



Status of the Solar Imaging Pipeline & Solar Data Center

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Solar Key Science Project

LOFAR Status Meeting 2012, July 11

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 ($\leq 1\text{s}$)

⇒ 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:

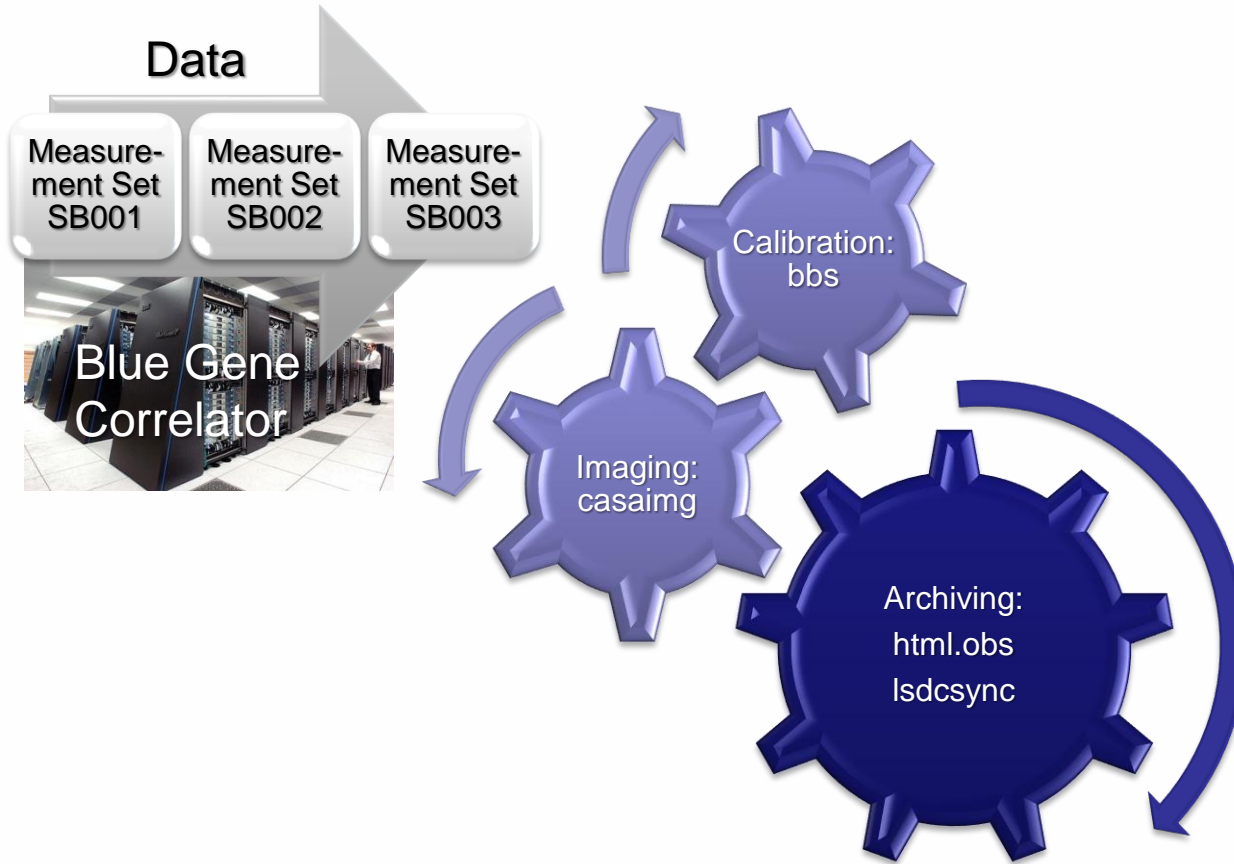
LOFAR Solar Data Center

Funding of the Solar KSP (PI Gottfried Mann)

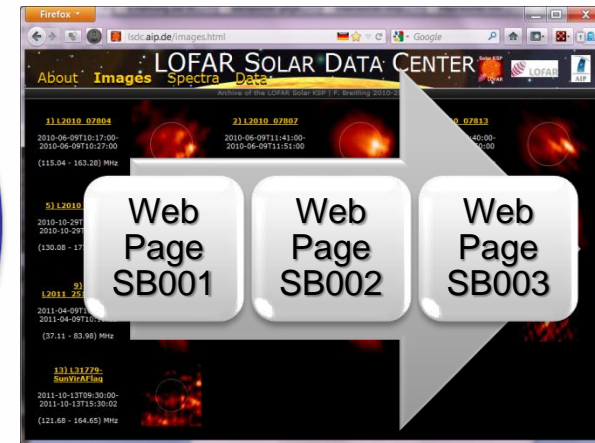


- LOFAR remote station of AIP in Potsdam-Bornim:
 - ≈ 930 k€ station
 - ≈ 250 k€ site preparation / constructions
 - ≈ 50 k€ for others
 - ≈ **1230 k€ in total**
- by German government:
 - D-LOFAR I + II (6 participants)
 - 400 k€ for 6 years (→ F. Breitling)
- by AIP – operation costs:
 - ≈ 80 k€ to 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



Front end / Web interface



- Programs

- ndppp, flag
- bbs (calibration)
- casaimg (imaging)
- fits2SolarCoordinates.py
- autocorrelations / spectrum
- Data center scripts
- :

- Configuration files

- skymodel with calibrators
- parsets: calibration, simulation, solution transfer ...

- Tools

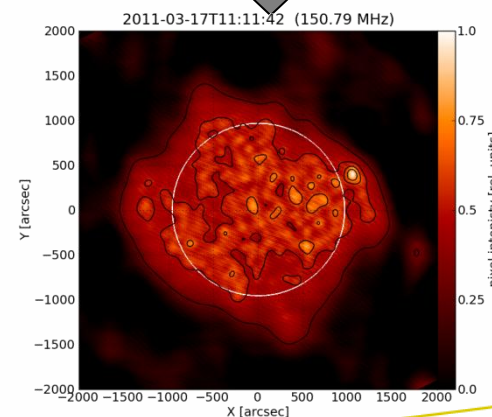
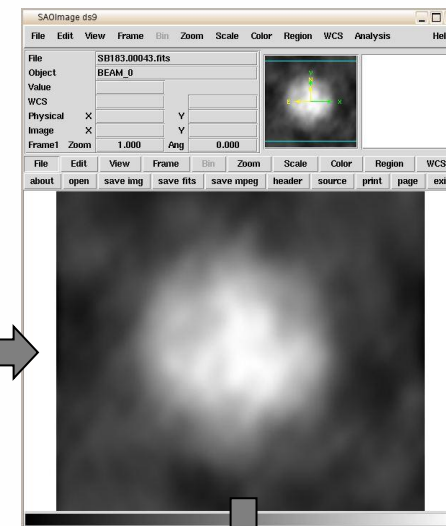
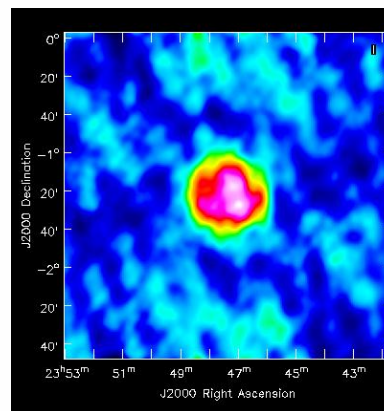
- findfiles (creating file lists)
- obstats (time, frequency, antennas, beam dir, etc.)
- subjobs (job submission)
- clusterload & clusterspace
- jpgmaker
- moviemaker (mp4)
- fixtracking.py
- :

- 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

```
ssh
Fri Jun 24 21:01:37 UTC 2011
CEP1
=====
sub1  sub2  sub3  sub4  sub5  sub6  sub7  sub8
-----
lce001 lce010 lce019 lce028 lce037 lce046 lce055 lce064
0,07 0,00 0,00 0,00 2,00 0,02 0,06 0,00 0,10
lce002 lce011 lce020 lce029 lce038 lce047 lce056 lce065
1,15 0,04 0,00 0,13 0,08 0,05 1,08 0,31
lce003 lce012 lce021 lce030 lce039 lce048 lce057 lce066
0,06 0,02 0,07 0,00 0,08 0,08 1,08 1,06
lce004 lce013 lce022 lce031 lce040 lce049 lce058 lce067
0,06 0,12 1,60 0,05 0,06 0,10 0,07 2,70
lce005 lce014 lce023 lce032 lce041 lce050 lce059 lce068
0,00 0,00 0,104 2,07 0,07 0,10 0,00 0,02
lce006 lce015 lce024 lce033 lce042 lce051 lce060 lce069
0,00 0,00 1,12 0,00 0,07 0,04 0,16 0,02
lce007 lce016 lce025 lce034 lce043 lce052 lce061 lce070
0,07 0,14 1,00 1,05 0,02 0,00 0,02 0,07
lce008 lce017 lce026 lce035 lce044 lce053 lce062 lce071
0,17 0,14 0,00 0,00 0,02 9,21 1,10 1,14
lce009 lce018 lce027 lce036 lce045 lce054 lce063 lce072
0,07 0,14 1,13 0,02 0,00 0,10 0,10 0,08
-----
lce005 lce033 lce043 lce003 lce042 lce054 lce008 lce024
0,00 0,00 0,02 0,06 0,07 0,10 0,17 0,12
lce006 lce035 lce044 lce004 lce058 lce063 lce065 lce027
0,00 0,00 0,02 0,06 0,07 0,10 0,31 1,13
lce010 lce045 lce061 lce040 lce070 lce064 lce025 lce071
0,00 0,00 0,02 0,06 0,07 0,10 1,00 1,14
lce014 lce052 lce068 lce046 lce038 lce013 lce023 lce002
0,00 0,00 0,02 0,06 0,08 0,12 1,04 1,15
lce015 lce055 lce069 lce001 lce039 lce029 lce034 lce022
0,00 0,00 0,02 0,07 0,08 0,13 1,05 1,60
lce019 lce059 lce011 lce007 lce048 lce016 lce066 lce028
0,00 0,00 0,04 0,07 0,08 0,14 1,06 2,00
lce020 lce012 lce051 lce009 lce072 lce017 lce056 lce032
0,00 0,02 0,04 0,07 0,05 0,14 1,08 2,07
lce026 lce036 lce031 lce021 lce049 lce018 lce057 lce067
0,00 0,02 0,05 0,07 0,10 0,14 1,09 2,70
lce030 lce037 lce047 lce041 lce050 lce060 lce062 lce053
0,00 0,02 0,05 0,07 0,10 0,16 1,10 9,21
=====
sh 1$ bash 2$ bash 3-$ bash 4$* bash 5$ bash 6$ bash 7!$

ssh
lce067 942177408 809838300 132339108 86% /data
lce059 942177408 809452220 132725188 86% /data
lce014 942177408 804470192 137707216 86% /data
lce068 942177408 790851488 151325920 84% /data
lce071 942177408 776012972 166164456 83% /data
lce065 942177408 777983688 164183720 83% /data
lce058 942177408 767138876 175038532 82% /data
lce051 942177408 763342332 173835076 82% /data
lce006 942177408 768547872 173629536 82% /data
lce049 942177408 748540844 193636564 80% /data
lce003 942177408 746938000 195239408 80% /data
lce066 942177408 739517960 202659848 79% /data
lce050 942177408 743533620 198643788 79% /data
lce001 941470592 739839048 201631544 79% /data
lce072 942177408 734567284 207610124 78% /data
lce012 942177408 717733200 22444208 77% /data
lce042 942177408 707300428 234876880 76% /data
lce039 942177408 709465900 232711508 76% /data
lce057 942177408 701211320 240866088 75% /data
lce040 942177408 702213680 239887328 75% /data
lce038 942177408 705190252 236887156 75% /data
lce013 942177408 696030304 246147194 74% /data
lce048 942177408 690212776 251964632 73% /data
lce011 942177408 685931888 256439220 73% /data
lce070 942177408 676131664 266045744 72% /data
lce063 942177408 674301436 267875972 72% /data
lce046 942177408 670405820 271771888 72% /data
lce045 942177504 650505328 291672176 70% /data
lce005 942177408 655317240 286860168 70% /data
lce004 942177408 656571312 285606096 70% /data
lce007 942177408 635418544 306757864 68% /data
lce008 942177408 621850120 320327288 67% /data
lce035 942177408 617666972 324510436 66% /data
lce010 942177408 619418832 322758576 66% /data
lce009 942177408 602324316 339853092 64% /data
lce055 942177408 583933232 358244176 62% /data
lce017 942177408 572815436 369361972 61% /data
lce056 942177408 557974316 384203092 60% /data
lce016 942177408 546629304 395451104 59% /data
lce041 942177408 542430748 389746660 58% /data
lce018 942177408 537643044 404534364 58% /data
lce062 942177408 492680048 449497360 53% /data
lce060 942177408 447737072 494440336 48% /data
lce001:~$
sh 1$ bash 2$ bash 3-$ bash 4$* bash 5$ bash 6$ bash 7!$
```




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



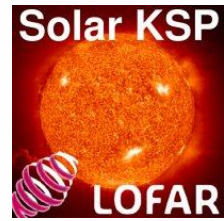
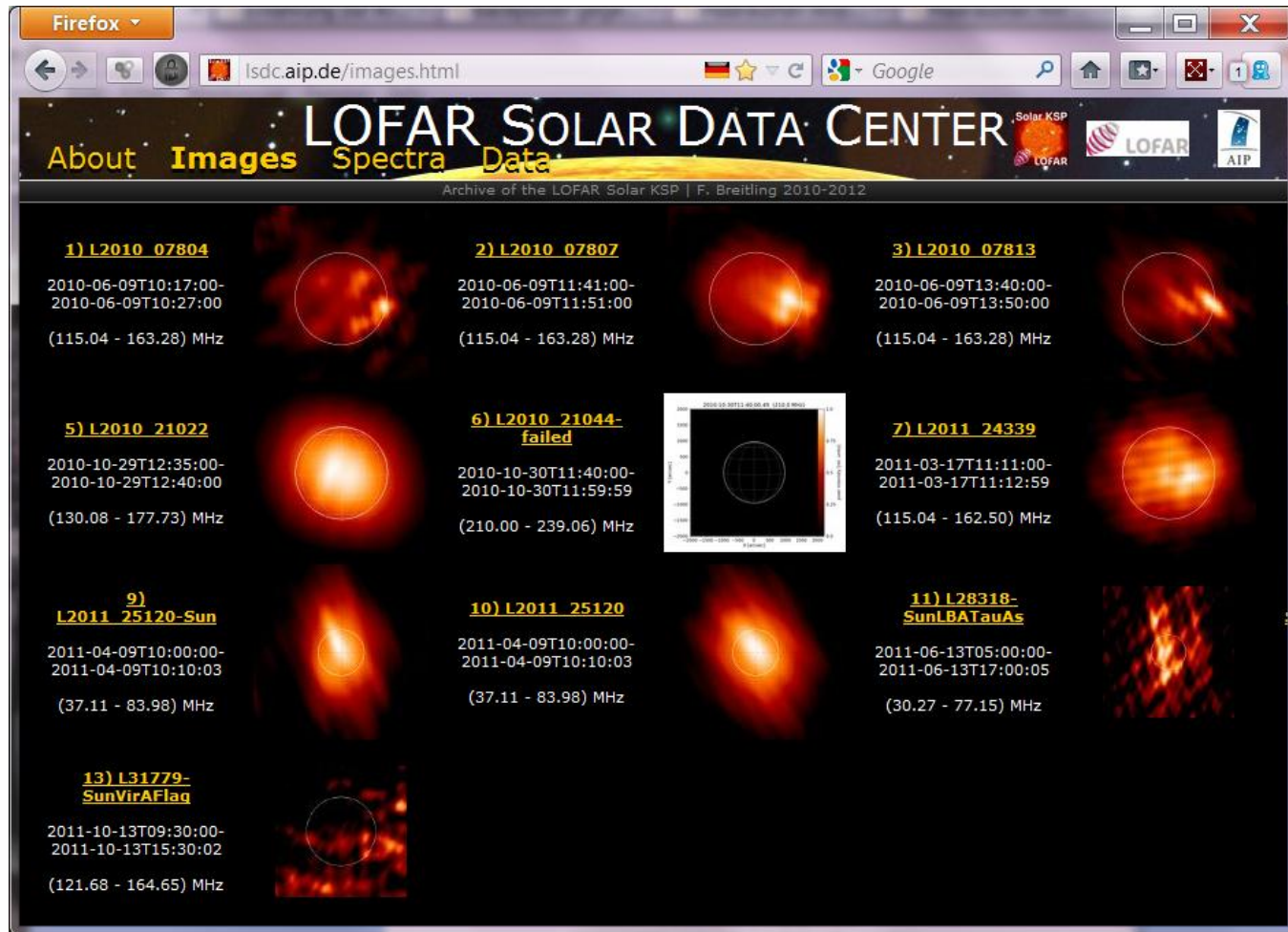
- New tools
 - fixtracking.py for tracking observations
 - data management (distribute data to cluster, transfer to data center)
 - splitms.py for measurement sets
 - fixarchive to update the data center
 - :

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





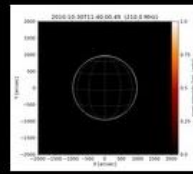








Firefox | lsdc.aip.de/images.html | Google

LOFAR SOLAR DATA CENTER

About **Images** Spectra Data

Archive of the LOFAR Solar KSP | F. Breitling 2010-2012

<p>1) L2010_07804</p> <p>2010-06-09T10:17:00- 2010-06-09T10:27:00</p> <p>(115.04 - 163.28) MHz</p> 	<p>2) L2010_07807</p> <p>2010-06-09T11:41:00- 2010-06-09T11:51:00</p> <p>(115.04 - 163.28) MHz</p> 	<p>3) L2010_07813</p> <p>2010-06-09T13:40:00- 2010-06-09T13:50:00</p> <p>(115.04 - 163.28) MHz</p> 
<p>5) L2010_21022</p> <p>2010-10-29T12:35:00- 2010-10-29T12:40:00</p> <p>(130.08 - 177.73) MHz</p> 	<p>6) L2010_21044- failed</p> <p>2010-10-30T11:40:00- 2010-10-30T11:59:59</p> <p>(210.00 - 239.06) MHz</p> 	<p>7) L2011_24339</p> <p>2011-03-17T11:11:00- 2011-03-17T11:12:59</p> <p>(115.04 - 162.50) MHz</p> 
<p>9) L2011_25120-Sun</p> <p>2011-04-09T10:00:00- 2011-04-09T10:10:03</p> <p>(37.11 - 83.98) MHz</p> 	<p>10) L2011_25120</p> <p>2011-04-09T10:00:00- 2011-04-09T10:10:03</p> <p>(37.11 - 83.98) MHz</p> 	<p>11) L28318- SunLBAuAs</p> <p>2011-06-13T05:00:00- 2011-06-13T17:00:05</p> <p>(30.27 - 77.15) MHz</p> 
<p>13) L31779- SunVirAFlaq</p> <p>2011-10-13T09:30:00- 2011-10-13T15:30:02</p> <p>(121.68 - 164.65) MHz</p> 		

Observation L31779 – Overview of all SBs / frequencies



Firefox | lsd.c.aip.de/images.html | Google

LOFAR SOLAR DATA CENTER

About Images Spectra Data

Archive of the LOFAR Solar KSP | F. Breitling 2010-2012

Observation: L31779-SunVirAFlag
 Subband: SB000-SB055 (121.68-164.65 MHz)
 UTC start - stop: 2011-10-13T09:30:00 - 15:30:02
 Phase center: +00:00:00.0,+00:00:00.0
 Frequency / wavelength: 121.68-164.65 MHz / 2.46-1.82 m
 Int. time x int. steps: 1.00663 s x 21460
 No. of antennas: 53
 Calibration date & files: 2012-05-31T09:25:24+0000

152.93 MHz (SB)

Time resolution: 1/1 1/60 1/600 1/3600

09:30:00 (#00001) [page 0001 of 2146] SB000 (121.68MHz)

observed corrected / [MP4] model psf spectrum

Time 09:30:00 (#00001) 09:30:01 (#00002) 09:30:02 (#00003) 09:30:03 (#00004) 09:30:04 (#00005) 09:30:05 (#00006) 09:30:06 (#00007) 09:30:07 (#00008) 09:30:08 (#00009) 09:30:09 (#00010)

SDO [MOV] [IMG]

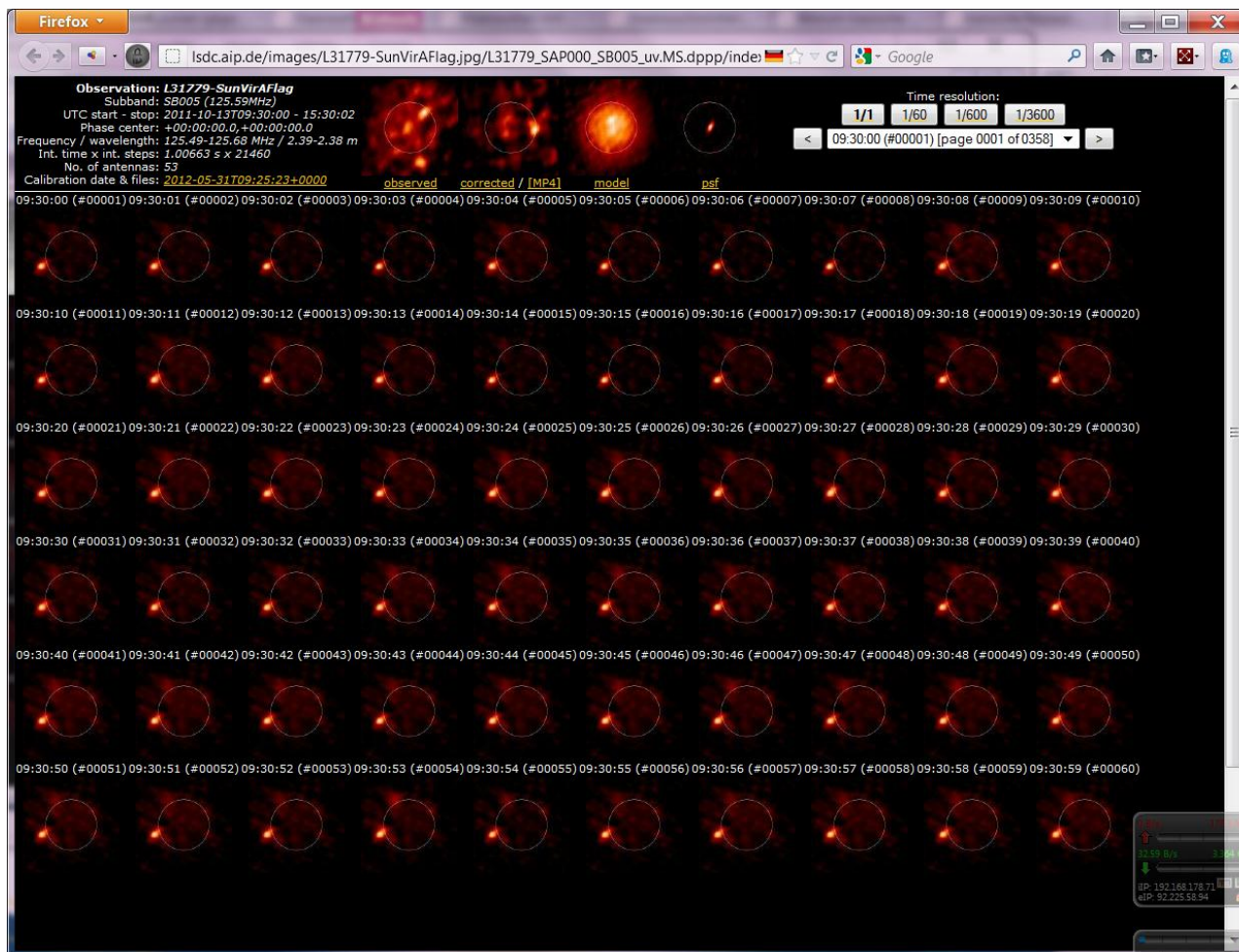
LOFAR 152.93 MHz (SB)

NRH [MOV] [IMG]

Time 09:30:00 (#00001) 09:30:01 (#00002) 09:30:02 (#00003) 09:30:03 (#00004) 09:30:04 (#00005) 09:30:05 (#00006) 09:30:06 (#00007) 09:30:07 (#00008) 09:30:08 (#00009) 09:30:09 (#00010)

121.68 MHz (SB000)

Observation L31779 – SB005 / 125MHz



Learned so far

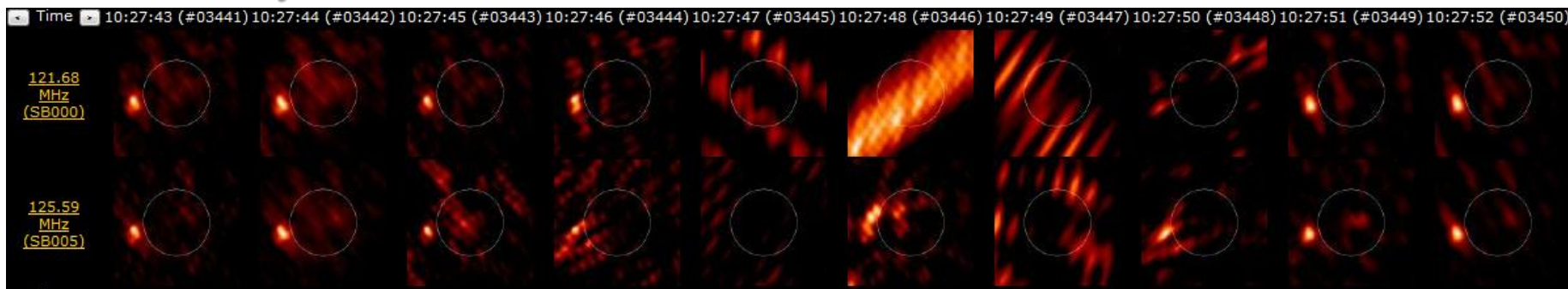


- self-calibration works
- calibration with calibrator sources works even better:
 - correct astrometry
 - correct fluxes
 - good agreement with Nancay
 - short solar bursts (<5s) are detected very well
 - solutions only valid for ± 10 minutes (need simultaneous calibrator beams)
- but sun needs strong 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)

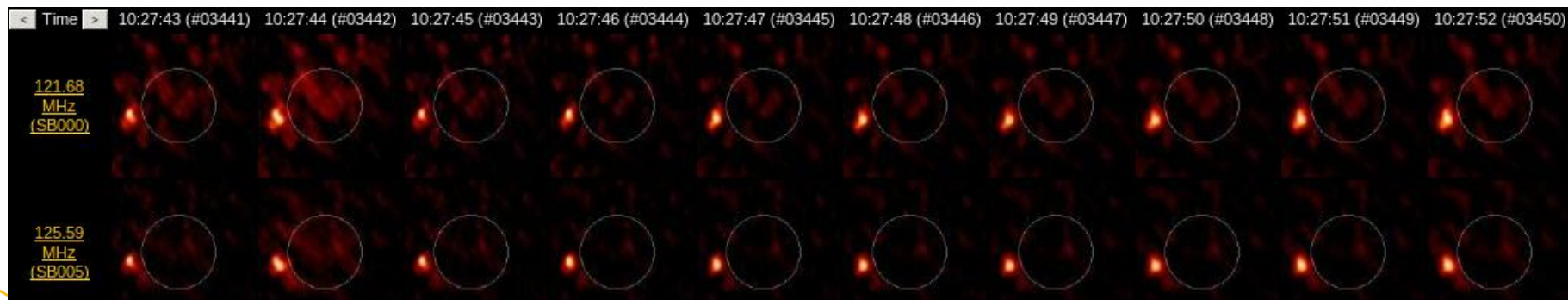
Learned: Calibration strategies for solar bursts



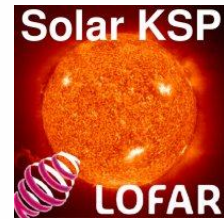
Problem: flagging removes bursts => we cannot flag the beam to the Sun
=> but many radio bursts outshine calibrators => bad calibration



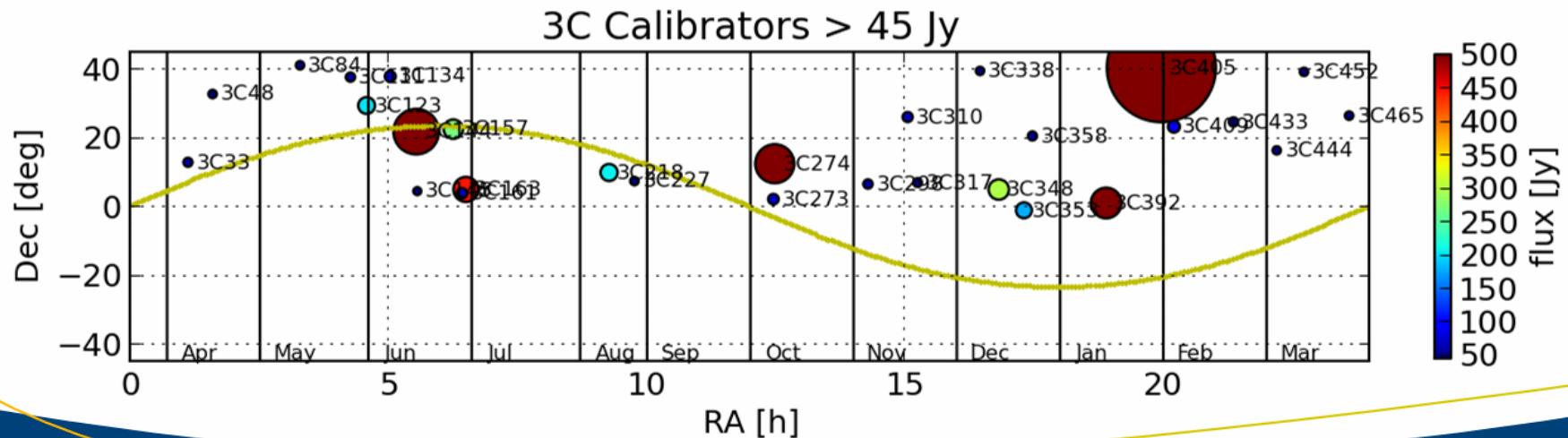
Solution: flagging calibrators only, then transfer solution to Sun beam



Learning in progress – 1st systematic solar calibrator study



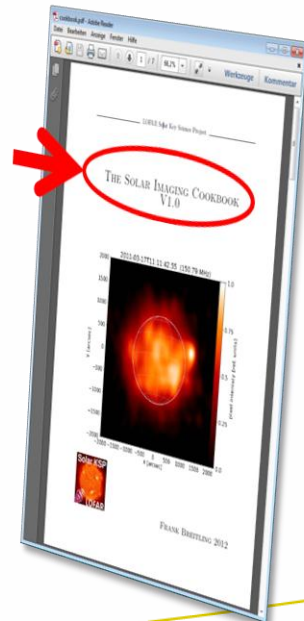
- ⇒ develop map / calendar of best LOFAR calibrators for the Sun
(started with Tau A in June 2012)
- Short (<10 min) observation in the morning
 - with strong
 - point like (<1arcmin) calibrators
 - over one year



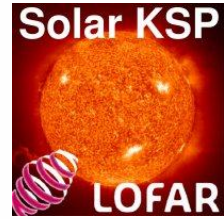
Version 3(.0) and later (to do)



- 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



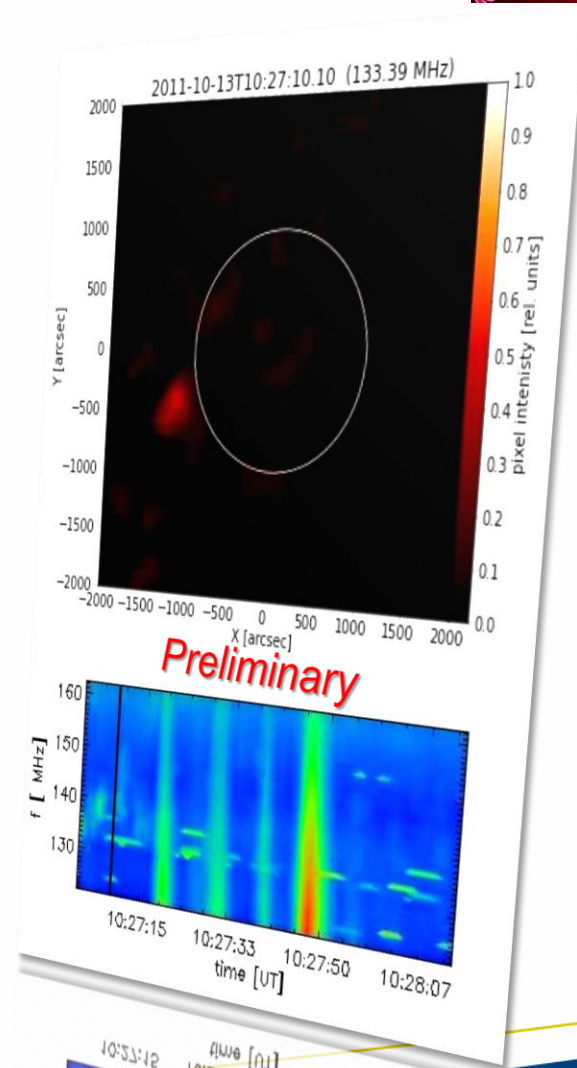
- + Version 2 of Solar Imaging Pipeline is working and produces
 - images and spectra
 - at all frequencies in low- and high-band
 - with a time resolution of 1 second
 - of the active Sun and in particular of radio bursts

⇒ 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

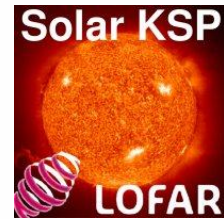


- Many radio bursts have been detected in the commissioning data
- These preliminary results are currently studied in detail and will be presented at future meetings
- The data will become available through the Data Center
- An example is show to the right

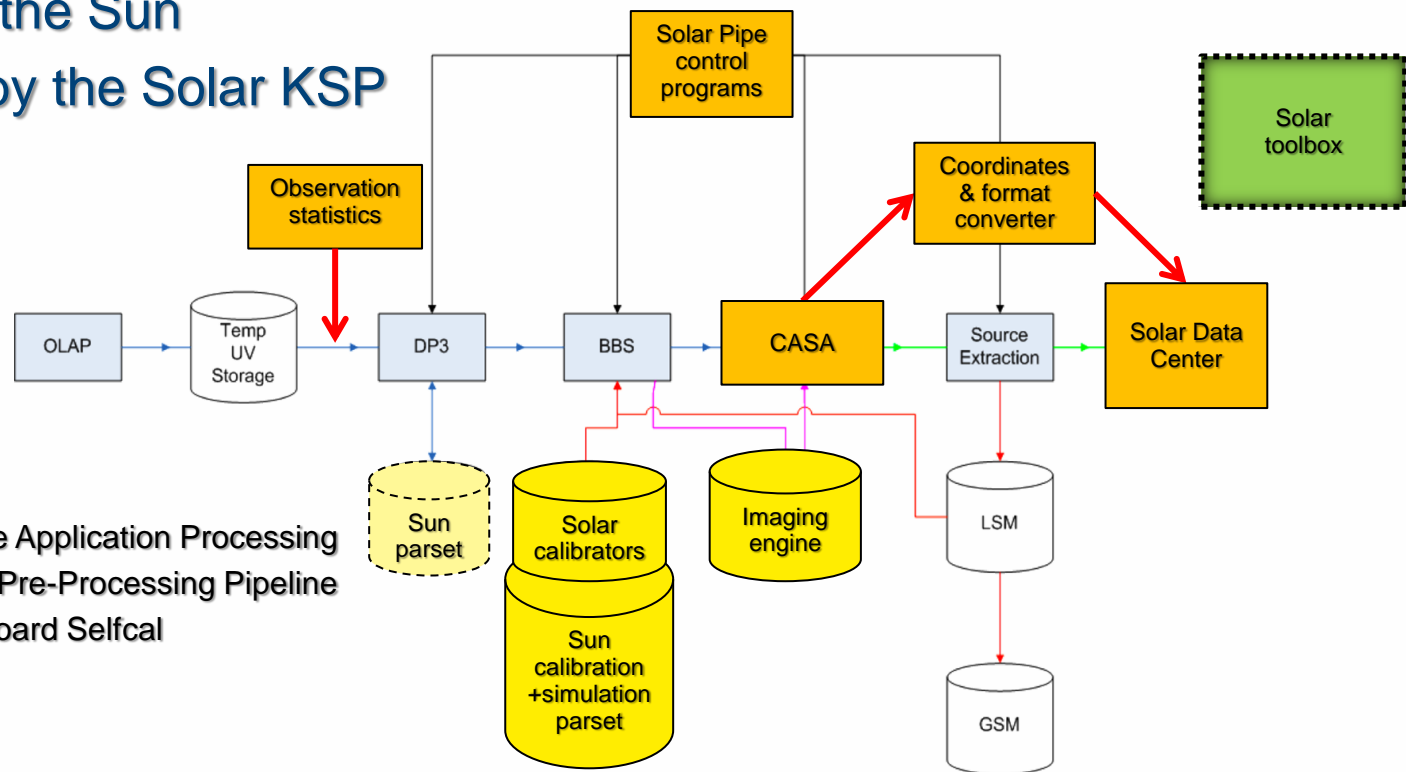


Thanks for your attention!

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

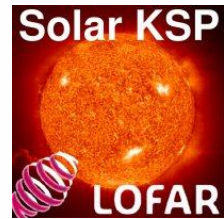
- OLAP: Online Application Processing
- DP³: Default Pre-Processing Pipeline
- BBS: BlackBoard Selfcal
- CImager

- 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

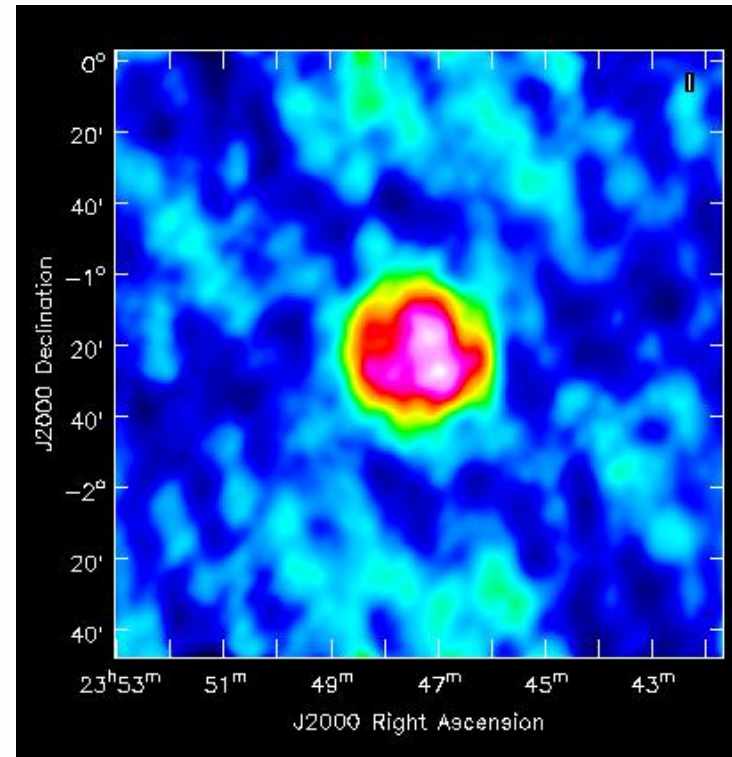
```
# (Name, Type, Patch, Ra, Dec, l, Q, U, V, ReferenceFrequency='7.38000e+07', SpectralIndex='[]', MajorAxis,  
MinorAxis, Orientation) = format  
# The above line defines the field order and is required.
```

```
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

