Status of the Solar Imaging Pipeline & Solar Data Center

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Solar Key Science Project

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ASTRON

Overview

- Motivation
- Status of the Solar Imaging Pipeline
- Status of the Solar Data Center
- Learned and to be learned
- Roadmap, Summary, Outlook

Objective of the Solar KSP

Study of solar activity / monitoring of solar radio bursts (space weather)

⇒ images of high time resolution (≤1s)

⇒ poor uv coverage (no aperture synthesis)

⇒ flood of images (43200 in 12 h)

⇒ for every subband / frequency

⇒ automatic processing required:

LOFAR Solar Imaging Pipeline

⇒ archive with interface required:

LOFAR Solar Data Center

Funding of the Solar KSP (PI Gottfried Mann)

- LOFAR remote station of AIP in Potsdam-Bornim:
  - ≈ 930 k€ station
  - ≈ 250 k€ site preparation / constructions
  - ≈ 50 k€ for others
  - **≈ 1230 k€ in total**

- by German government:
  - D-LOFAR I + II (6 participants)
    400 k€ for 6 years (→ F. Breitling)

- by AIP – operation costs:
  - ≈ 80 k€ to ASTRON
  - ≈ 35 k€ operating costs / electricity
  - ≈ 15 k€ data link
  - **≈ 120 k€ in total per year**
  - 1 staff position (→ C. Vocks LOFAR scientist at AIP)

The Solar Imaging Pipeline

Data

Measure-ment Set SB001

Measure-ment Set SB002

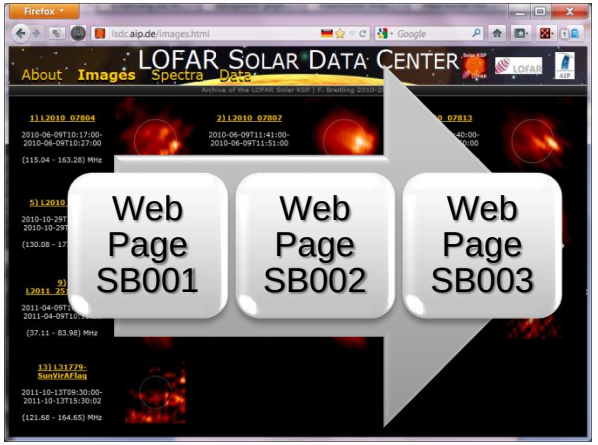
Measure-ment Set SB003

Calibration: bbs

Imaging: casaimg

Archiving: html.obs lsdcsync

Front end / Web interface



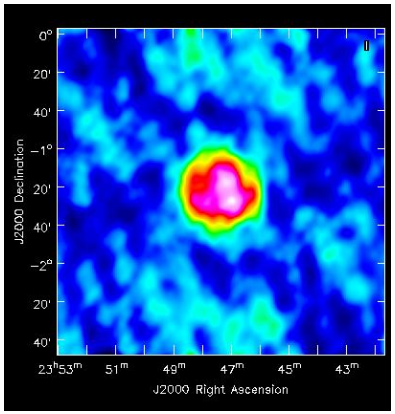
Components

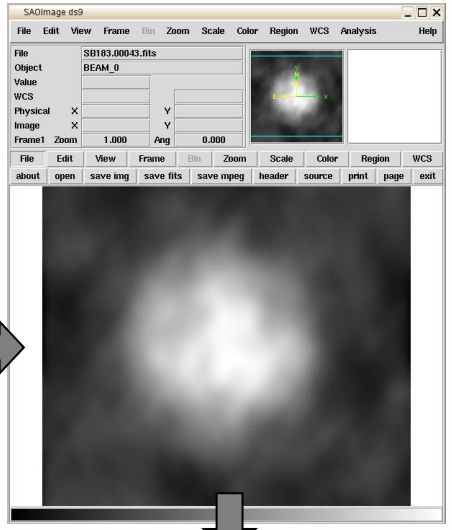
- Programs
  - ndppp, flag
  - bbs (calibration)
  - casaimg (imaging)
  - fits2SolarCoordinates.py
  - autocorrelations / spectrum
  - Data center scripts
  - :
- Configuration files
  - skymodel with calibrators
  - parsets: calibrartion, simulation, solution transfer …
- Tools
  - findfiles (creating file lists)
  - obstats (time, frequency, antennas, beam dir, etc.)
  - subjobs (job submission)
  - clusterload & clusterspace
  - jpgmaker
  - moviemaker (mp4)
  - fixtracking.py
  - :
- Documentation

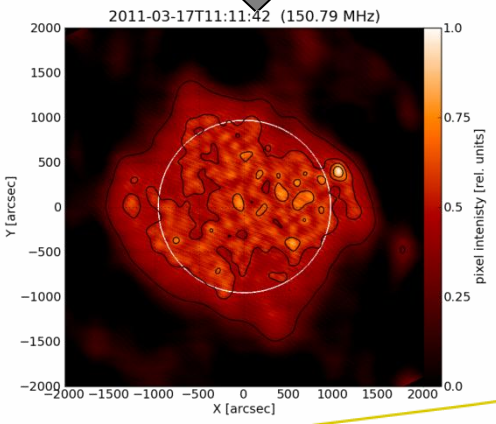
Milestones: Version 1(.0) – First prototype

(by June 2011)

- preprocessing
- calibration using sky models
- dirty images using CASA
- job submission for parallel processing on CEP1 cluster
- conversions to
  - solar coordinates
  - FITS, JPGs
  - thumbnails
- movies







⇒First burst detection

Version 1(.0) – Tools & Data Center

- Tools
  - findfiles
  - clusterload & clusterspace
  - changemount
  - obstats
- Solar Data Center
  - web server
  - frame work
  - static web pages

Version 2(.0) – Production pipeline

(by June 2012)

- improved calibration strategies with external calibrators
- complete rewrite of job submission
  - much cleaner (modular) design
  - working for CEP1 and CEP2
- code highly optimized and efficient
  - casaimg (CPU time -75%, speed up 4x)
  - exactimage lib (CPU time -80%, speedup 5x)
- multi-core parallelization for JPGs, thumbnails, etc. (speed up 10x)
- spectra from autocorrelations in imaging data
- flagging

Version 2(.0) – Tools & Data Center

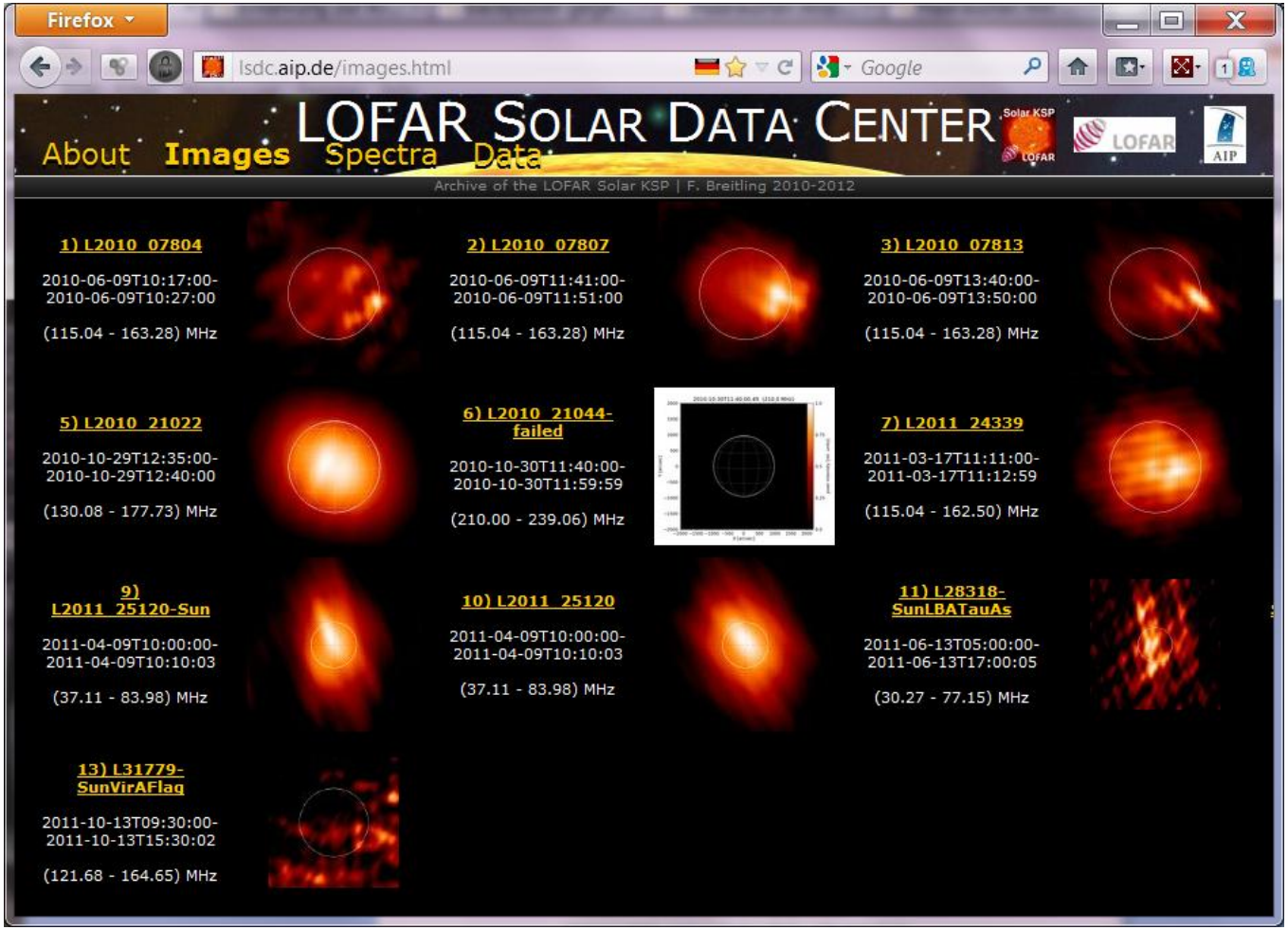
- New tools
  - fixtracking.py for tracking observations
  - data management (distribute data to cluster, transfer to data center)
  - splitms.py for measurement sets
  - fixarchive to update the data center
  - :

Solar Data Center

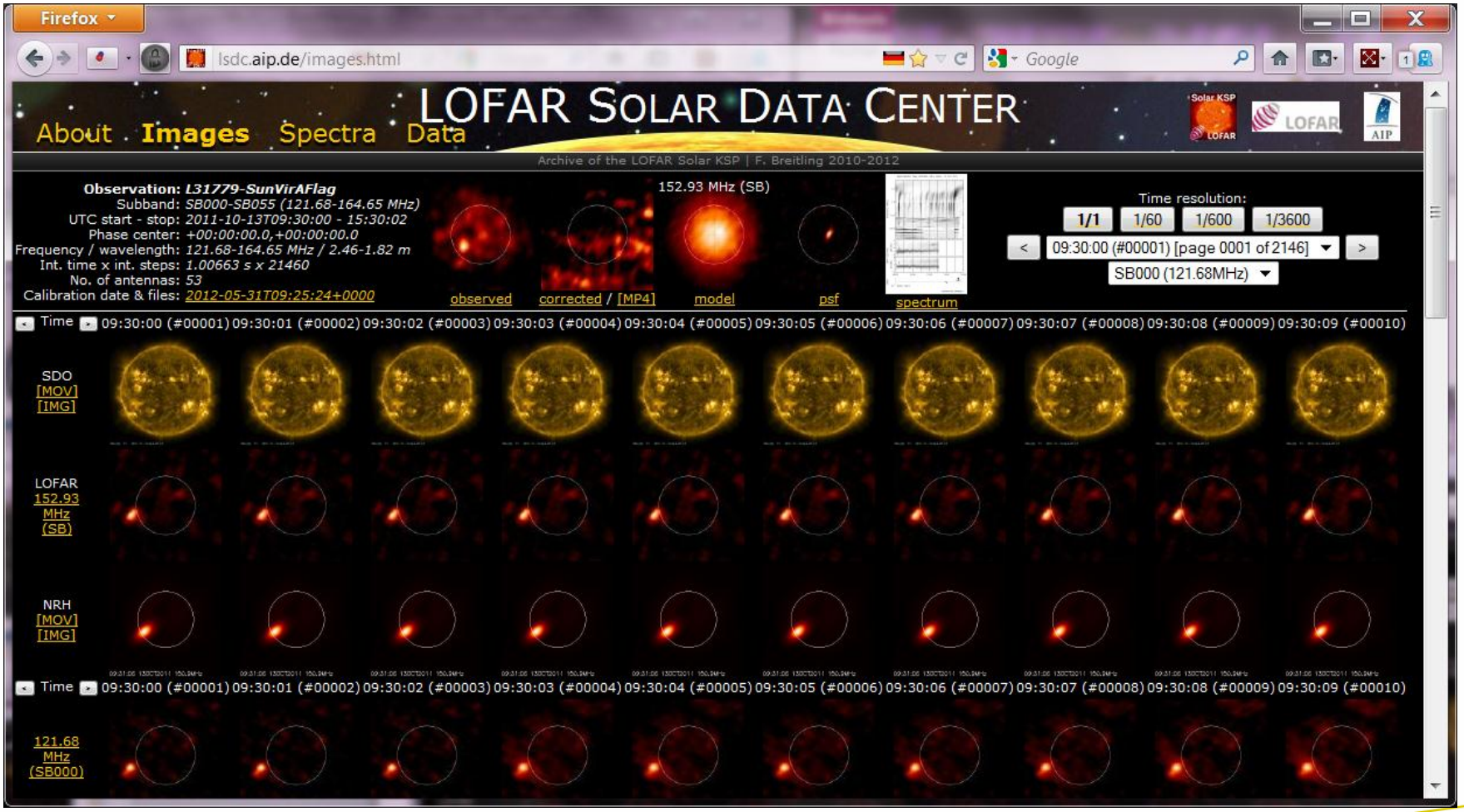
- modular web pages with frames and Javascript
  - ⇒ total data reduction for 12h 20SBs: 2500 MB => 200 MB
  - ⇒ speed up: 45 minutes => 10 minutes
  - ⇒ faster loading of pages and navigation
- additional data from
  - SDO, Nancay, Artemis (spectra)

⇒systematic analysis of data now possible

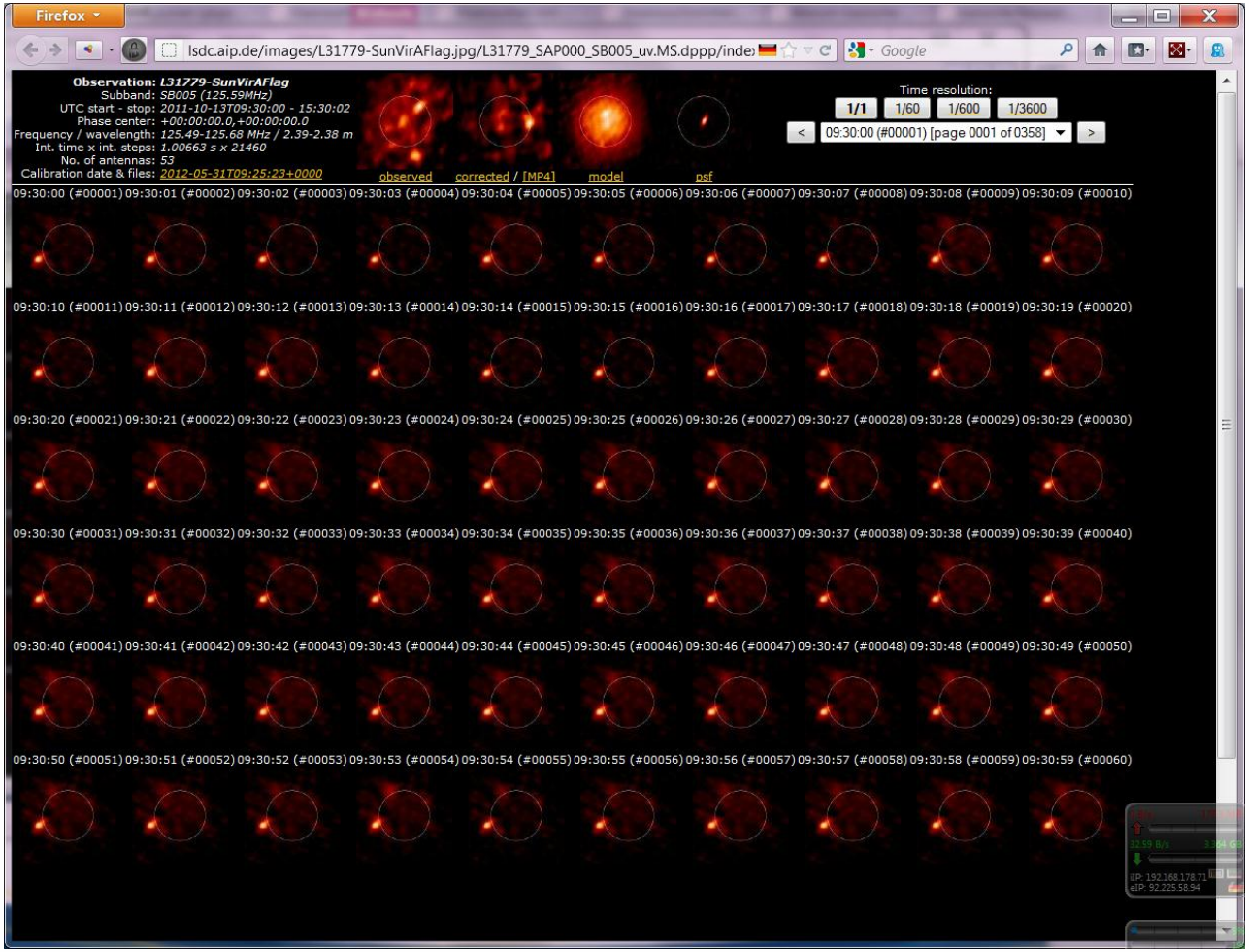
The Data Center's web interface



Observation L31779 – Overview of all SBs / frequencies



Observation L31779 – SB005 / 125MHz



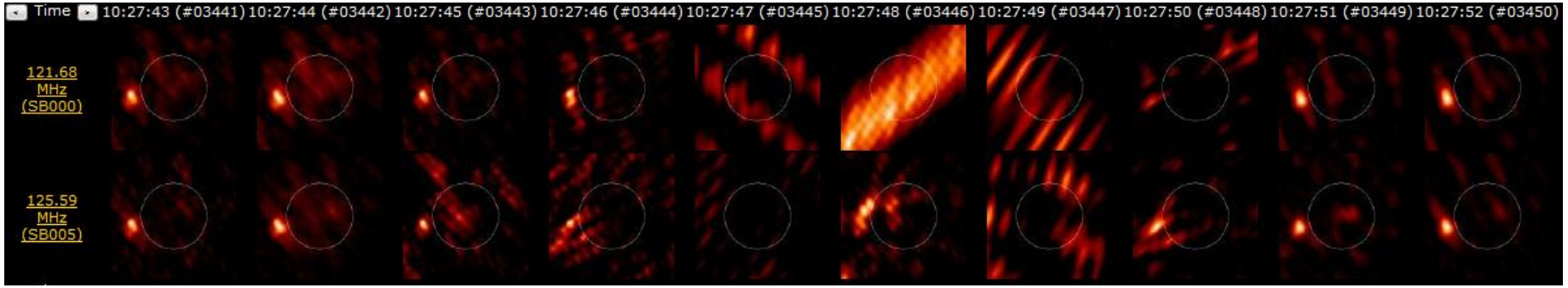
Learned so far

- self-calibration works
- calibration with calibrator sources works even better:
  - correct astrometry
  - correct fluxes
  - good agreement with Nancay
  - short solar bursts (<5s) are detected very well
  - solutions only valid for ±10 minutes (need simultaneous calibrator beams)
- but sun needs strong calibrators
  - working: Taurus A (1400 Jy), Virgo A (1100 Jy)
  - not yet working: 3C123 (204Jy), 3C157(270Jy),3C273(79Jy),3C279(25Jy)
- spectra can be obtained simultaneously and are ideal compl. products
- reduction of image quality
  - with frequency (different spectral index of sun and calibrator)
  - towards the afternoon (ionosphere)

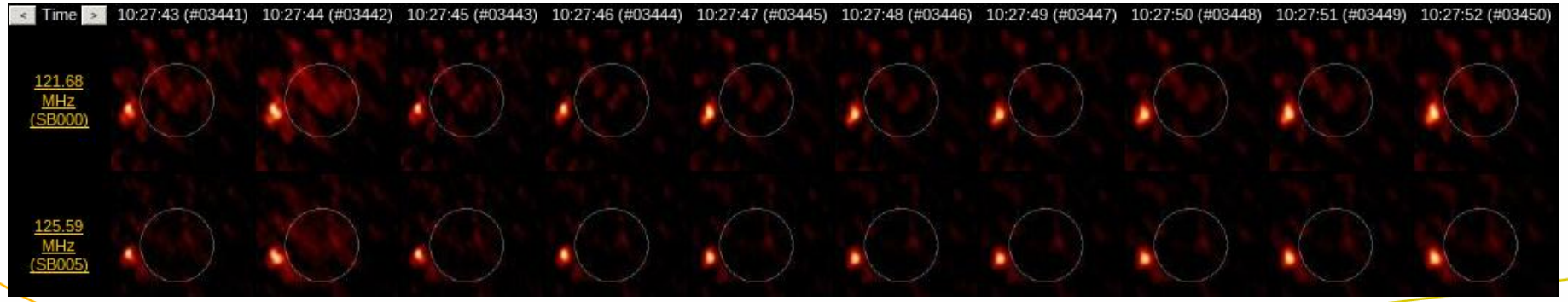
Learned: Calibration strategies for solar bursts

Problem: flagging removes bursts => we cannot flag the beam to the Sun

⇒ but many radio bursts outshine calibrators => bad calibration



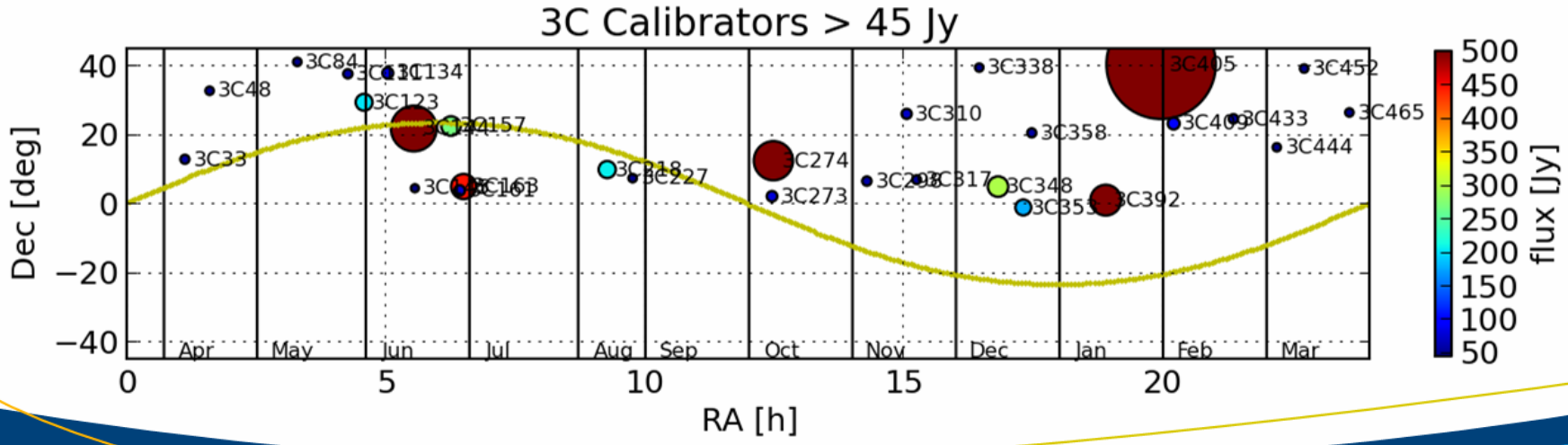
Solution: flagging calibrators only, then transfer solution to Sun beam



Learning in progress – 1st systematic solar calibrator study

⇒ develop map / calendar of best LOFAR calibrators for the Sun (started with Tau A in June 2012)

- Short (<10 min) observation in the morning
- with strong
- point like (<1arcmin) calibrators
- over one year



Version 3(.0) and later (to do)

- Outstanding implementations
  - Verify absolute flux scale
  - Fix CASA imaging performance issue (partition MSs) / AWImager
  - (Multiscale-) Clean
  - Ionospheric corrections
  - Calibration + imaging synthesis of tracking observations (LOFAR2.0)
  - Polarization
- Add
  - Spectra from LOFAR imaging data
  - High resolution spectra from single station / BF observations
  - Interplanetary scintillation data from R. Fallows et al.
  - Measurement Sets and FITS files
  - Data from the GOES satellite
- Administration
  - Migrate the LSDC prototype to its new server at the AIP
  - Set up backup with the LOFAR Long Term Archive
  - Process the data from the first 48h campaign this fall
- Documentation
  - Solar Imaging Cookbook

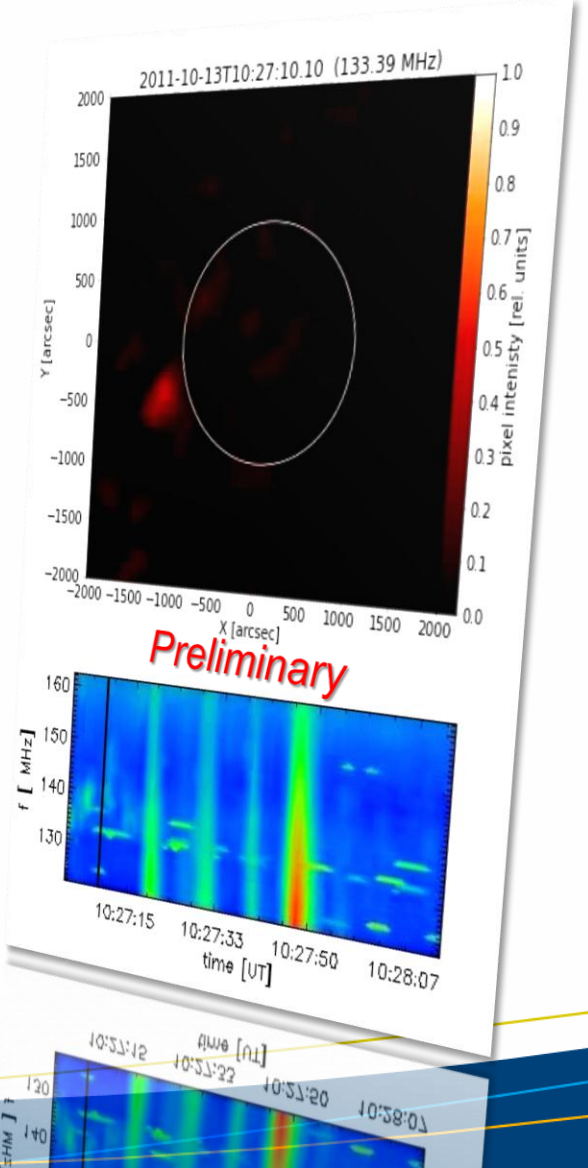
Summary

+ Version 2 of Solar Imaging Pipeline is working and produces
  - images and spectra
  - at all frequencies in low- and high-band
  - with a time resolution of 1 second
  - of the active Sun and in particular of radio bursts

  ⇒ a useful tool to process and analyze solar data
+ a couple of things have been learned about solar imaging
+ there is more to learn, e.g. from 1st systematic solar calibrator study
+ The Solar Data Center has been set up
- Some features of the Solar Imaging Pipeline are still missing but will be implemented in version 3 or later
- Possible due to substantial funding by the Solar KSP

Outlook

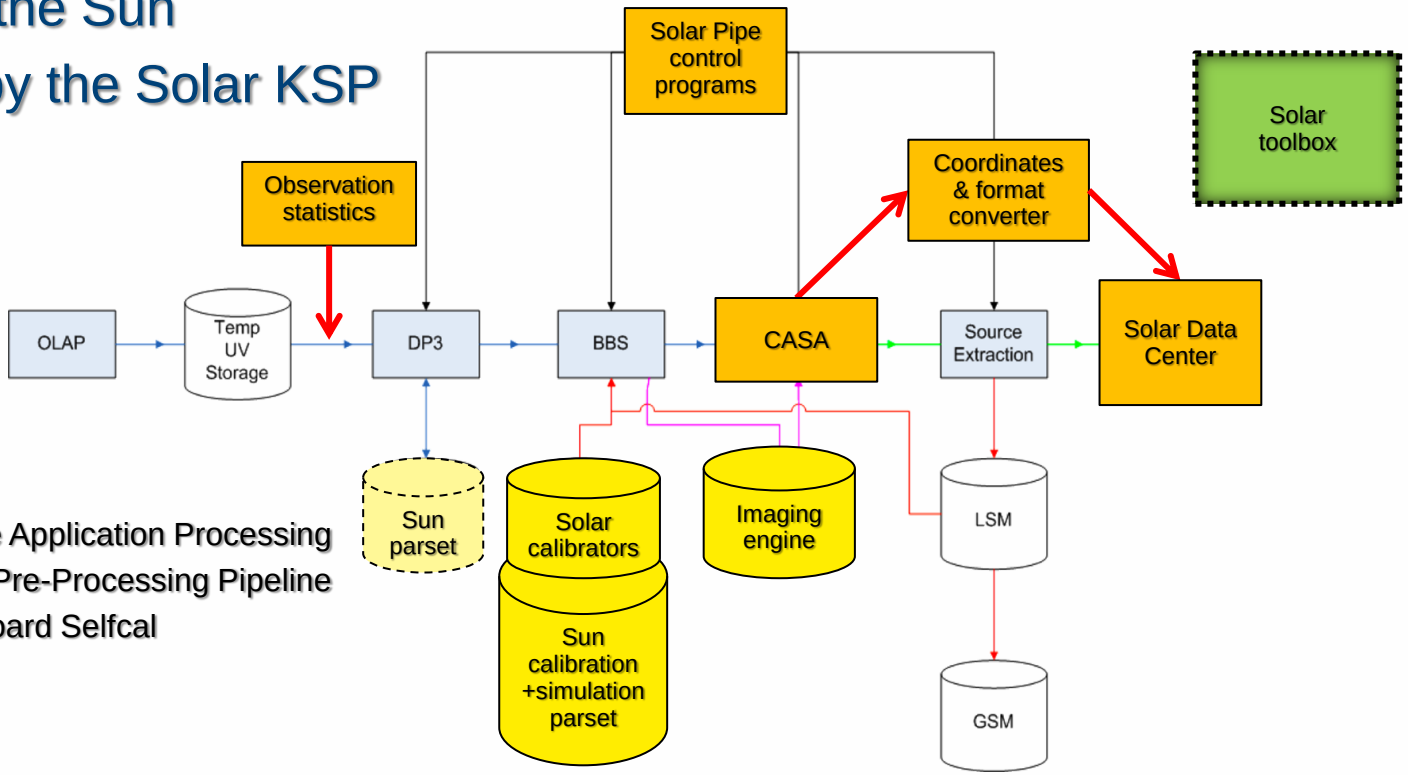
- Many radio bursts have been detected in the commissioning data
- These preliminary results are currently studied in detail and will be presented at future meetings
- The data will become available through the Data Center
- An example is show to the right



Thanks for your attention!

Solar vs. Standard Imaging Pipeline

- the Solar IP is an extension to the LOFAR Standard IP
- for imaging the Sun
- developed by the Solar KSP



Components

- OLAP: Online Application Processing
- DP^3: Default Pre-Processing Pipeline
- BBS: BlackBoard Selfcal
- CImager

BBS

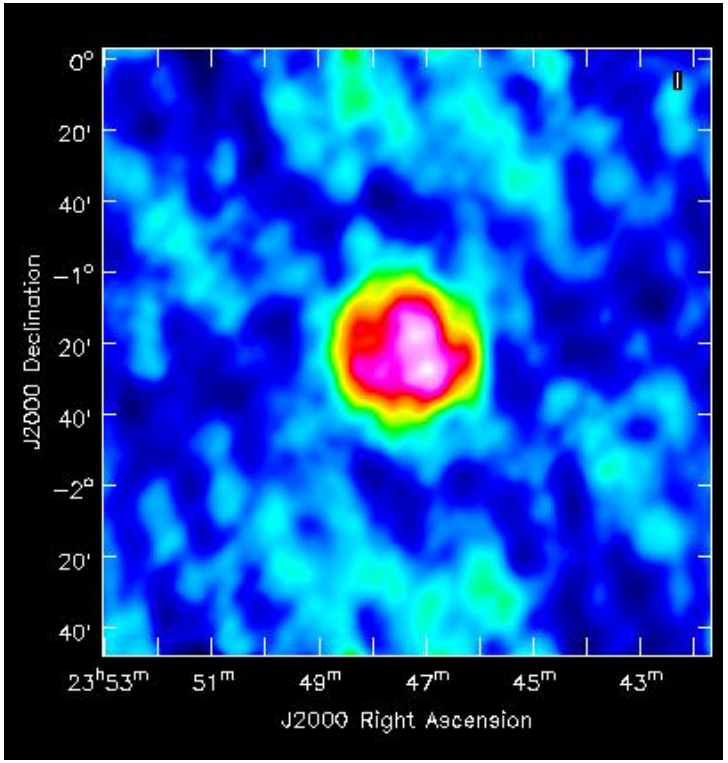
- generates skymodels with calibrators and correct Sun position
- generates parsets for calibration, simulation and solution transfer
- distributes the processes to the cluster
- organizes the log files

```
# (Name, Type, Patch, Ra, Dec, I, Q, U, V, ReferenceFrequency='7.38000e+07', SpectralIndex='[]', MajorAxis,
MinorAxis, Orientation) = format
# The above line defines the field order and is required.

Sun,    GAUSSIAN, , 23:47:12.34, -01.23.09.0,  35000, , , ,160e6, [2.0],  2000.0, 2000.0
TauA,  GAUSSIAN, , 05:34:32.00,+22.00.52., 1888.5, , , ,81.5e6,[-0.299], 420.,   290.
3C123,    POINT, , 04:37:04.72, +29.40.15.6, 454.97, , , , 7.4e7, [-1]
```

Casaimg

- creates images for every
  - time step
  - subband (frequency)
- runs distributed on the cluster
- keeps log files
- runs CASA makeimage / clean
- converts it further via fits2SolarCoords.py
- creates thumbnails



fits2SolarCoords.py

- Reads pixel intensities from FITS image
- Calculates Sun's position angle and rotate
- Sets Field of View
- Adds color palette
- Adds date and frequency
- Exports as JPG