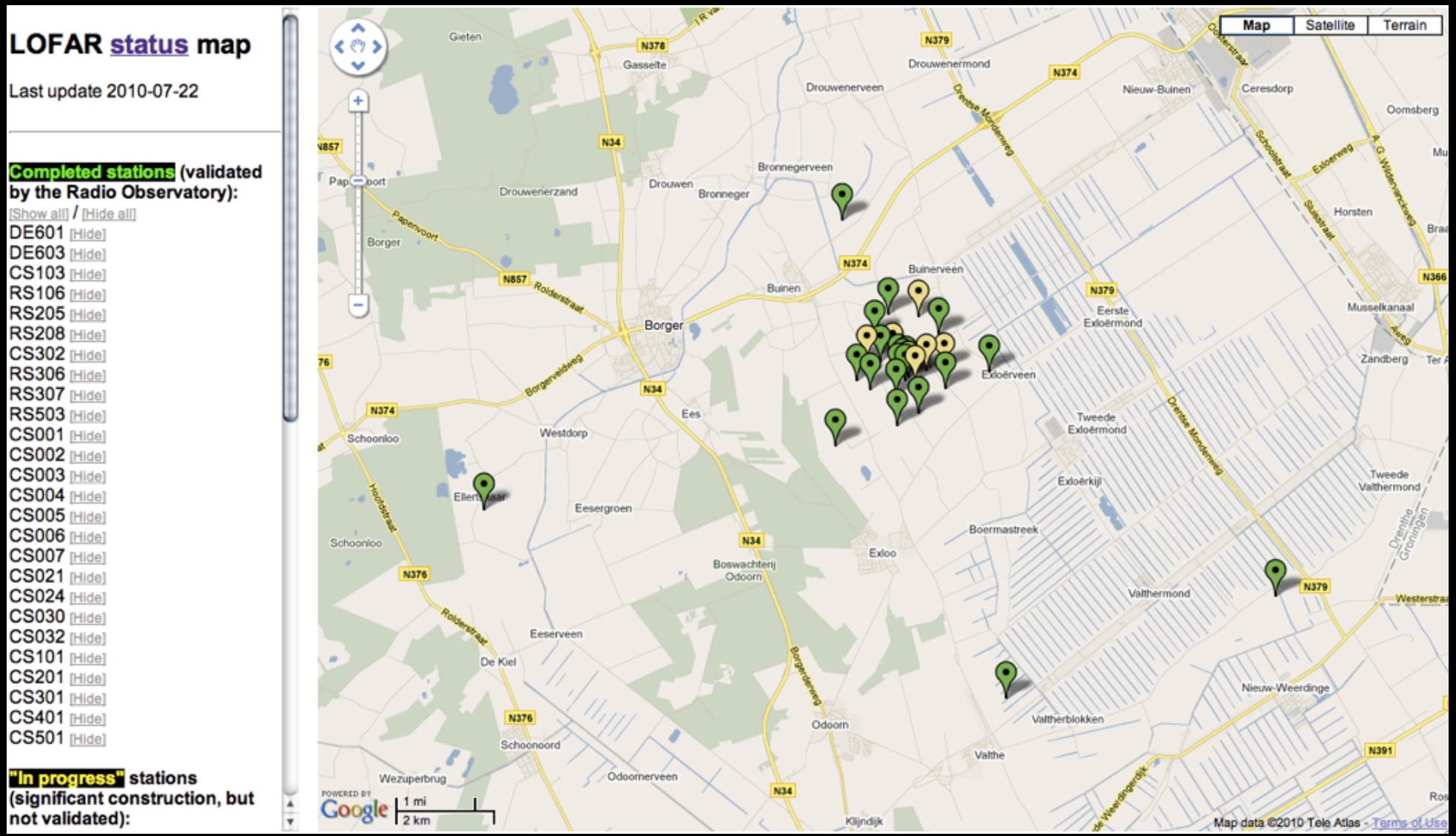
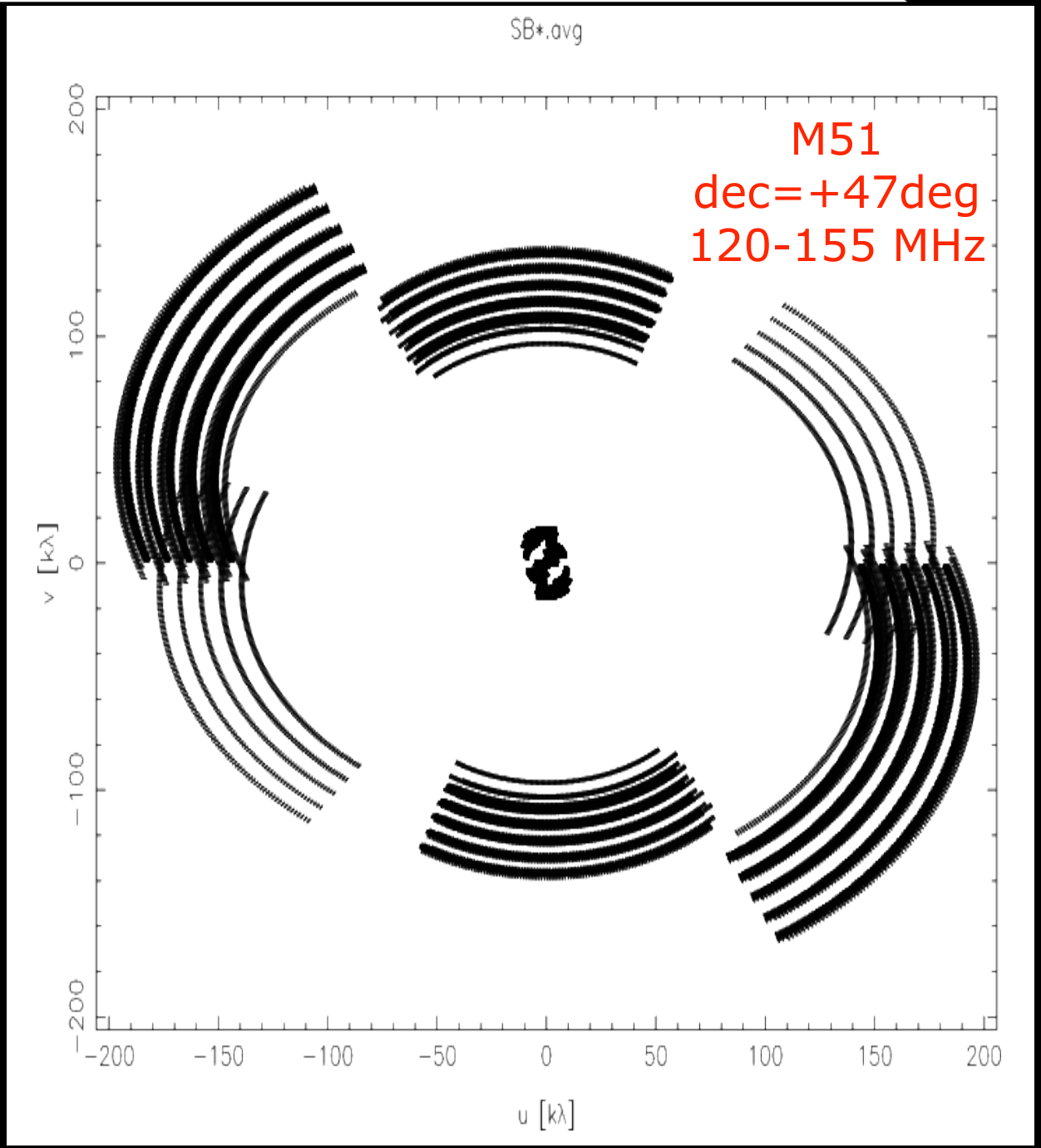


Typical (current) uv coverage

LOFAR ASTRON

- Recall:
  ~300% fractional bandwidth in LBA, ~200% in HBA....



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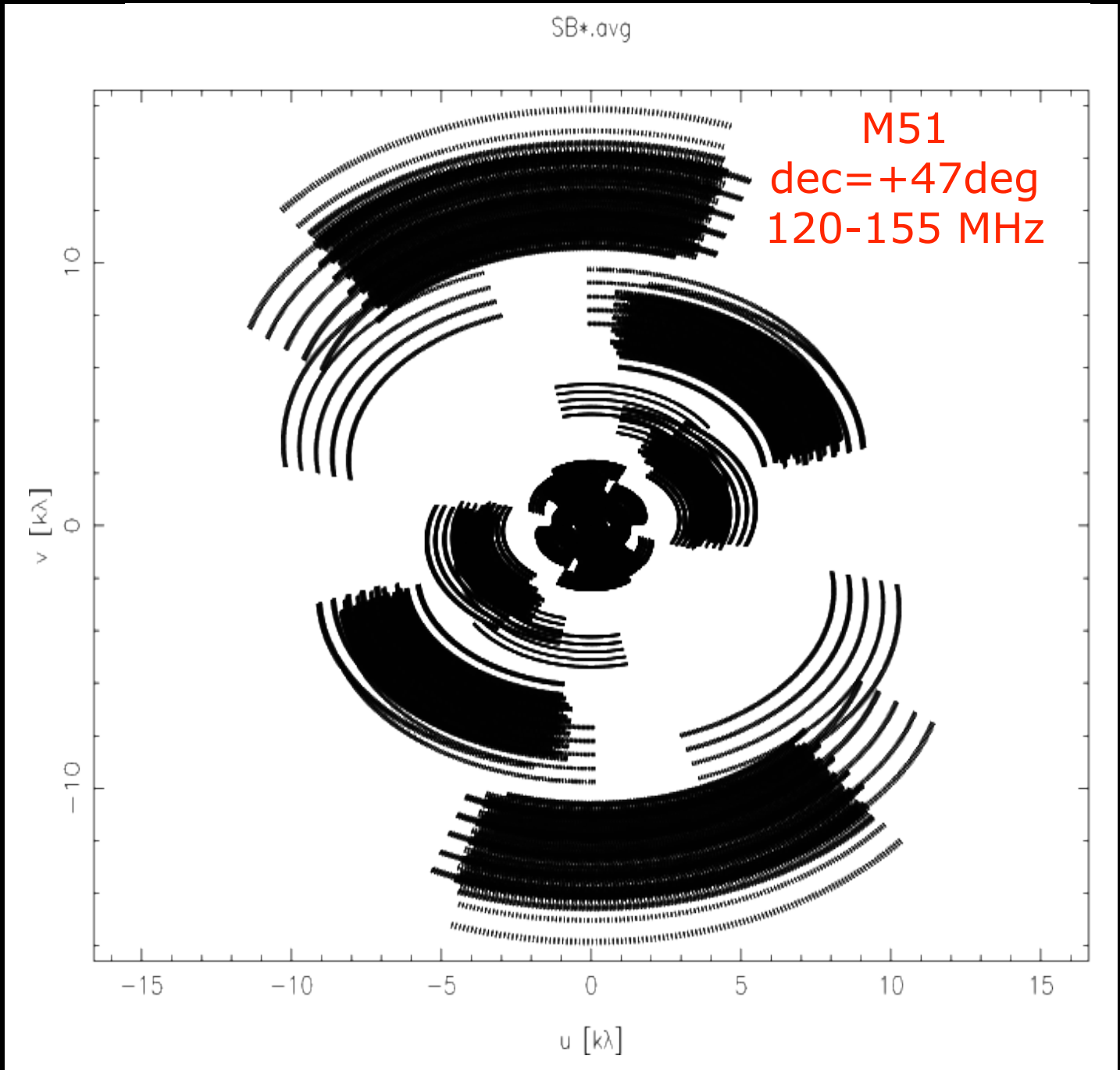
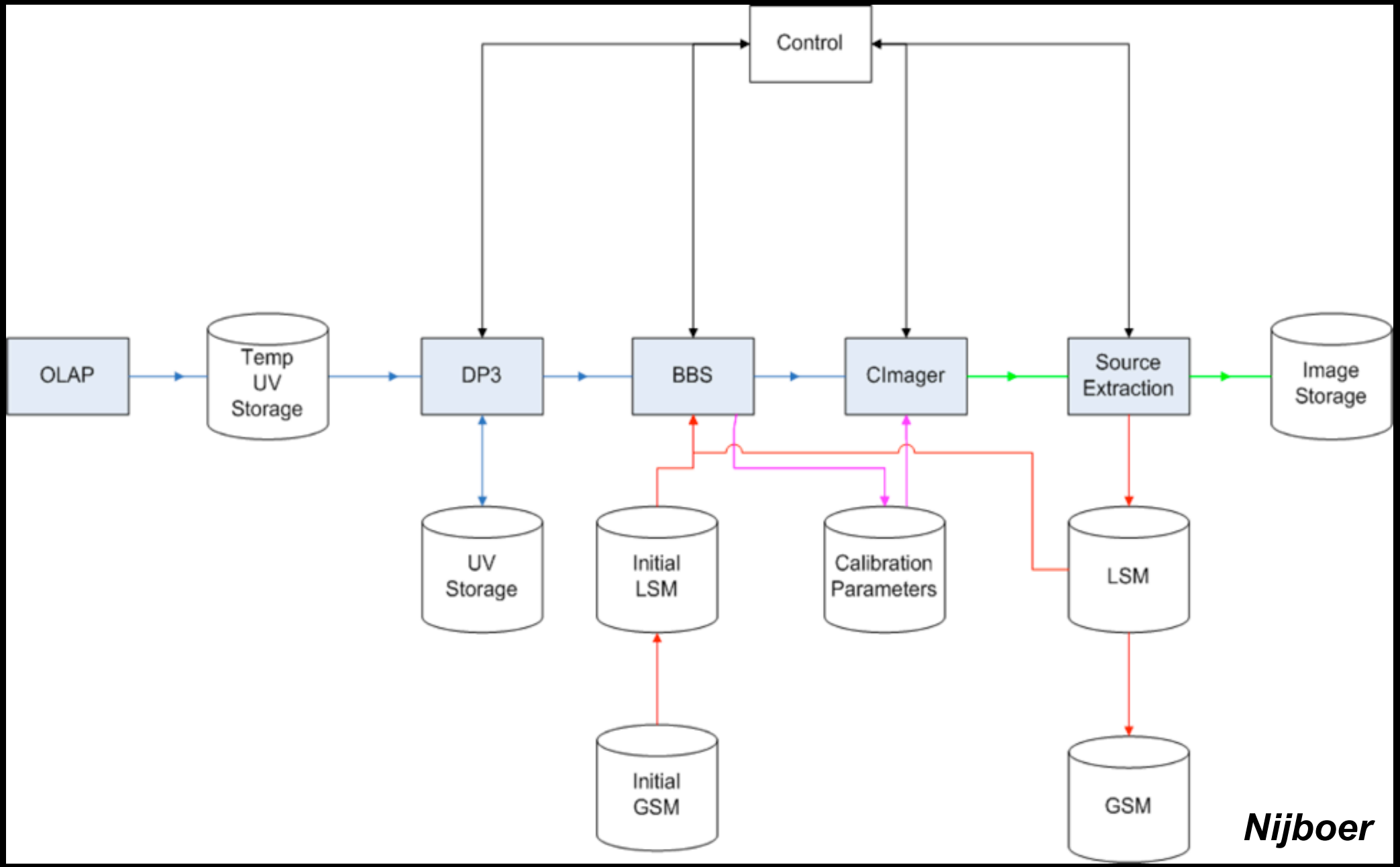


Imaging pipeline schematic



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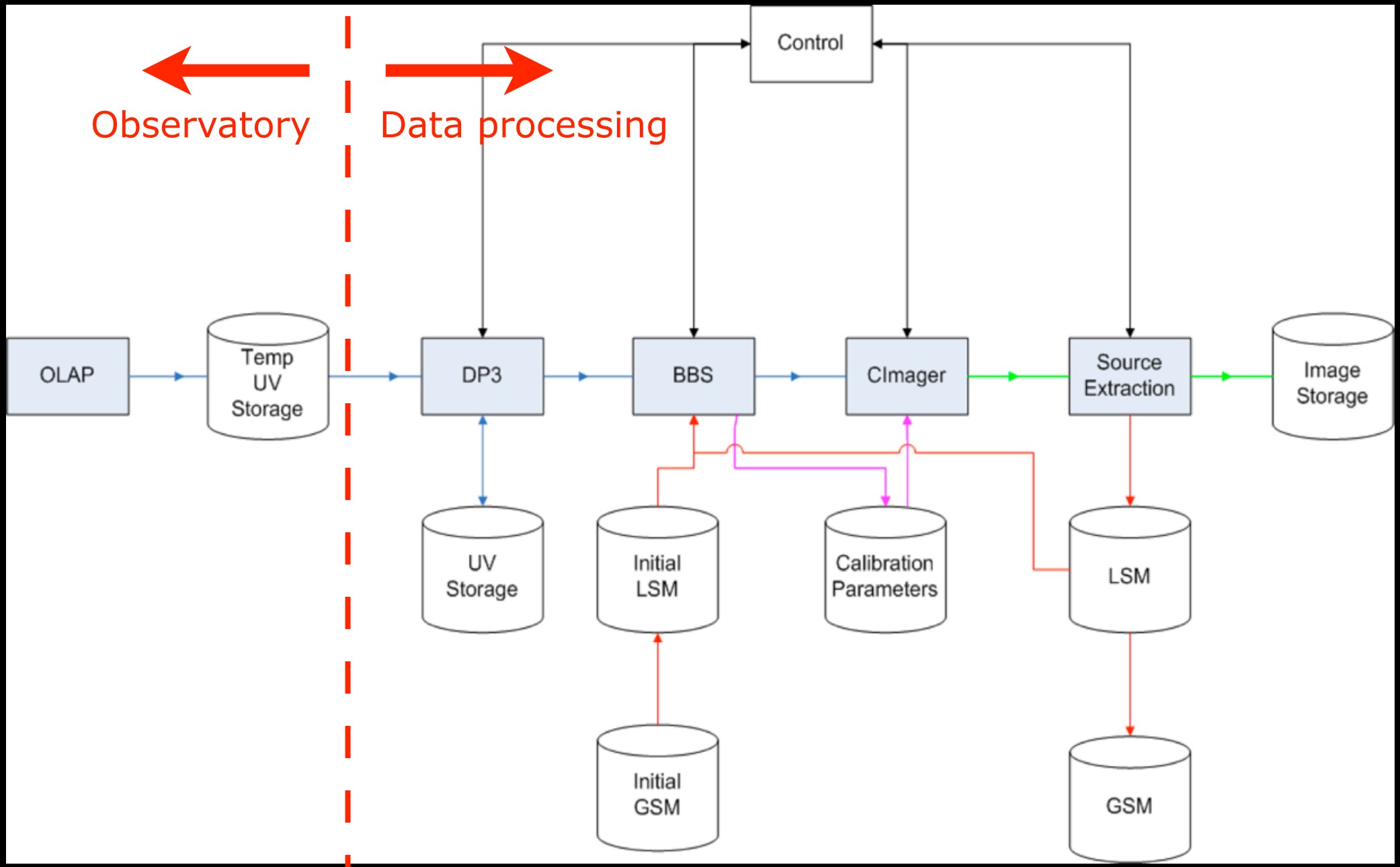

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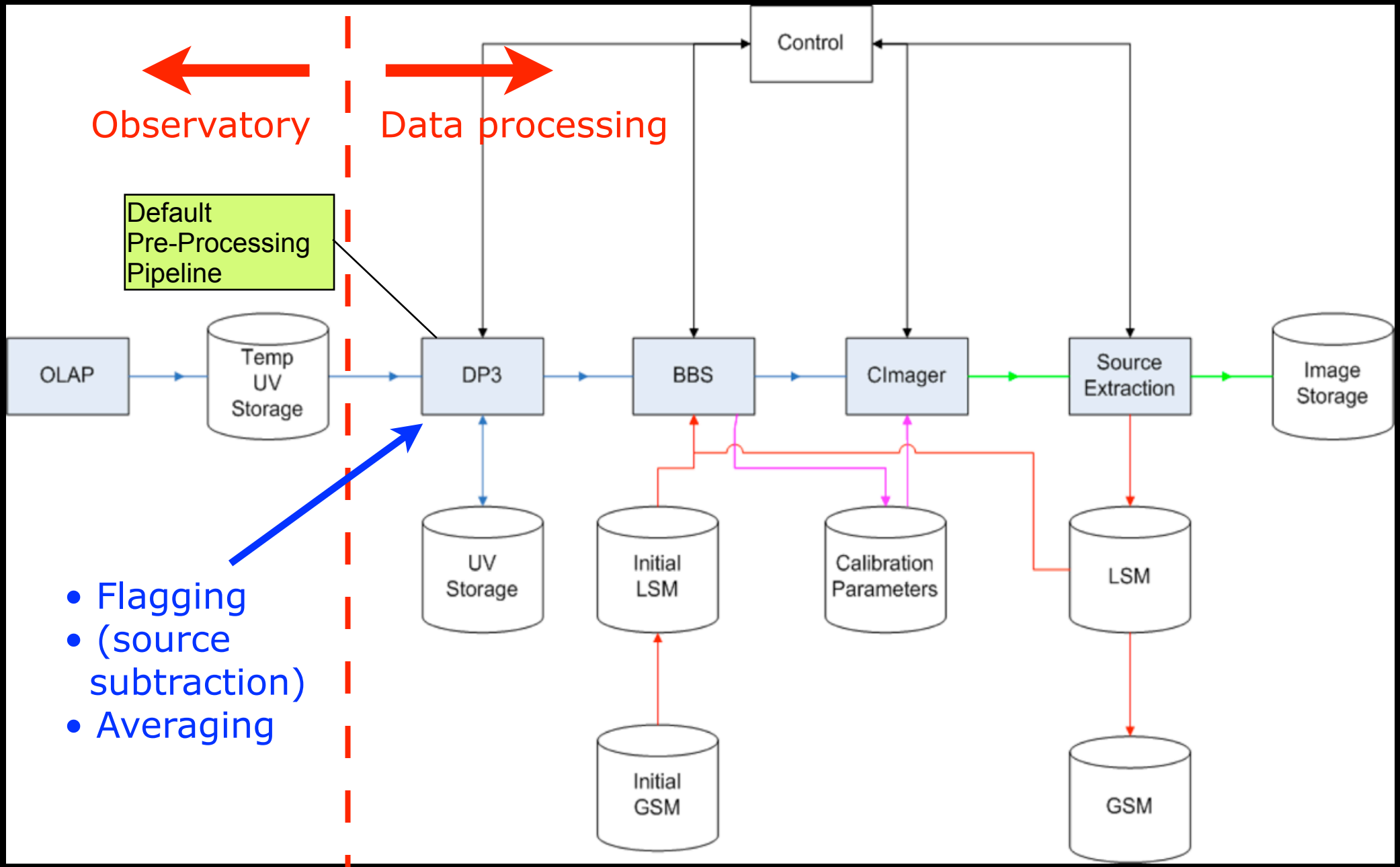

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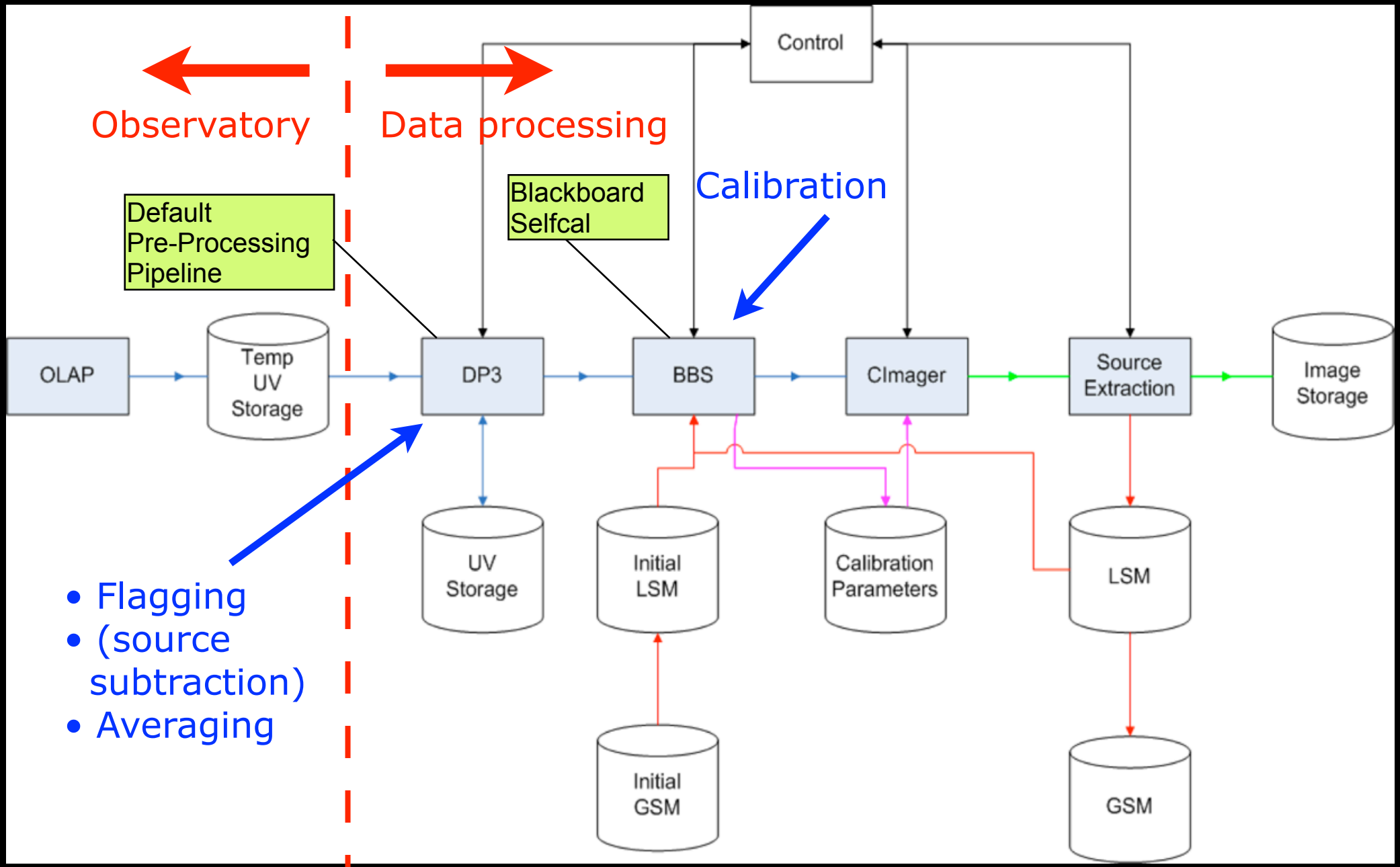

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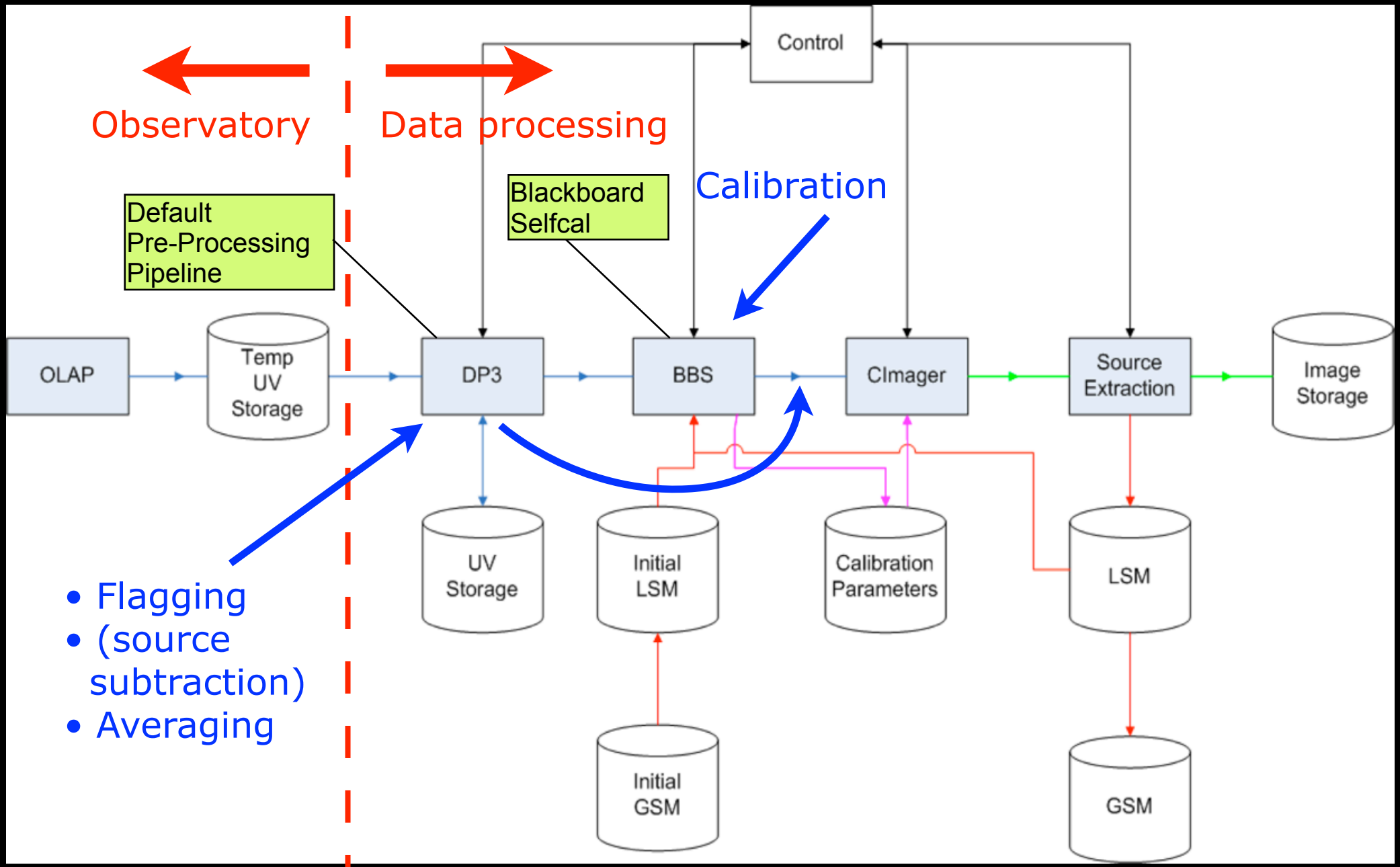

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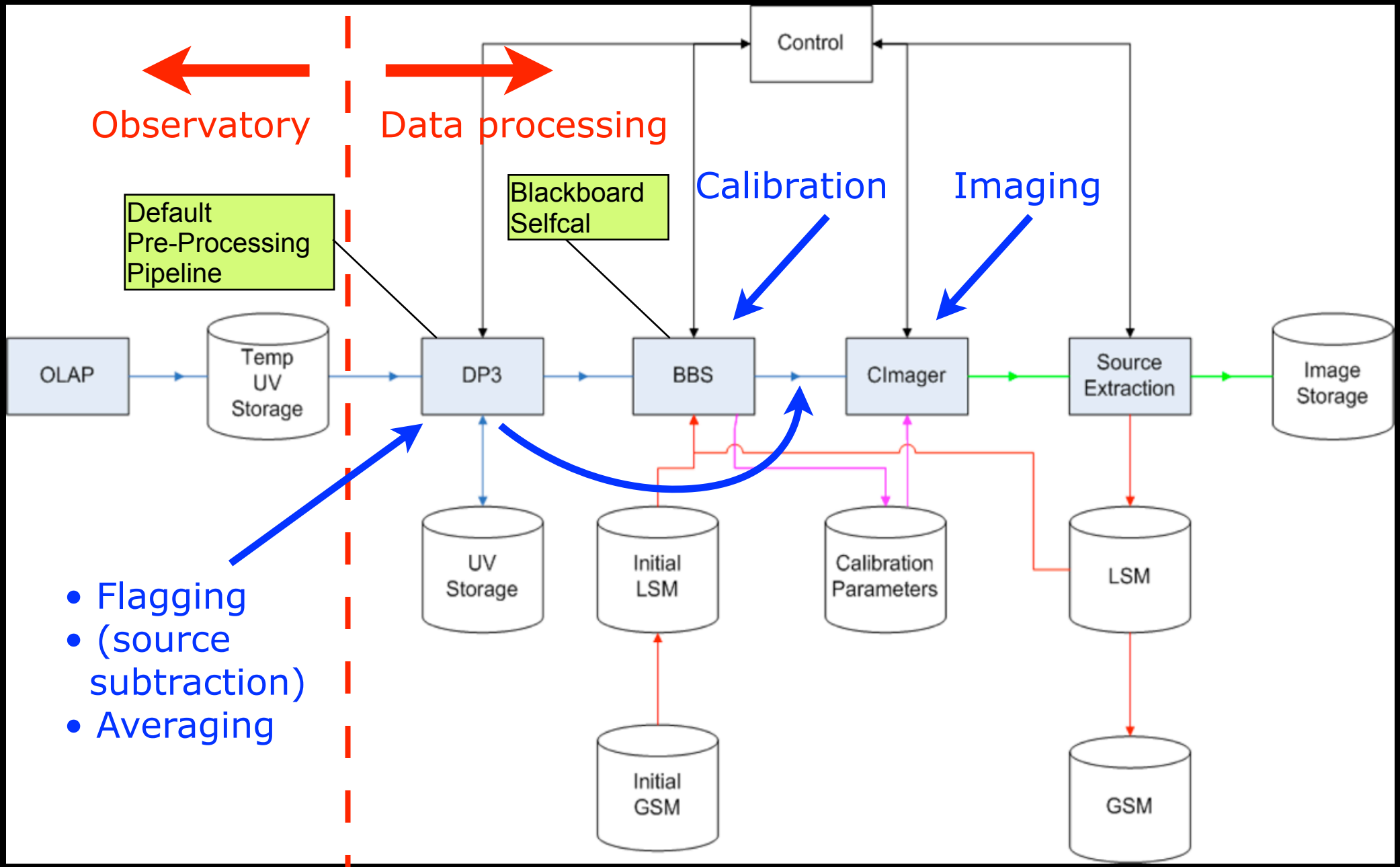

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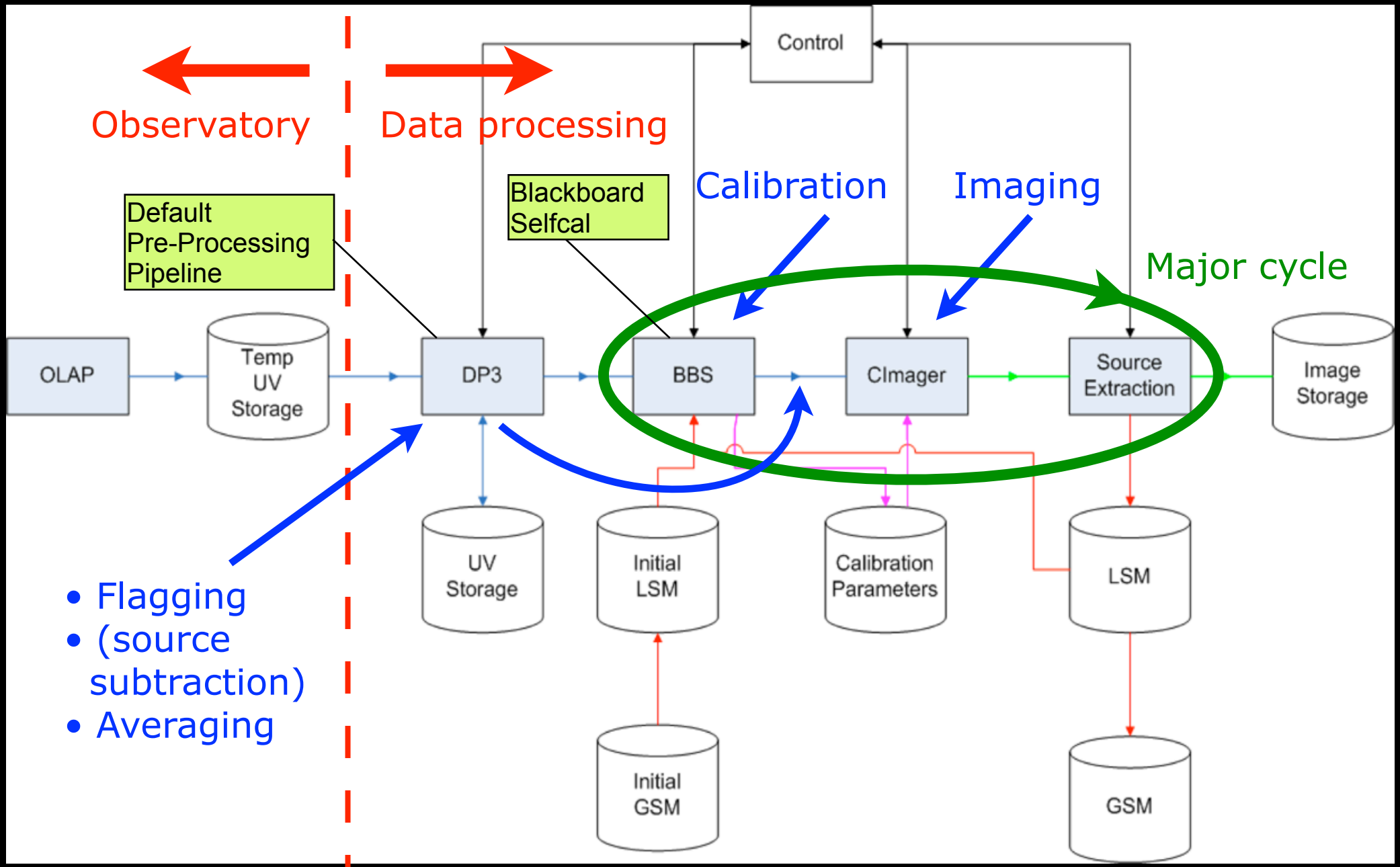
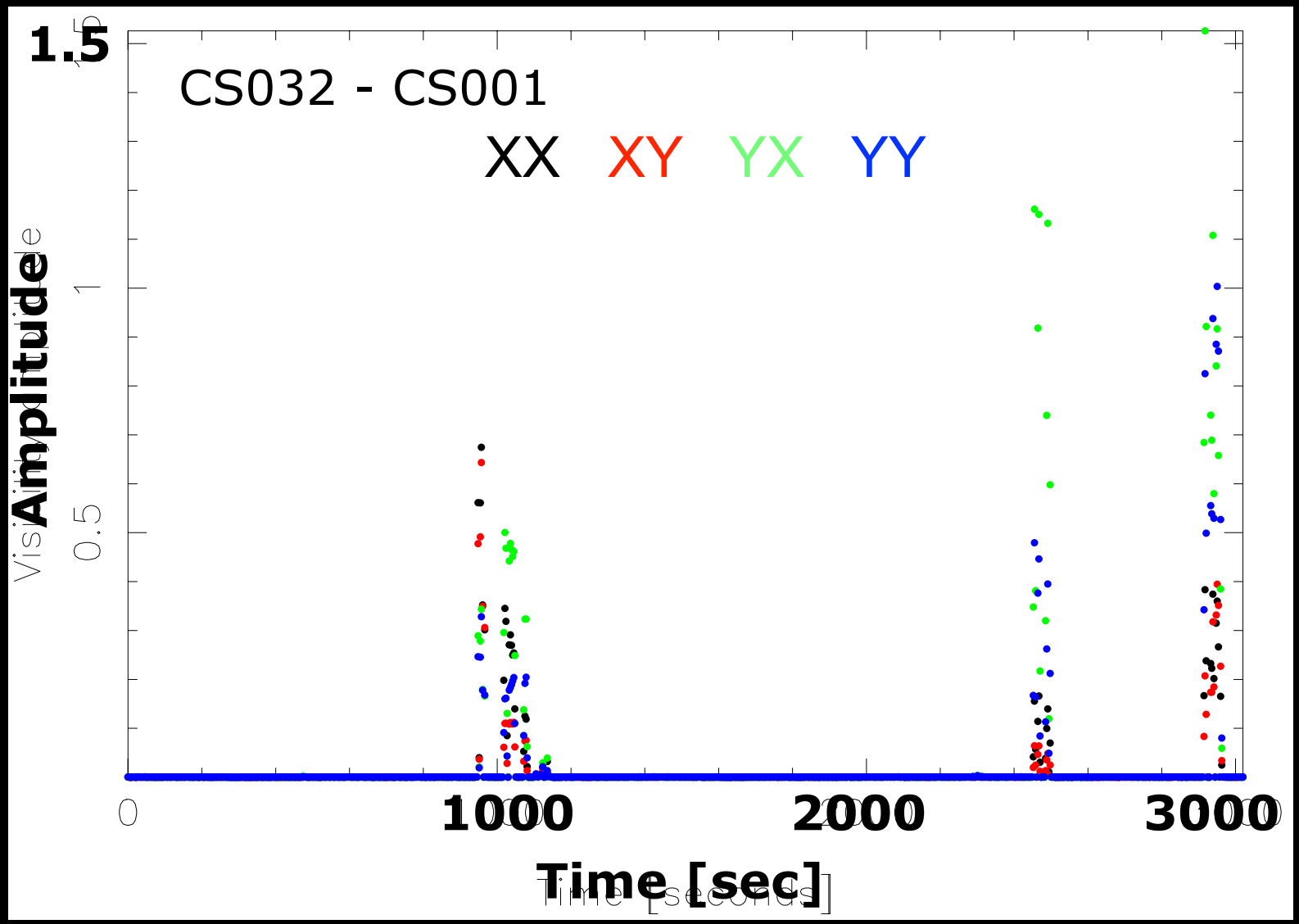


Pipeline implementation

- Pipeline is implemented in python, and wraps together a hodge-podge of components (compilied executables, python scripts, libraries)
- Designed to be under control of the LOFAR MAC system - e.g. a pipeline run will be initiated at the end of a normal imaging observation to generate standard system output (images, cubes, ...)
- Based on the LOFAR Transients Pipeline developed by John Swinbank (John is also instrumental in pushing forward the Imaging Pipeline development)
  - Each component of the pipeline is wrapped in a “recipe” which homogenizes the interface to the components, and provides services such as distribution over the processing cluster
  - The recipe + input parameters = tasks which move data through the pipeline

Pt 1: DPPP [flagging]

- High frequency (1 channel ~ 700 Hz) and time (~1-3 sec typical) sampling allows excellent RFI excision



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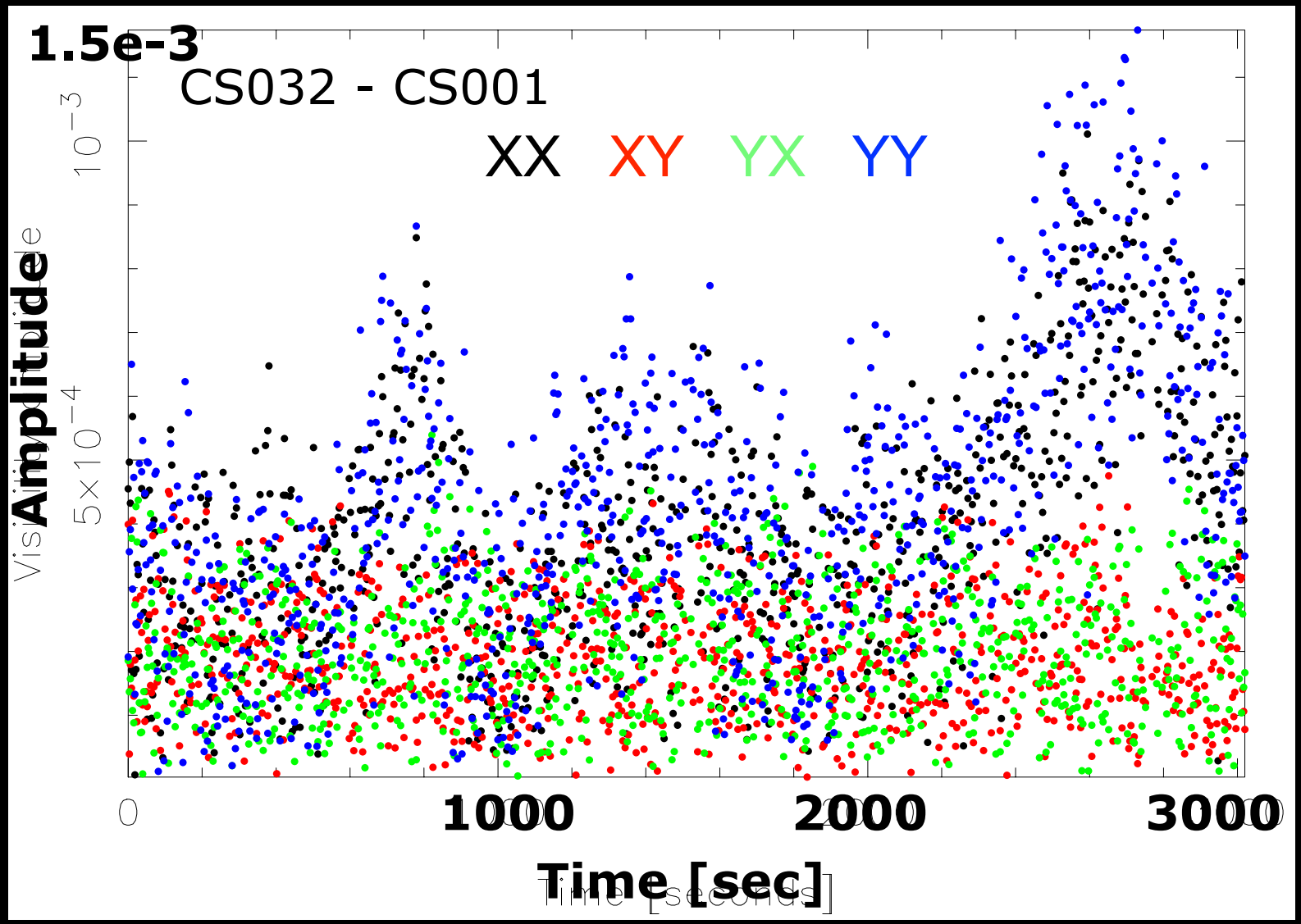


Aside: plotting visibilities

LOFAR ASTRON

- LOFAR data sets are HUGE ... for a typical recent observation:

  4 hr, 1 second integration

  18 (core) LBA stations

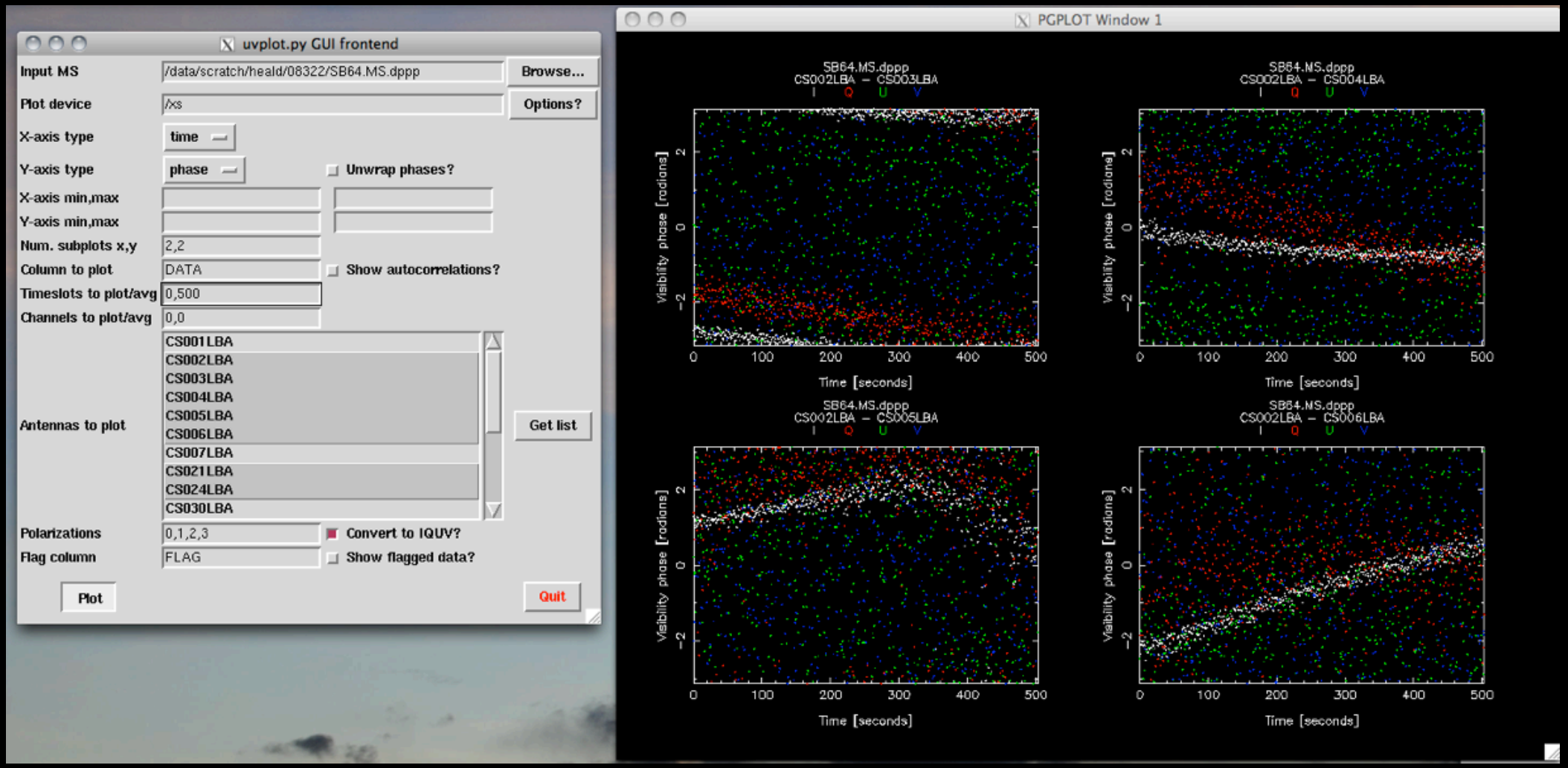
  1 subband = 256 channels, 4 correlations

  1 subband = 20 GByte

  248 subbands ~ 5 TByte

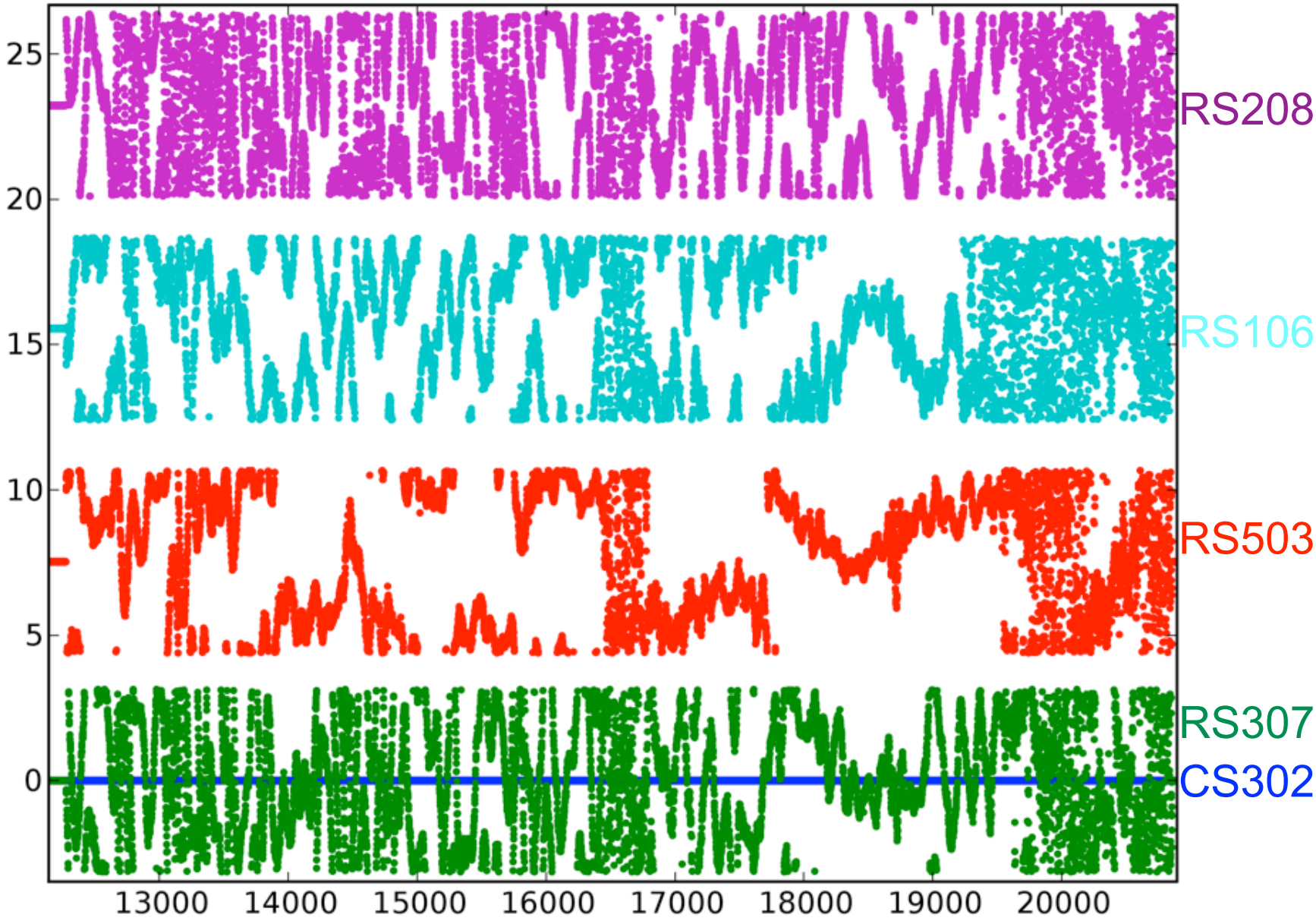
- Fast access to visibilities for baseline-based plotting required! Best option was a home-grown python script using pyrap, ppgplot, and (optionally) Tkinter
- *Not pretty or feature-rich, but it does the job quickly*
- Will also prove useful for automated pipeline diagnostic output

Aside: plotting visibilities



(Inspired in large part by miriad uvplt)

Pt 2: BBS [calibration]



Early 3C196 observation.

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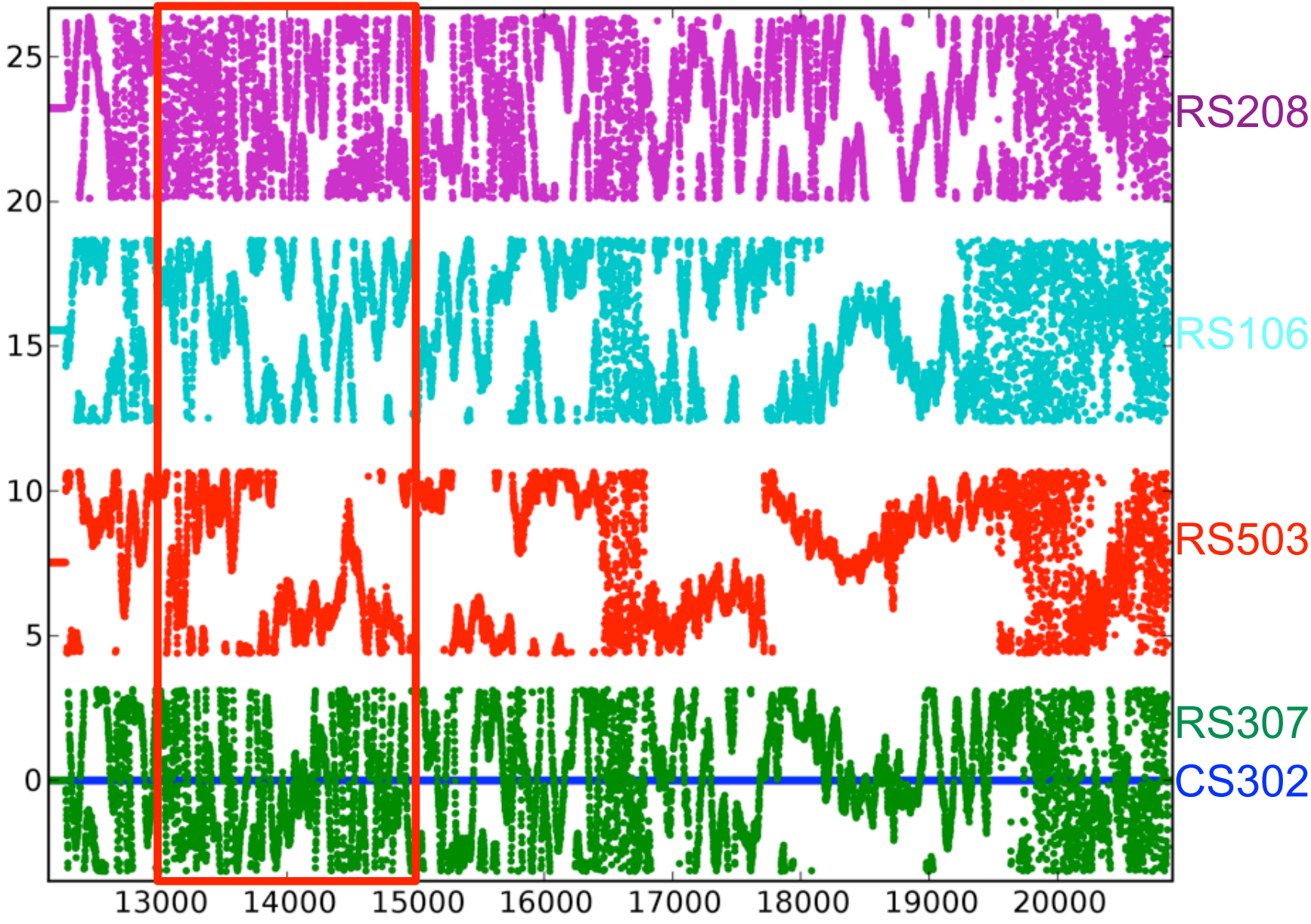

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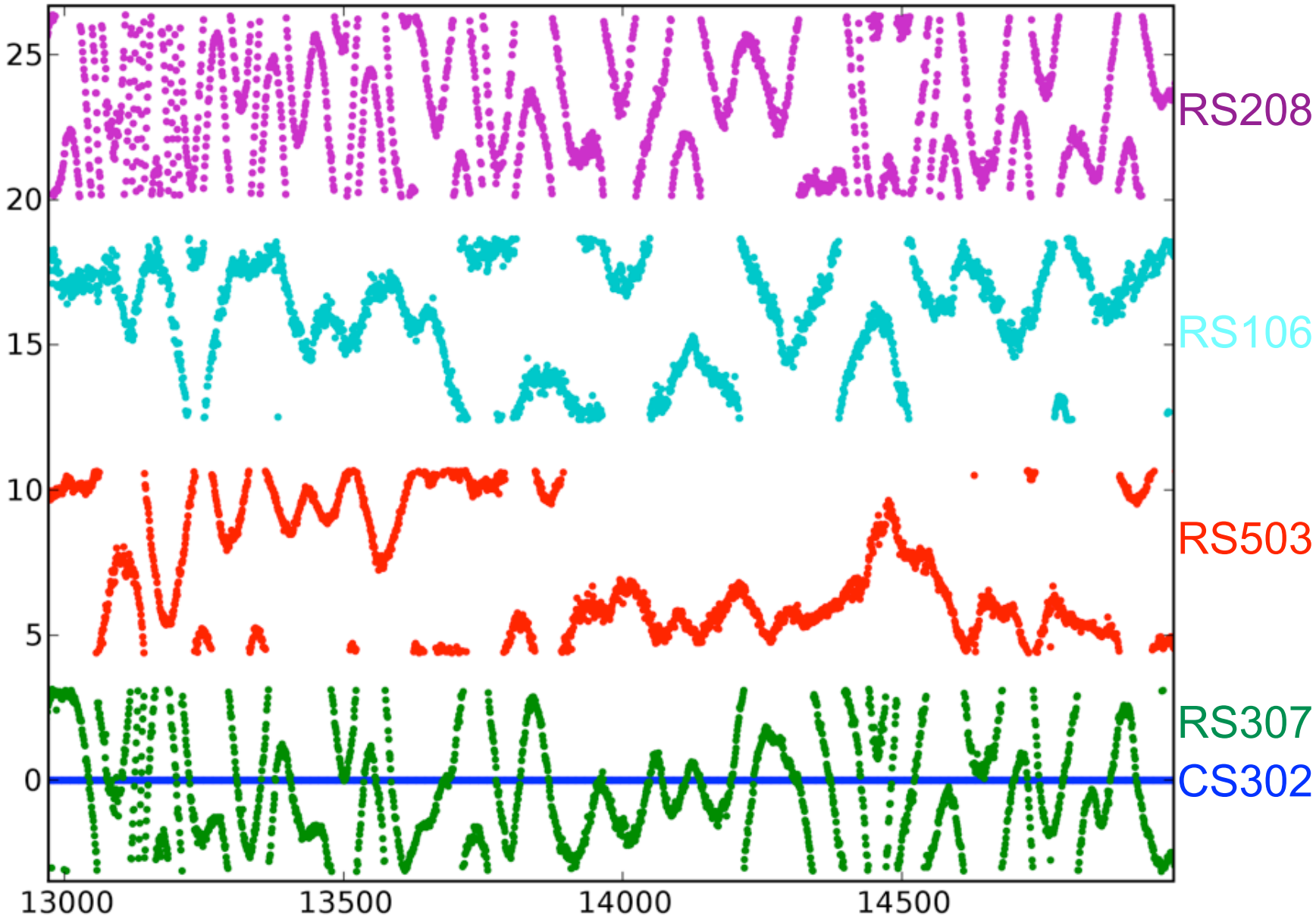

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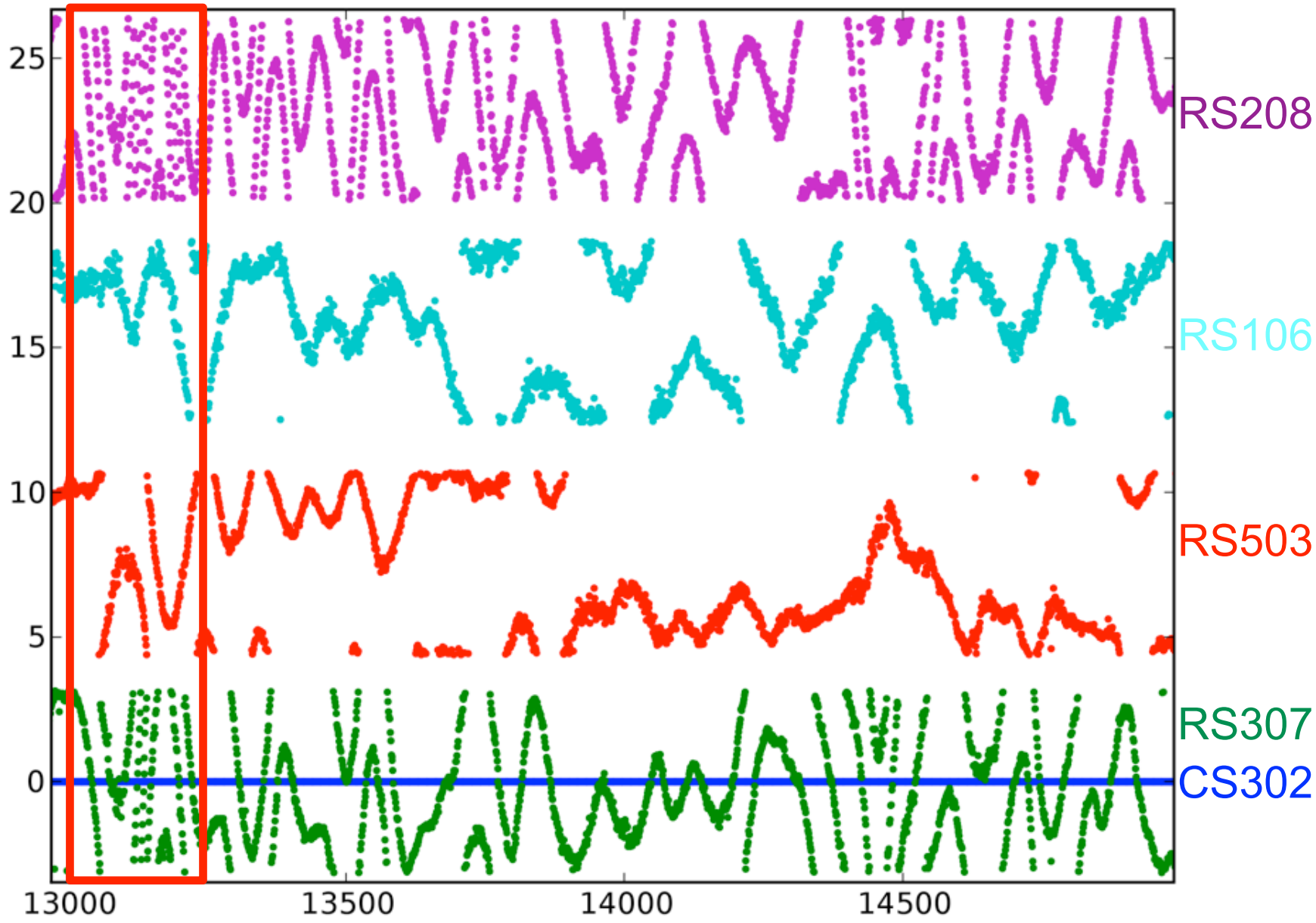

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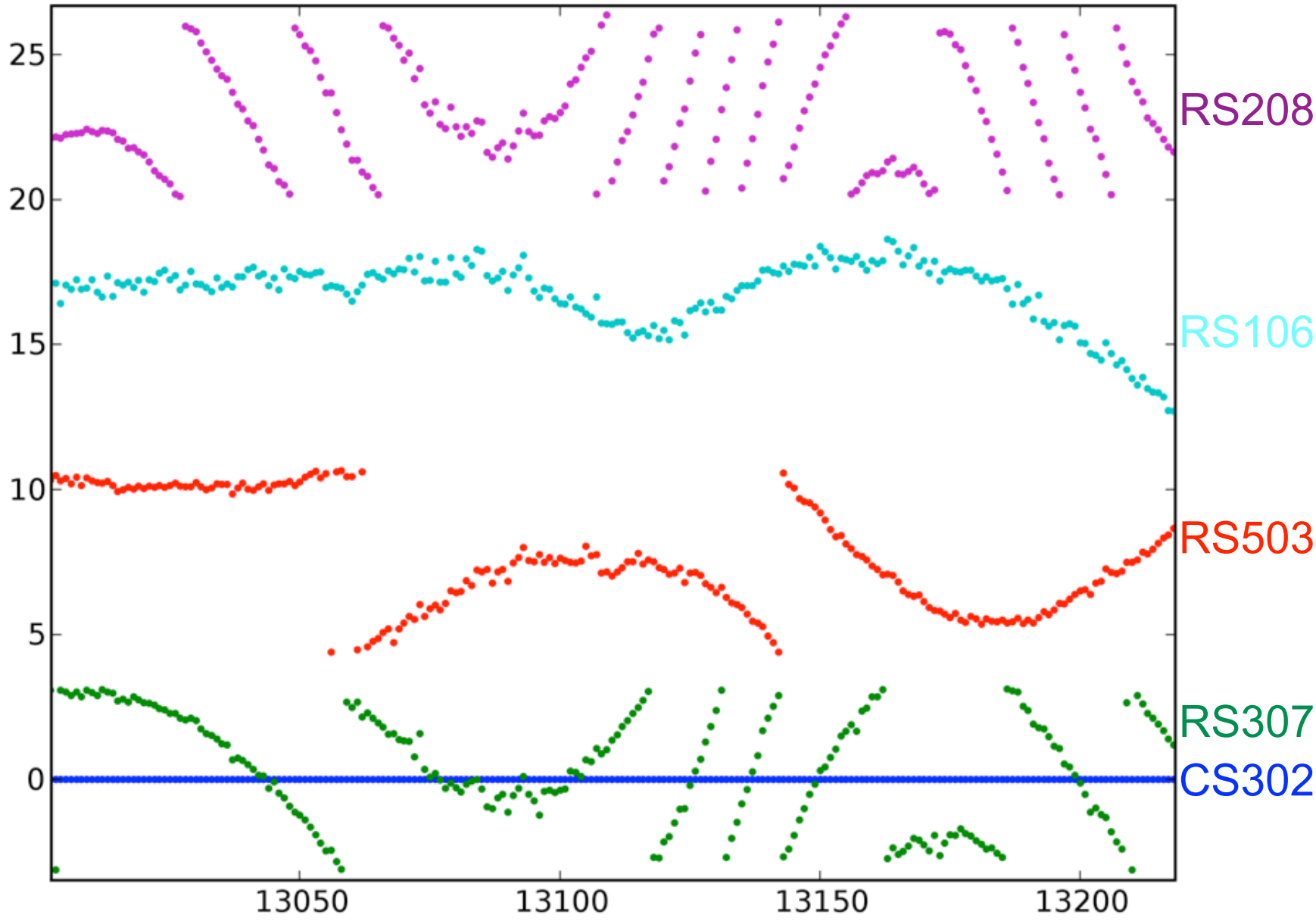
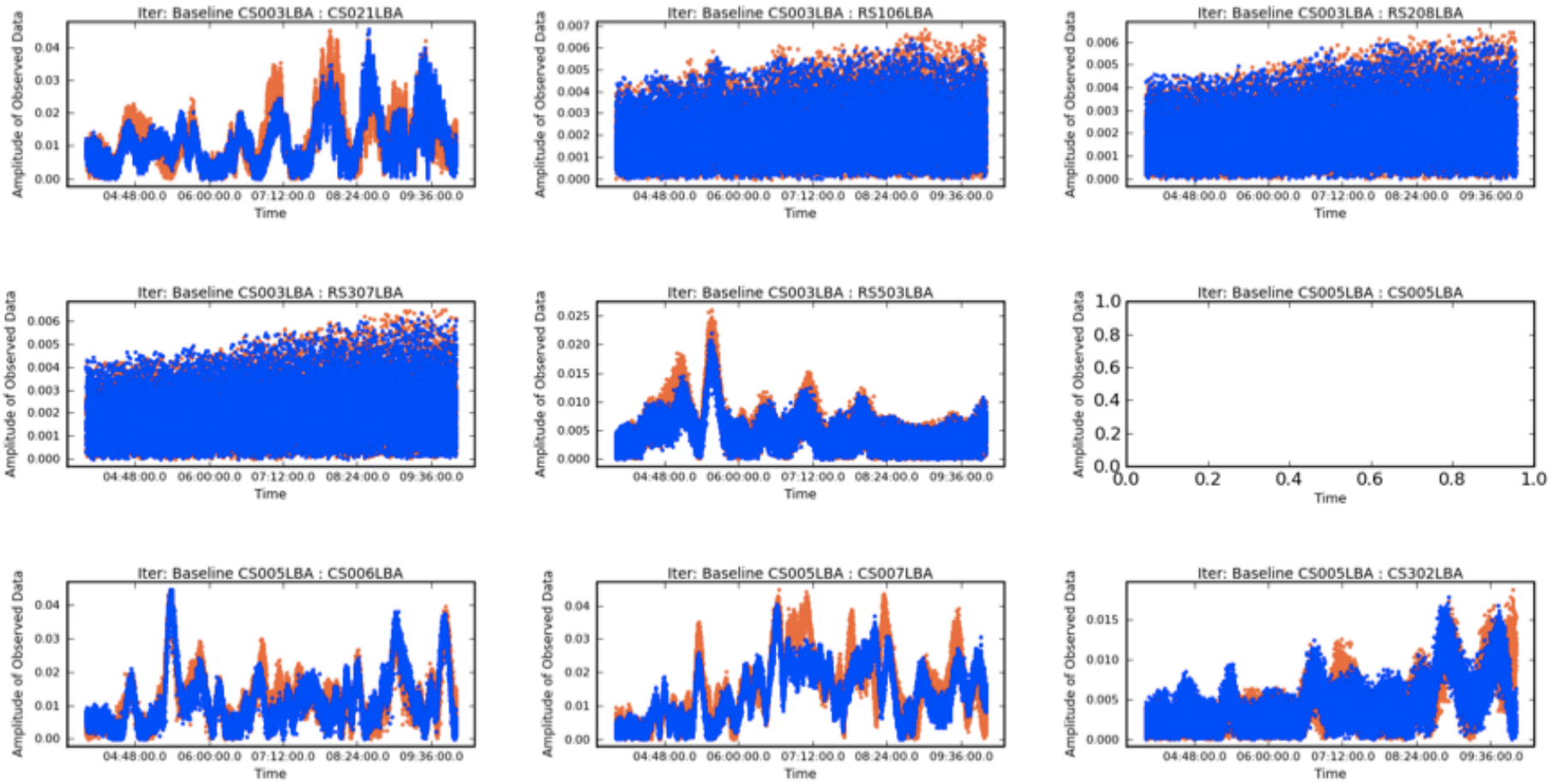


Early 3C196 observation.

Station gains - complications

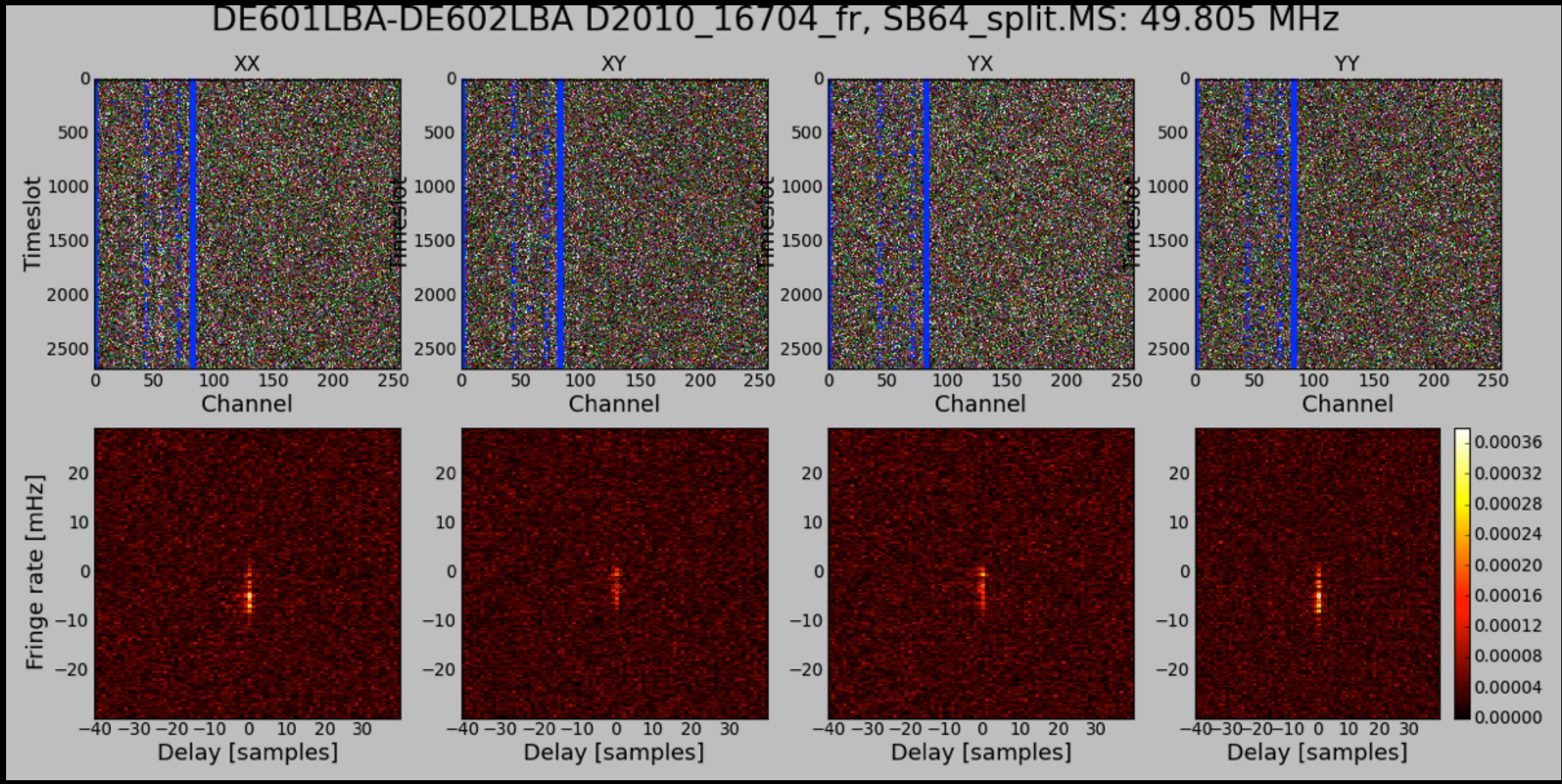
- Off-axis sources entering though sidelobes



- Solution (in progress): predict, solve, subtract using BBS

Station gains - complications

- Differential Faraday rotation



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Station gains - complications

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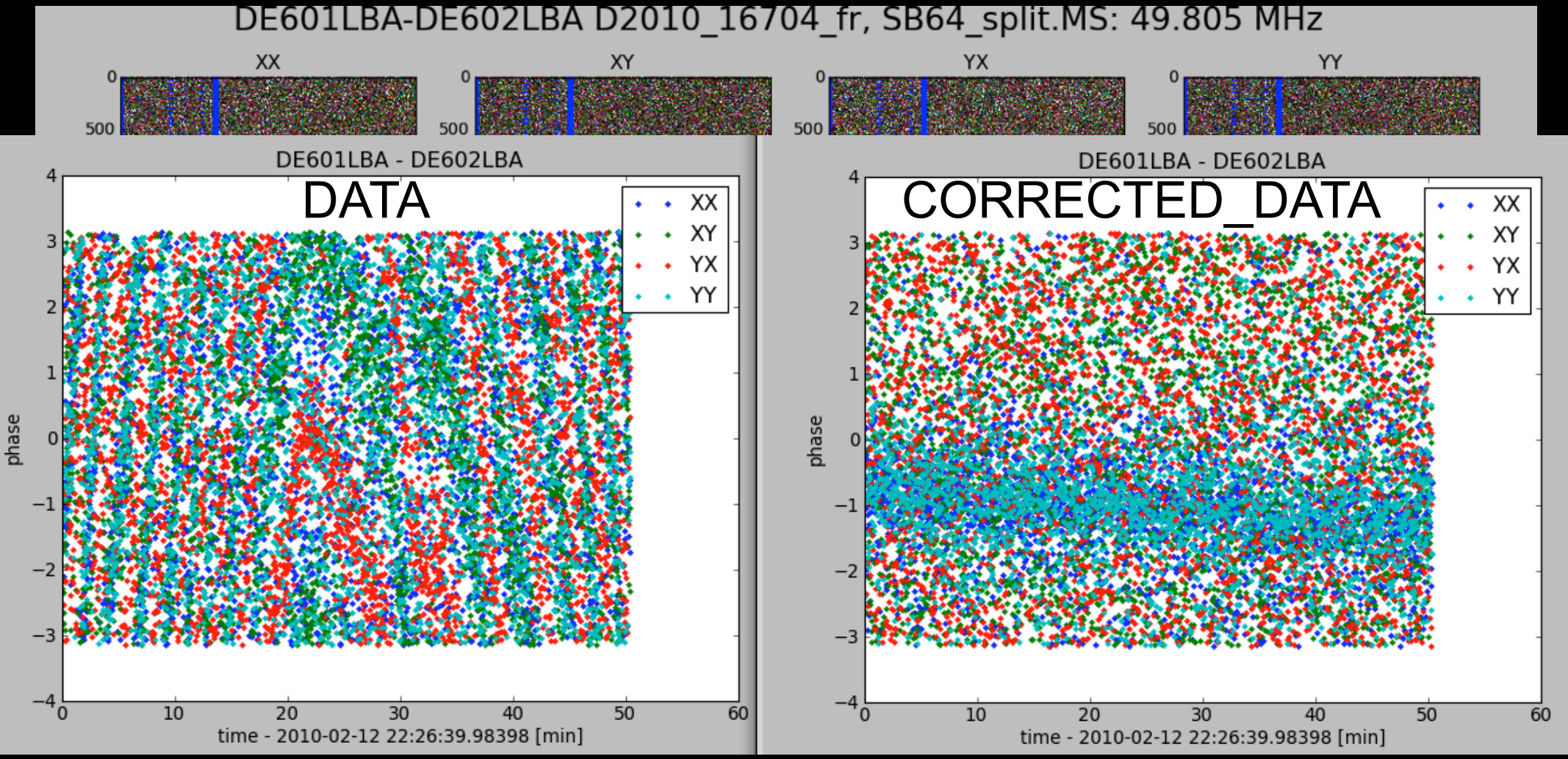

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Imaging “busy weeks”

- Week-long work session, bringing in many people to Dwingeloo
- Very effective way of building an army of commissioners, and strengthening connection between astronomers and engineers
- Testing every part of pipeline

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  - RFI under control (typical flagging stats <~10% in LBA and HBA, mostly from the flagging on uncompressed frequency data)
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  - Ionosphere is, so far, well behaved!
  - Extra complications present in LOFAR data ...

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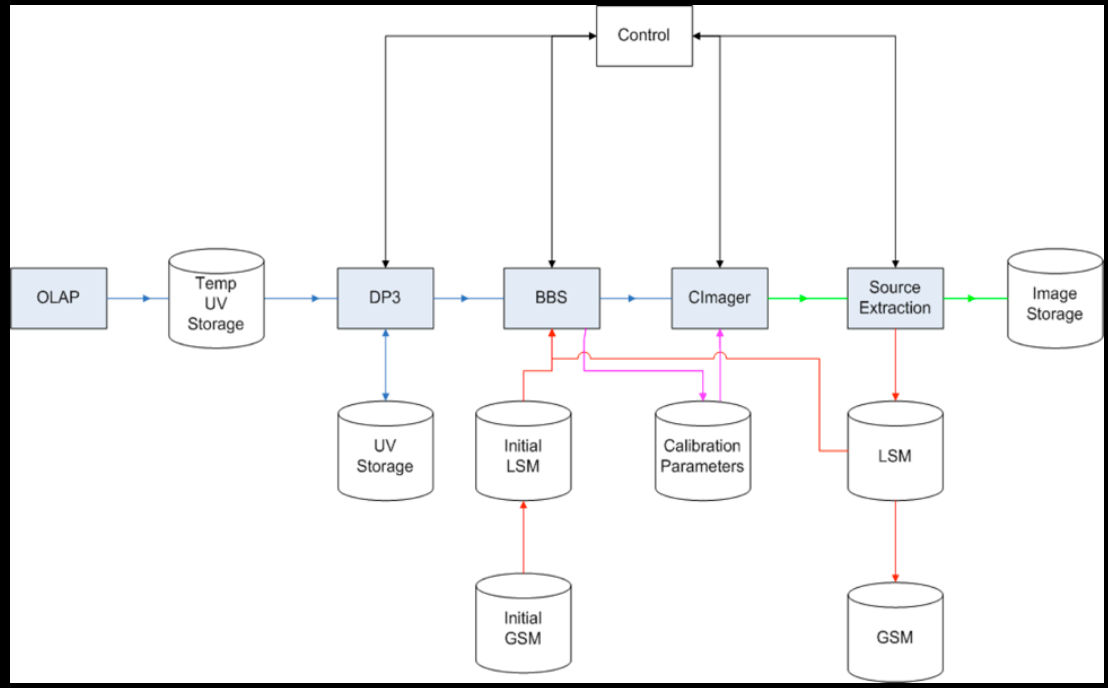
  - Ionosphere is, so far, well behaved!
  - Extra complications present in LOFAR data ...
- The Imaging Pipeline works as an automated system right now on "known fields": we have been focusing on improving the individual components, and are now extending to 10min "blind field" snapshots

Coming additions to the pipeline

- Initial (Mark-0) GSM is VLSS catalog:
  Sky model generation now automated
- Mark-1 GSM will be created by the upcoming "MSSS"
- Pipeline kickoff by observatory system



- Major cycle loop: skymodel updates via source characterization (instead of clean components)

- Major benefit will come from station beam calibration

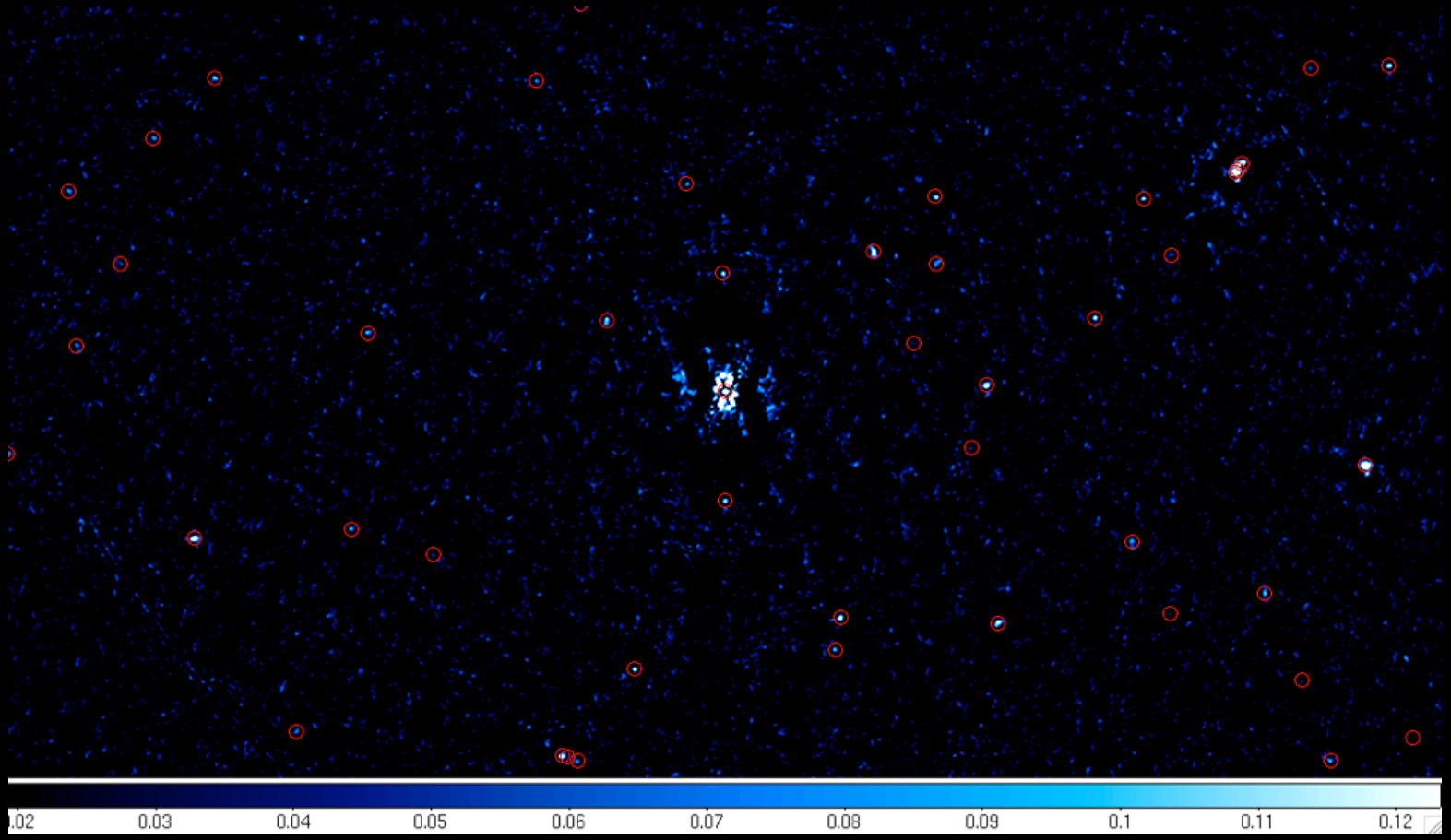
- *Application of direction dependent effects required in the imager*

Recent imaging results

Early LOFAR observation: 3C196

LOFAR ASTRON

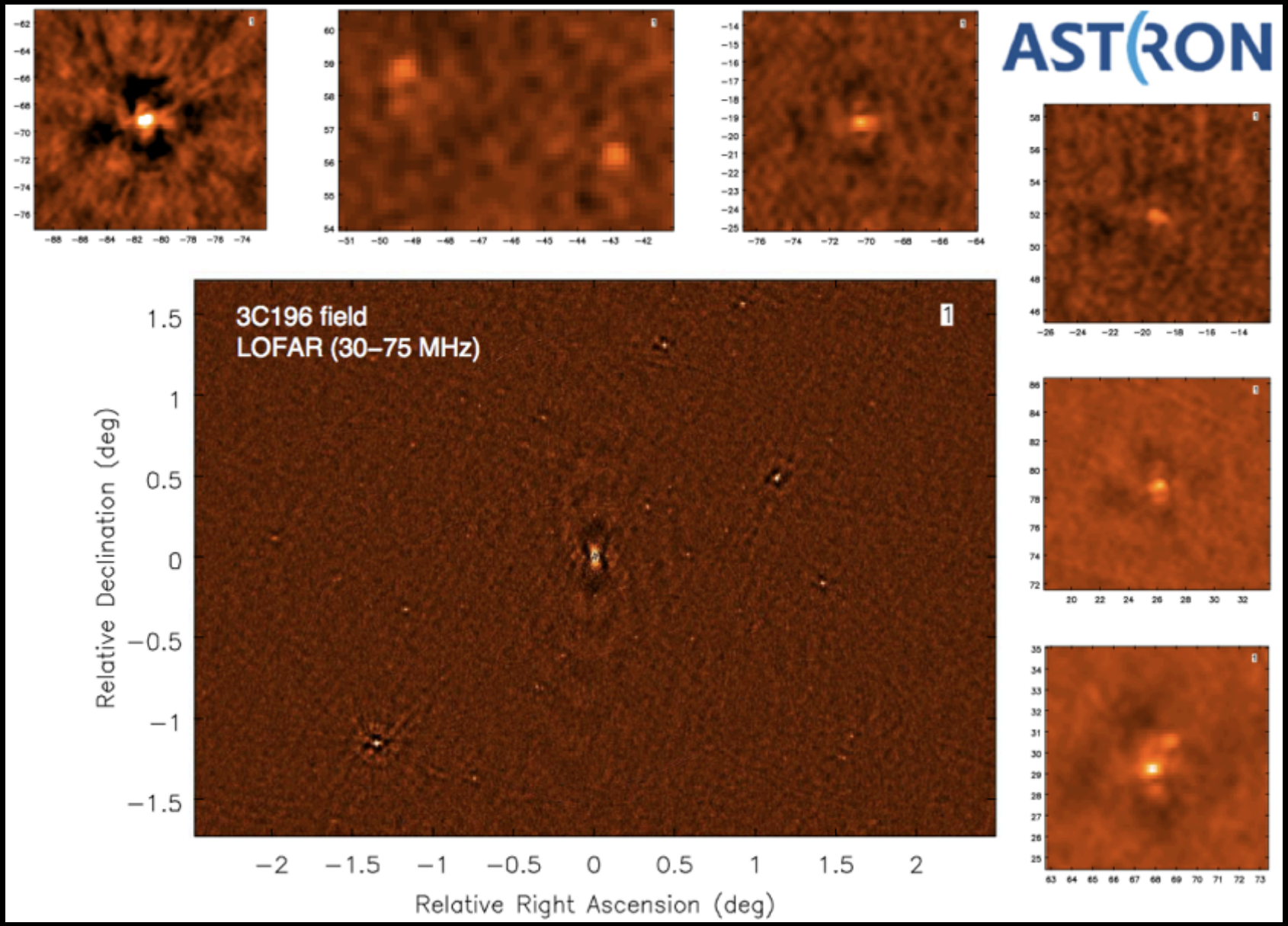
- LBA, filter 10-90 MHz
- 1 sec integration
- 11 stations (CS003,005,006,007,302,030,021 + RS106,208,307,503)
- 6 hr observation: data volume = 248 x 12 GB ~ 3.0 TB



Early LOFAR observation: 3C196

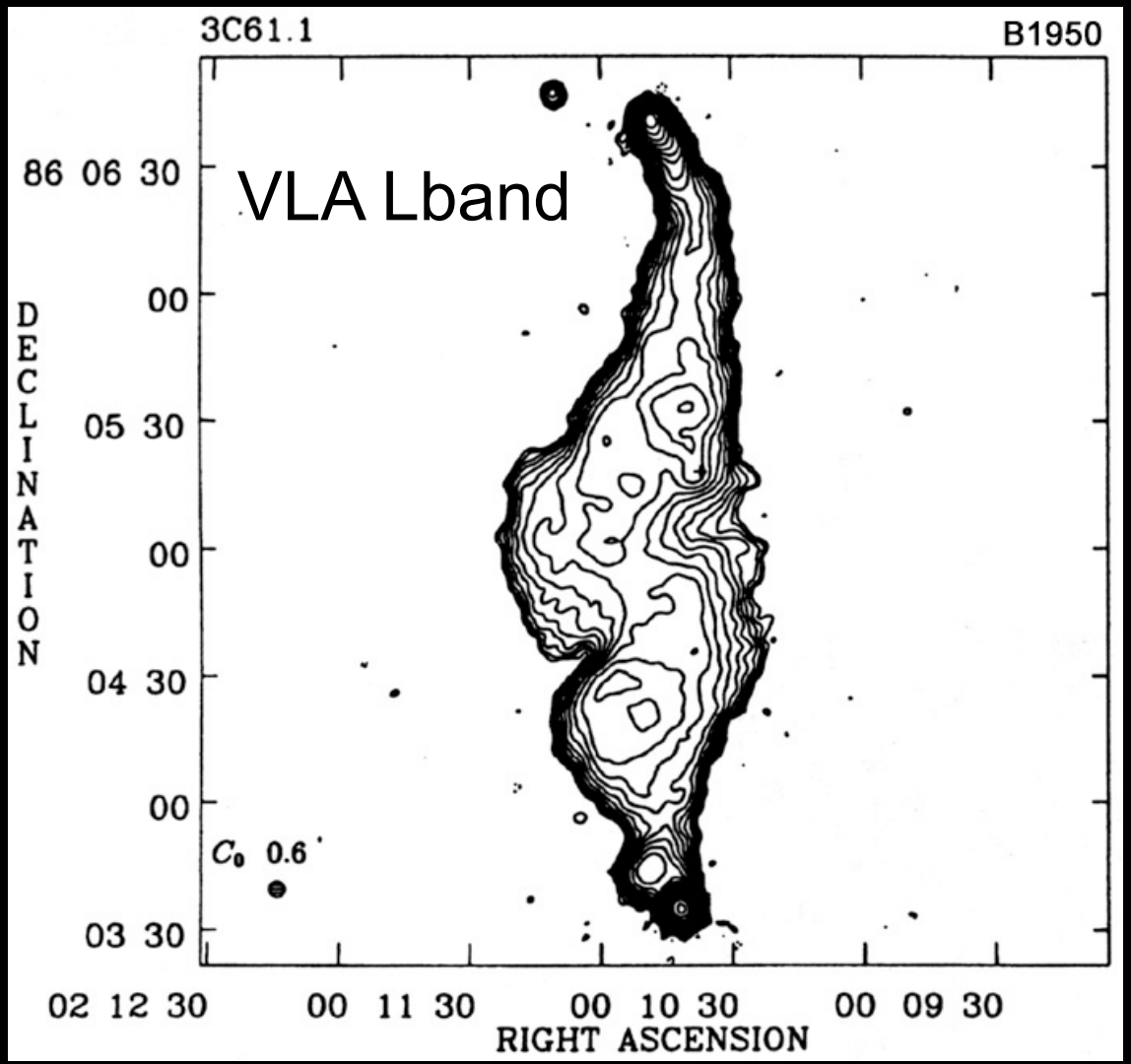
- Automated pipeline run:

McKean



Early LOFAR observation: 3C61.1

- HBA, filter 110-190 MHz; 16(x2)+4 stations; 1 subband; 60hr; 10”
- 3 (1) sec integration
- “20” stations (CS002,003,004,005,006,007,030,302 + RS106,208,307,503)
- 60 hr (in some subbands)
  SB to 122 GB, total ~ 4.6 TB



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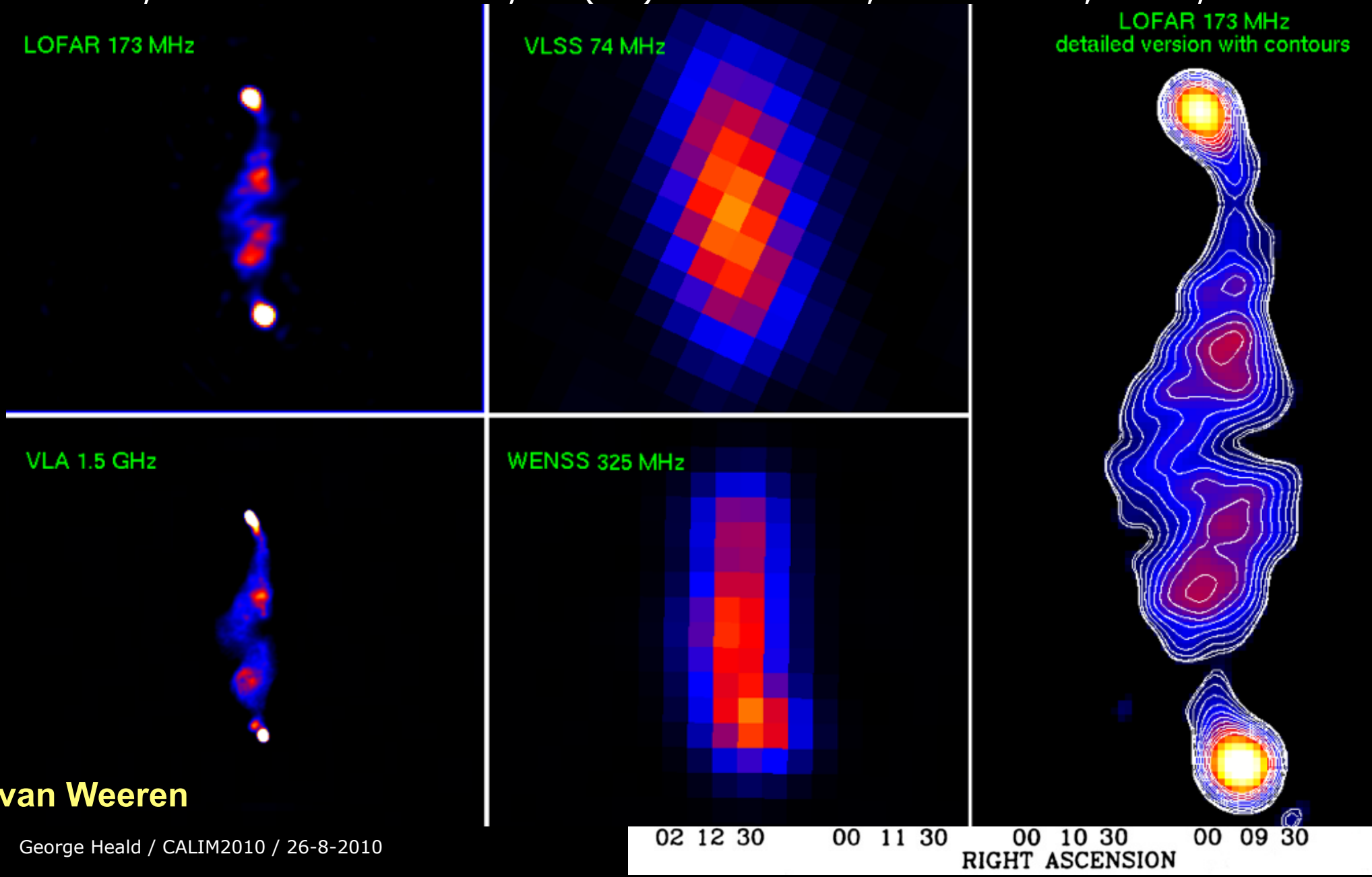
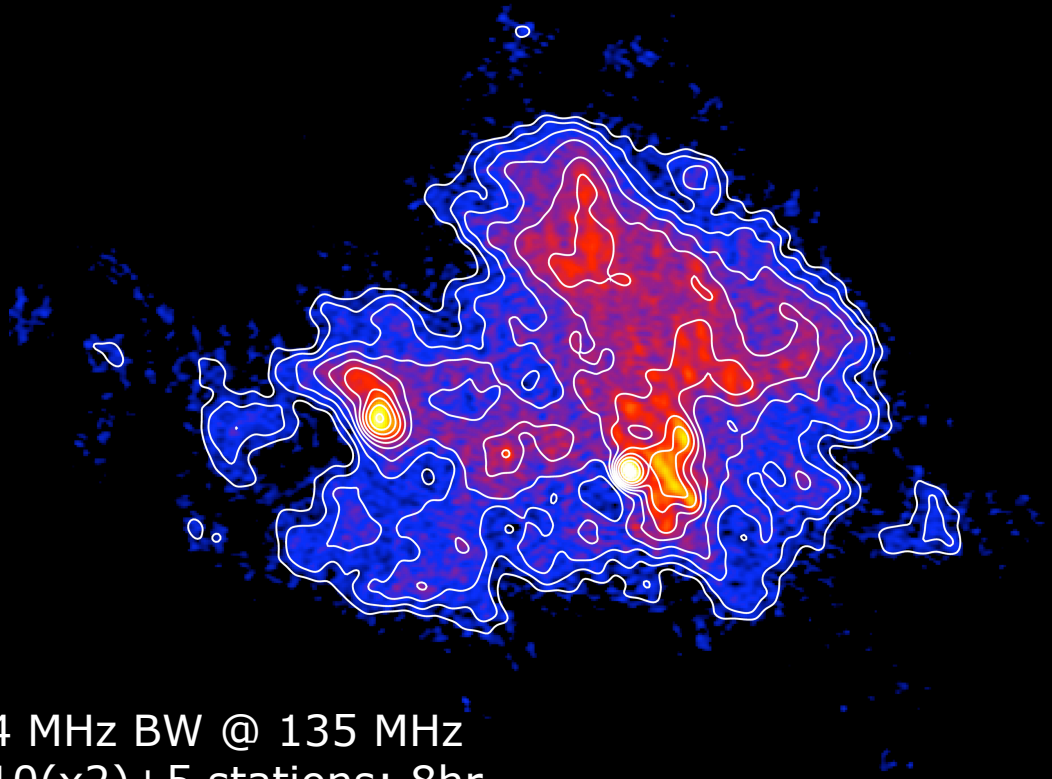
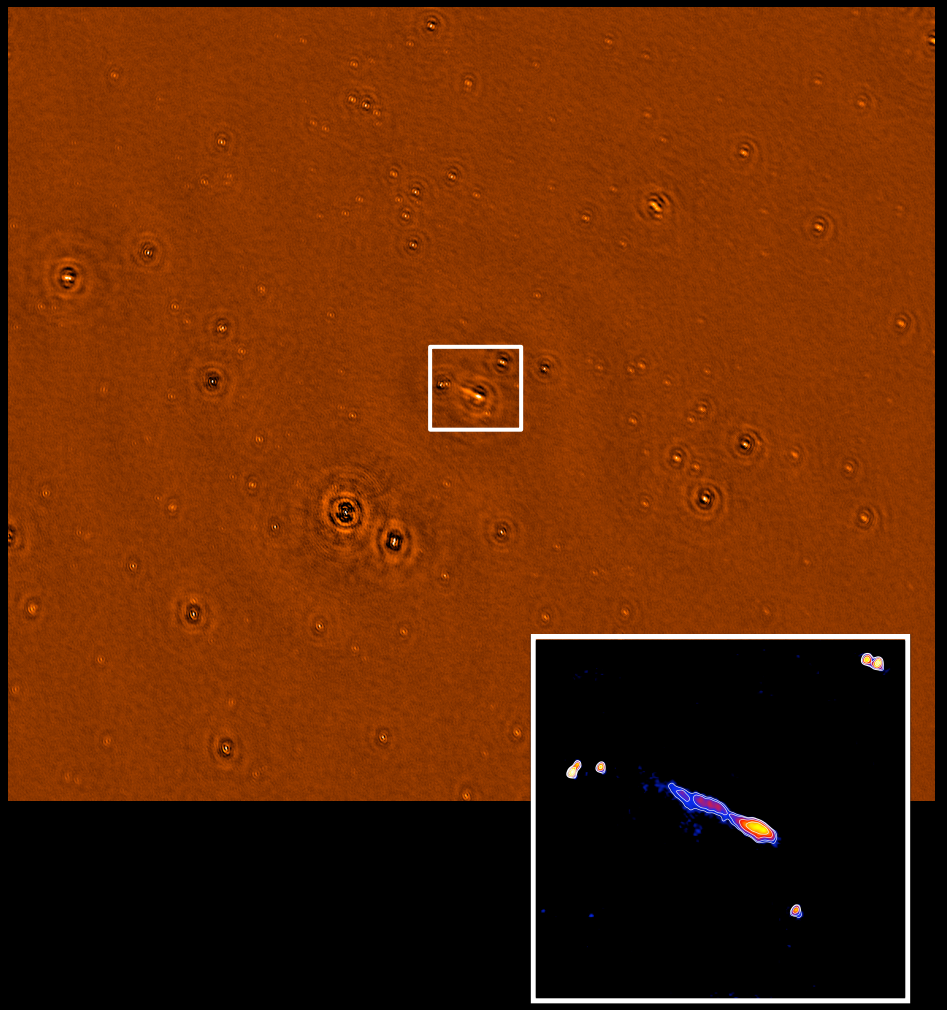


Abell 2256 & J0603+4214

LOFAR ASTRON

contours start at 22 mJy/beam
increasing in 25% increments



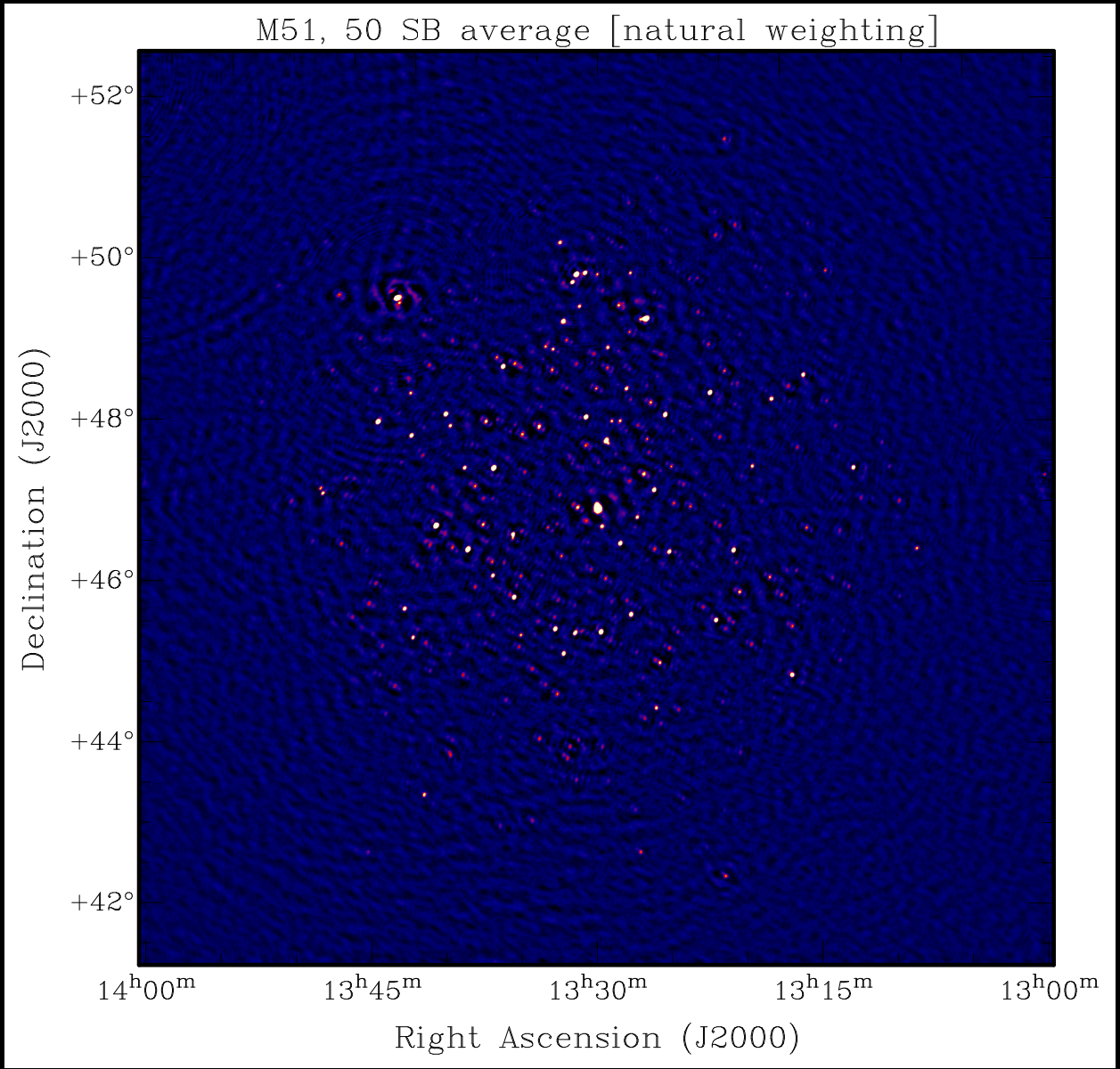


4 MHz BW @ 135 MHz
10(x2)+5 stations; 8hr
30”x20”; rms 5 mJy/beam

van Weeren, Orru, Pizzo, Bonafede, Ferrari, Macario, Shulevski, van der Tol

M51

- HBA 55 subbands



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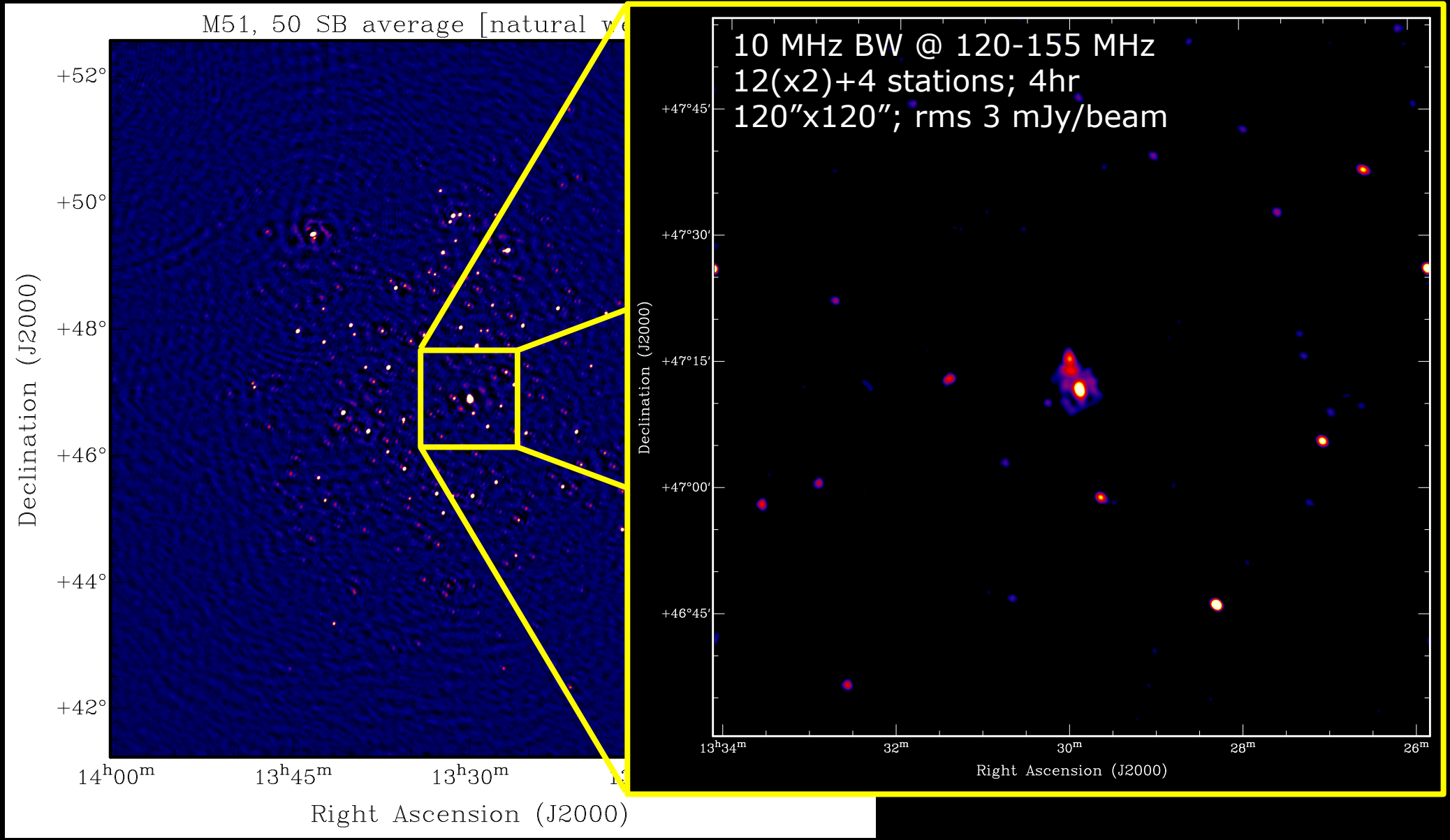
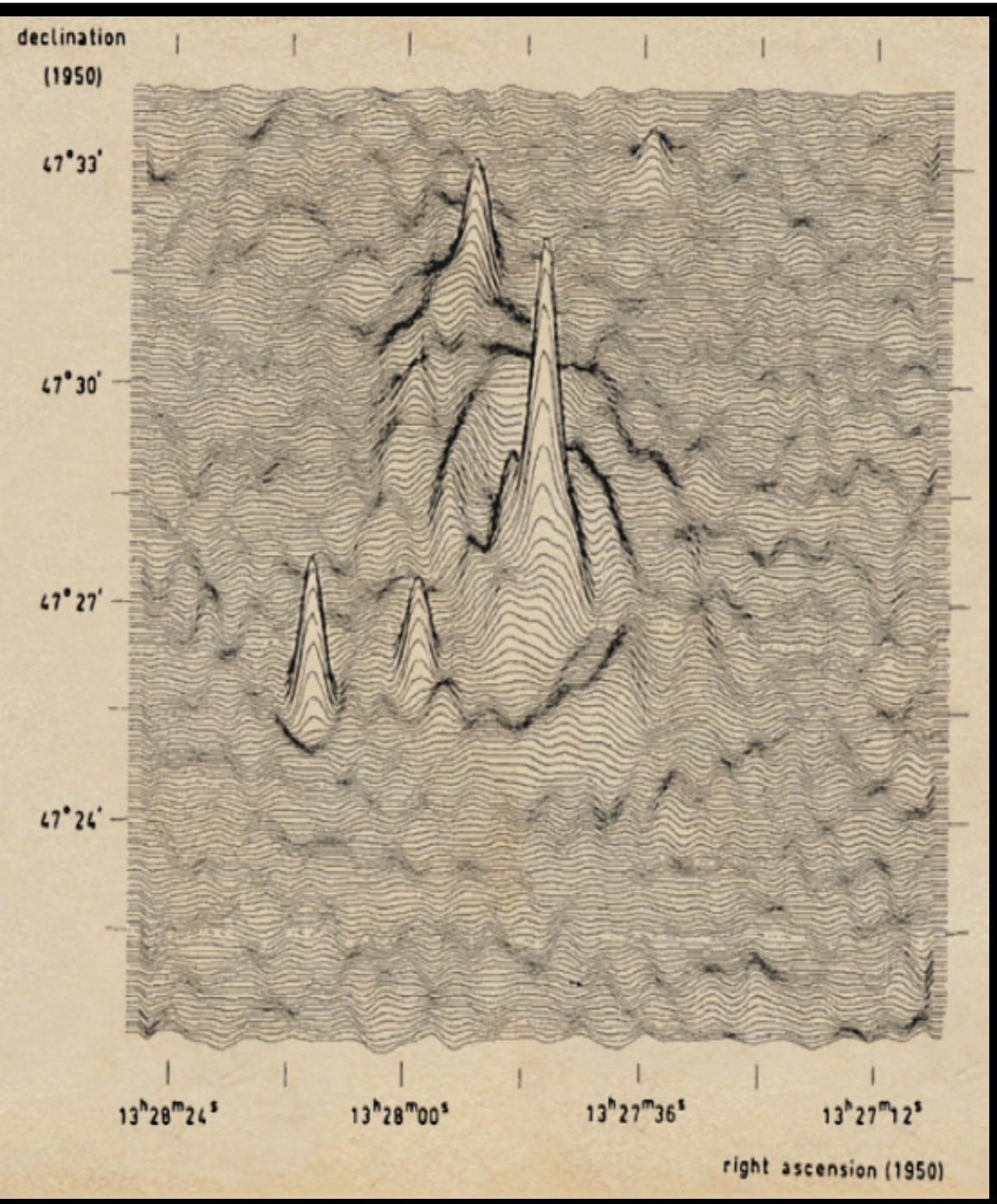
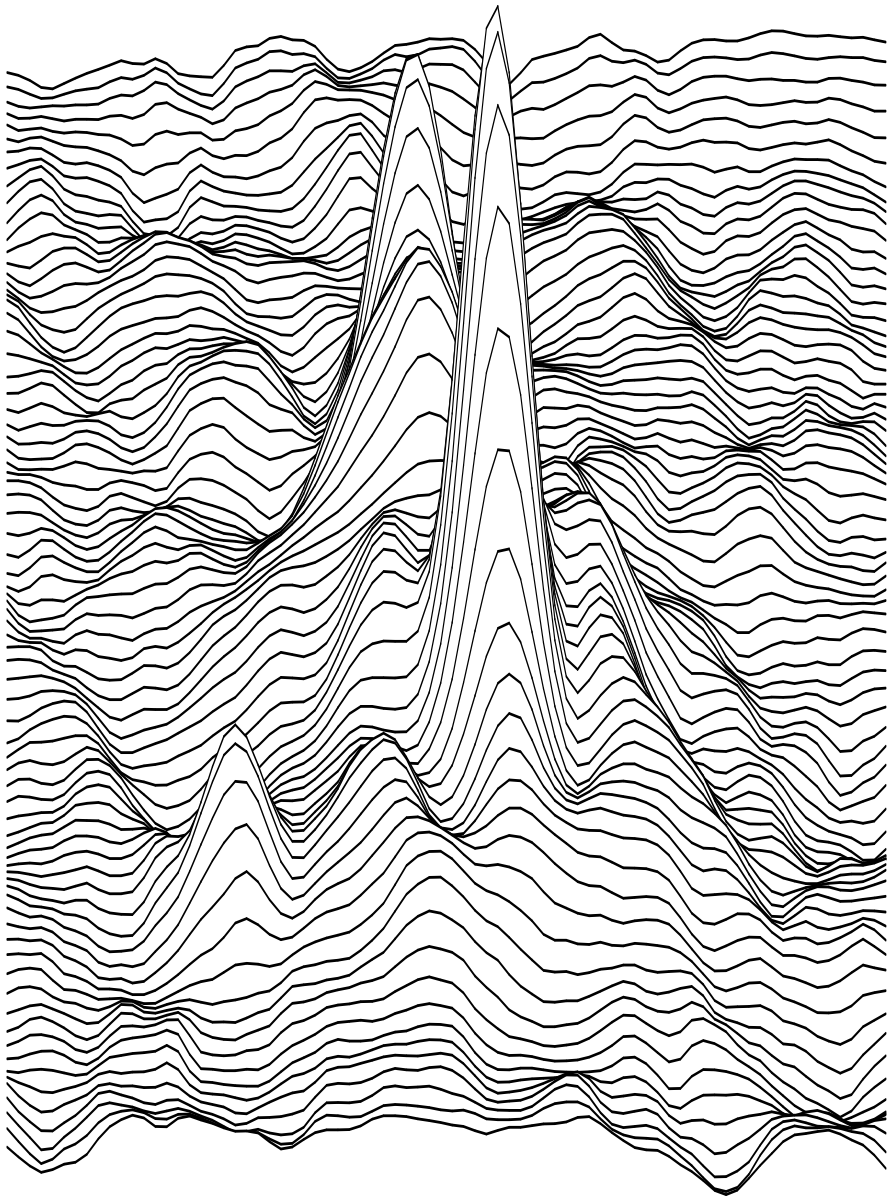
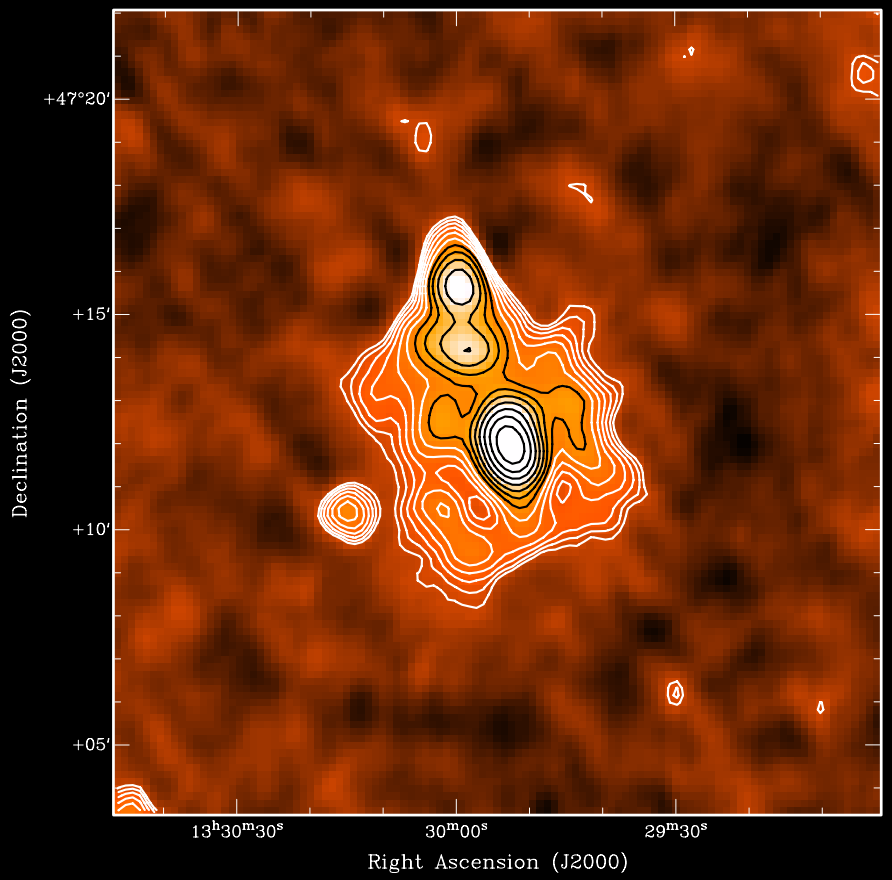


Ruled surface plots

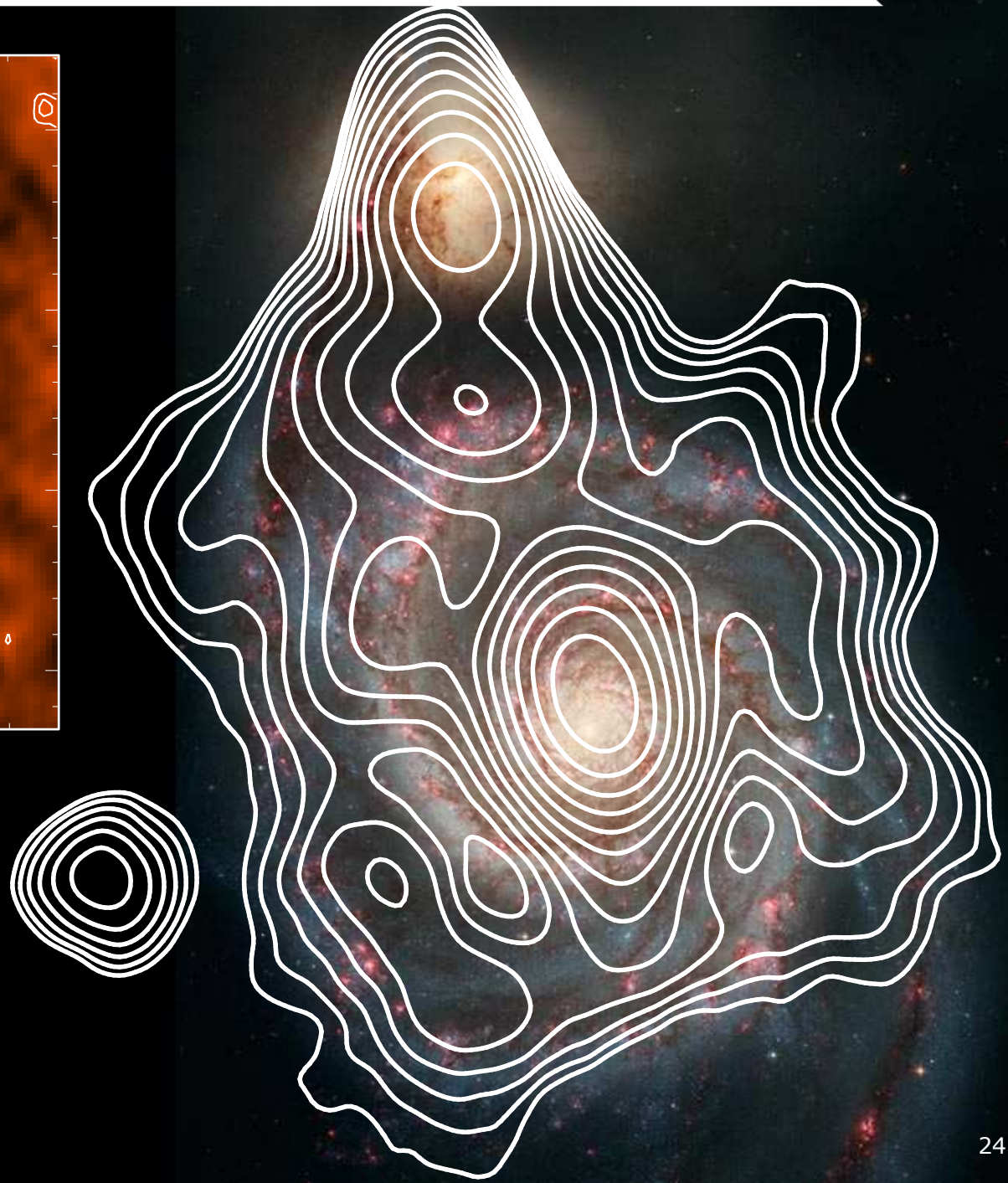




M51 close-up



contours start at 15 mJy/beam
increasing in 25% increments



optical image: Hubble Heritage

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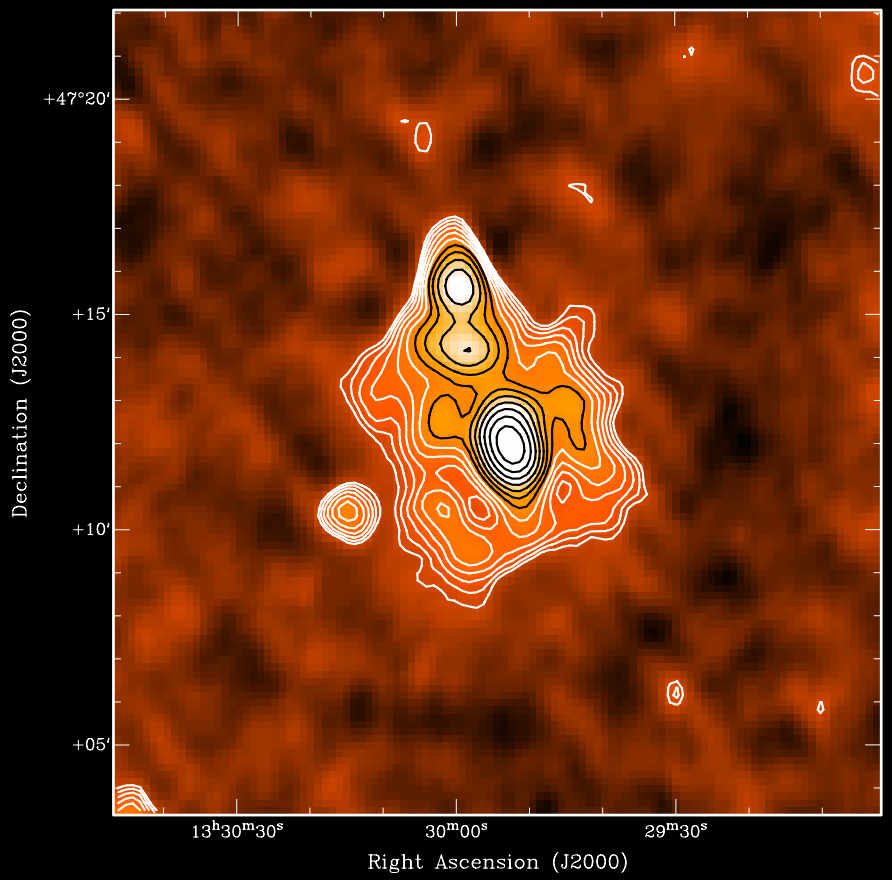

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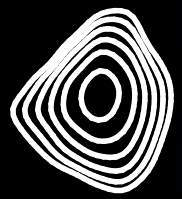

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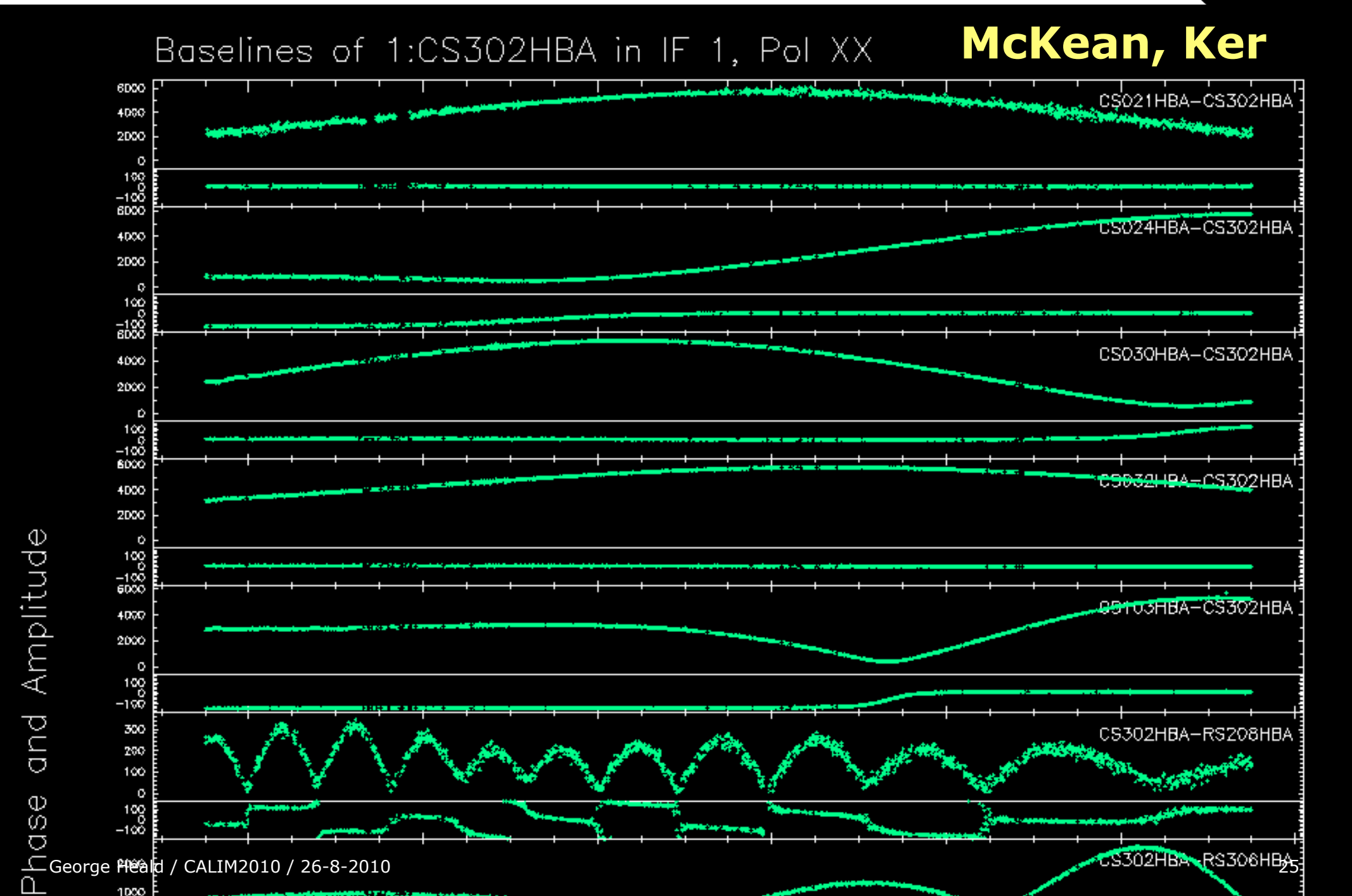
Cygnus A: visibilities

LOFAR ASTRON



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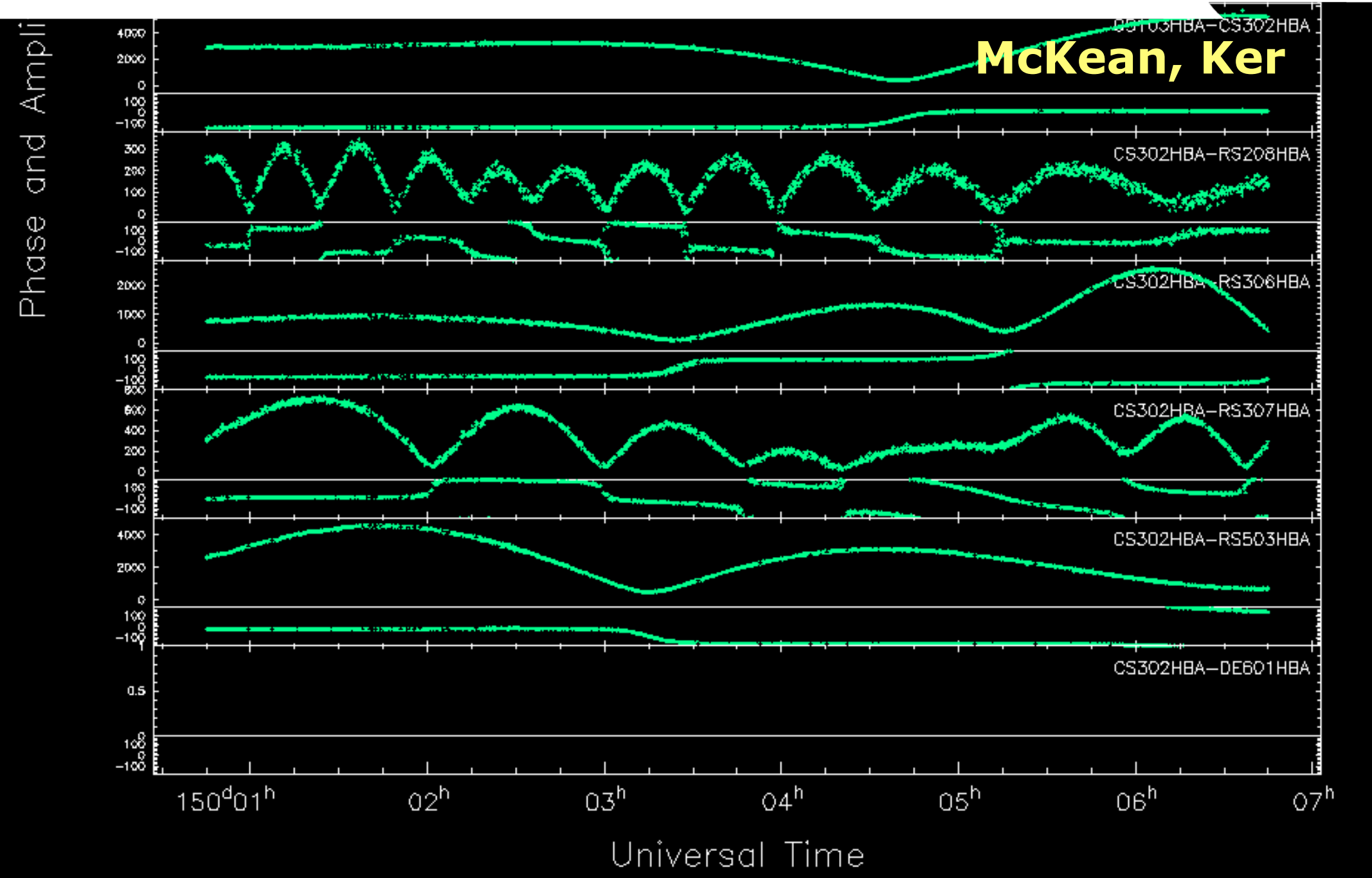

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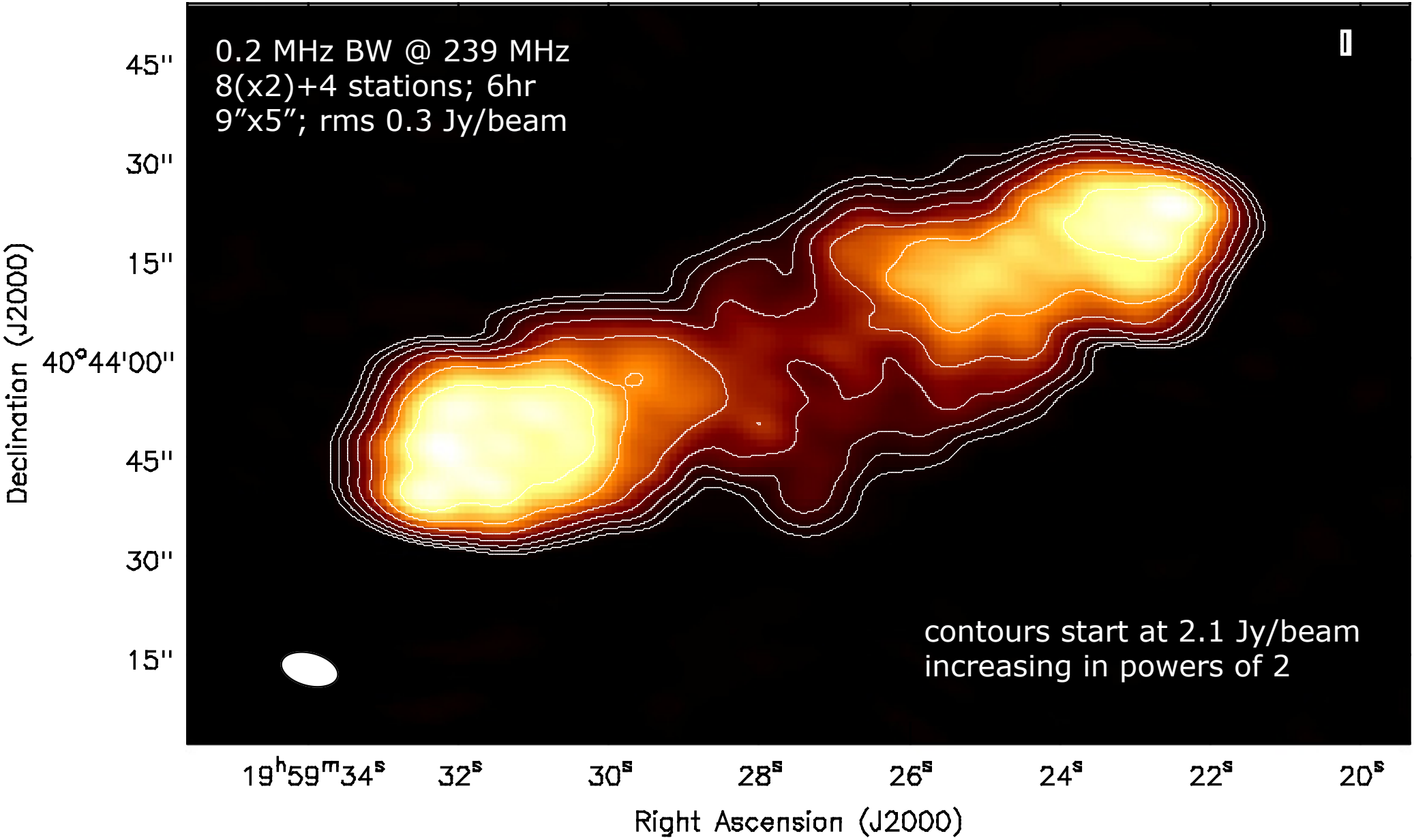
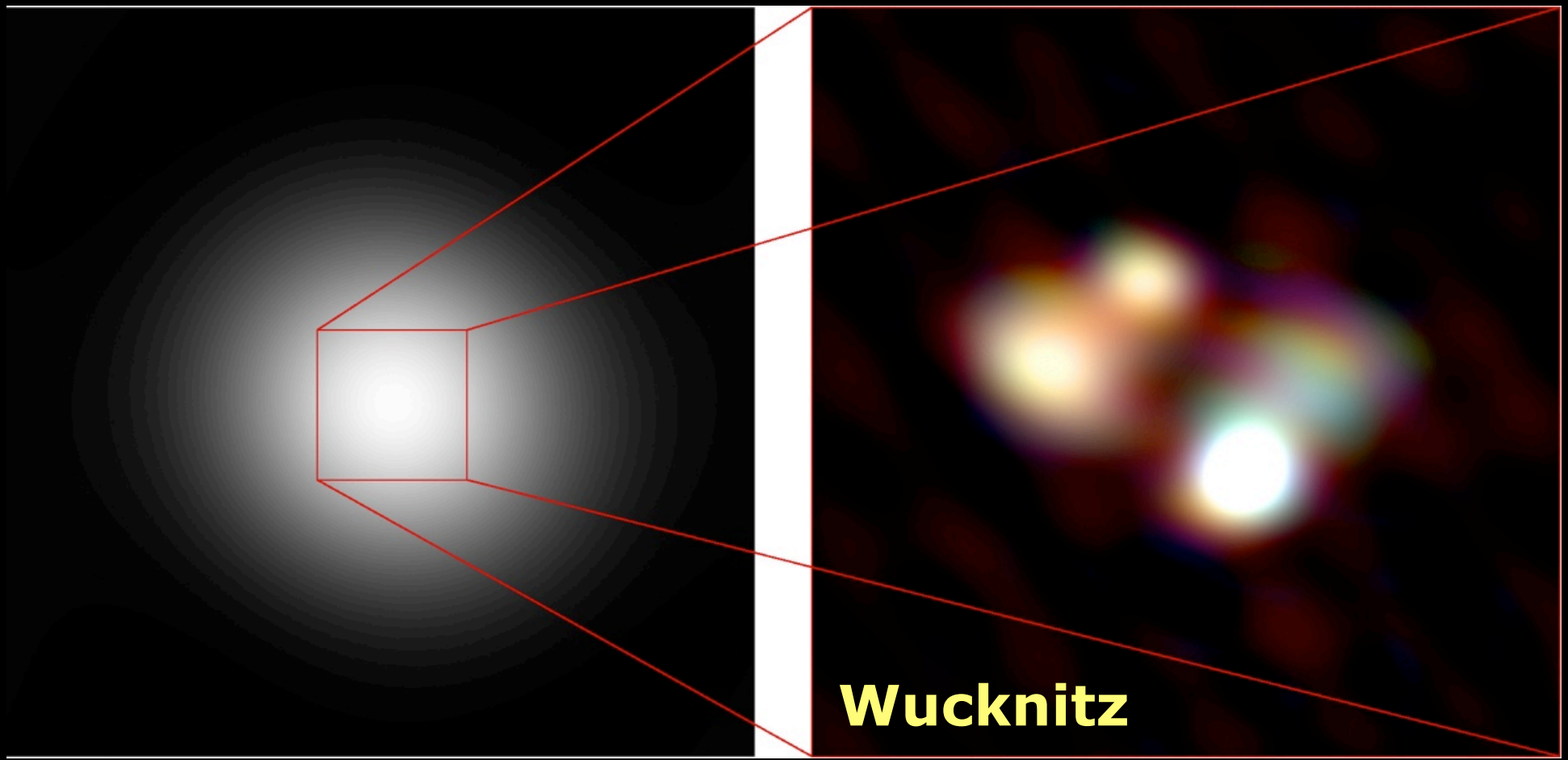


McKean, Ker

Long baselines with LOFAR

- 31 MHz bandwidth in range 30-80 MHz
  6hr observation of 3C196
  Left: 5 Dutch stations (30” beam)
  Right: +3 DE international stations (1.5” beam)



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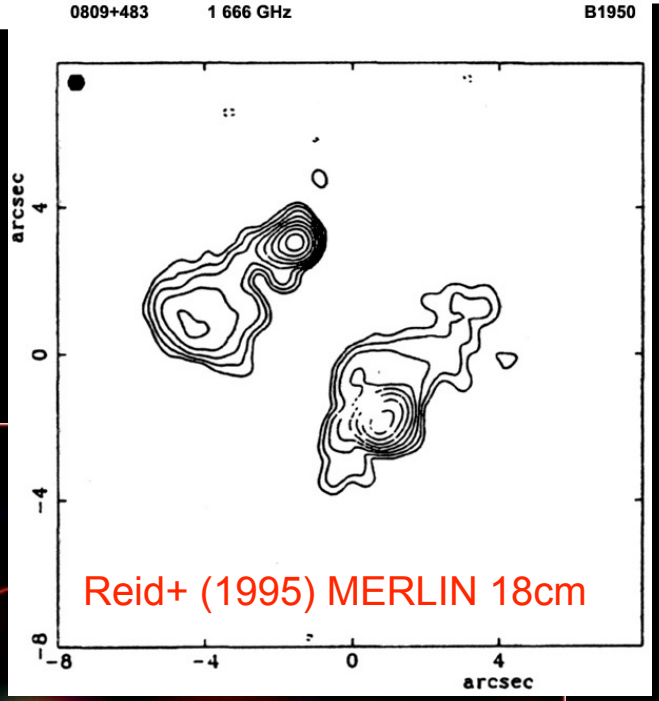
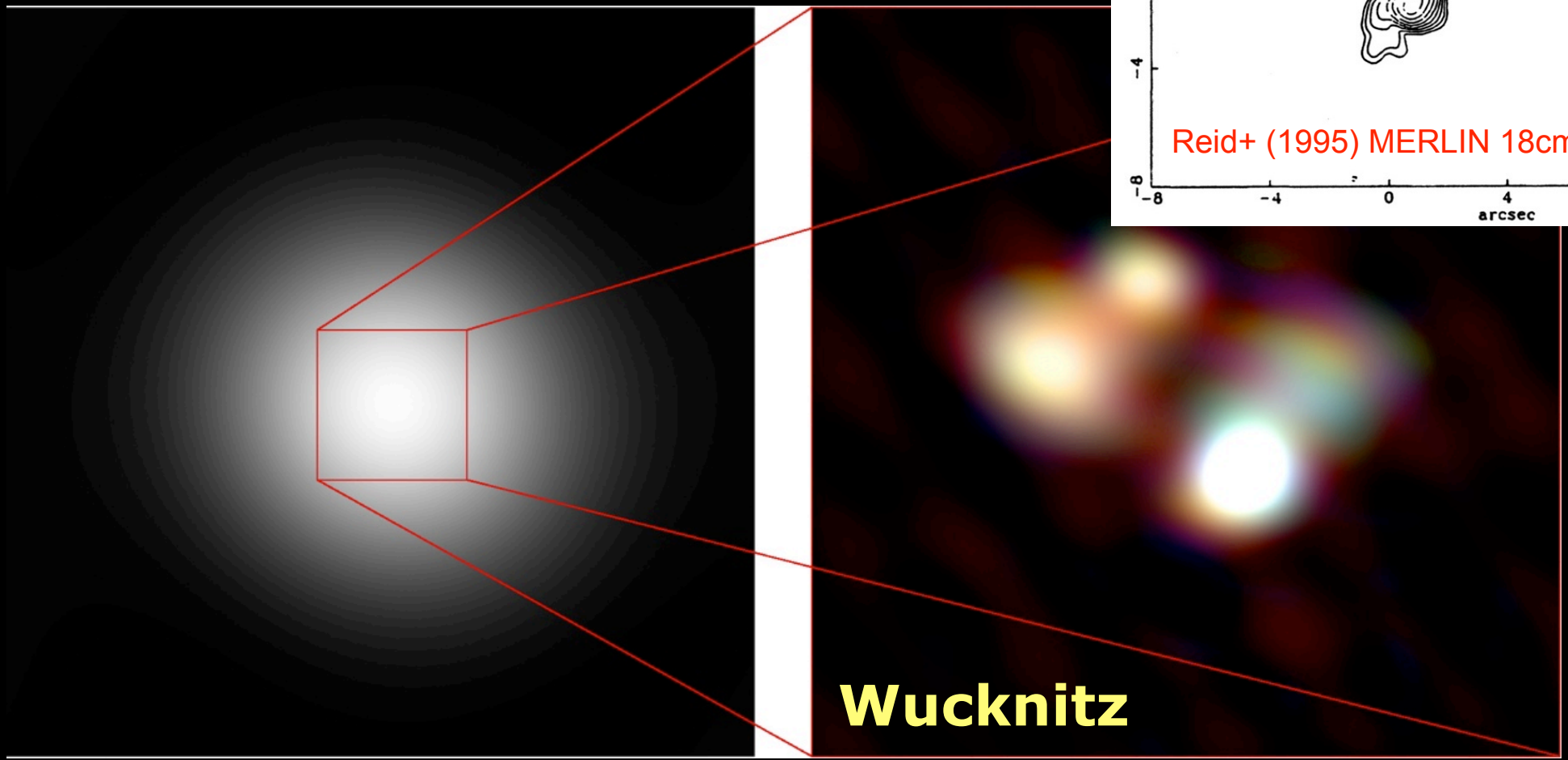
  Left: 5 Dutch stations (30” beam)
  Right: +3 DE international stations (1.5” beam)

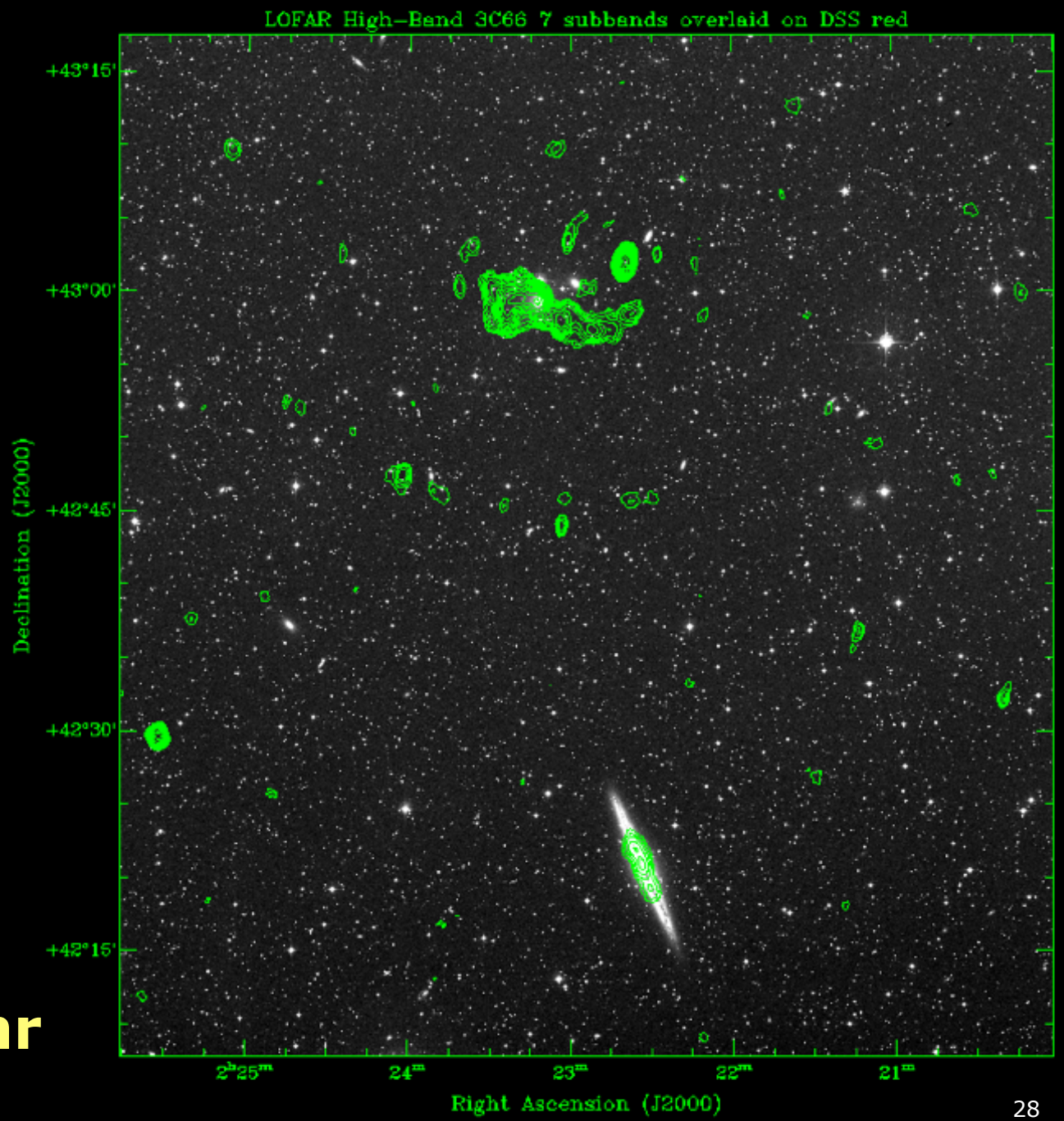




NGC 891 (in field of 3C66)

1.4 MHz BW @ ~140 MHz
11(x2)+5 stations; 6hr
110”x110”; rms 1.6 mJy/beam

(work in progress; also by Monica Trasatti, an ASTRON summer student)



Adebahr

Summary

- LOFAR's interferometric mode is well exercised
  - ... works even on long (~600km) baselines at LBA frequencies
  - both point source fields and diffuse sources manageable
  - pipeline works as a pipeline (at present, individual components are usually used separately for commissioning purposes)
    - current efforts are geared toward truly blind automated usage, and subsequent update of GSM

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- Still lots to learn about imaging with LOFAR
  - Key system development will be station beam calibration
    - Increases sensitivity
    - Better calibration
    - Polarization