Tutorial:
Direction-Dependent Calibration
Part 1

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Introduction

- Direction-dependent effects in LOFAR data are primarily caused by:
  - The ionosphere
    - Mostly phase effects (vary quickly in time)
  - The LOFAR beam
    - Mostly amplitude effects (vary slowly in time)
- Direction-dependent calibration attempts to correct for these effects

Factor

- Factor does direction-dependent calibration and imaging (HBA only)
  - Based on the facet-calibration scheme of van Weeren et al. (2016)
- Uses LOFAR pipeline framework as backend:
  - Allows distribution over cluster nodes
  - Allows resuming of interrupted jobs (due to node failure, etc.)
- Available from GitHub at https://github.com/lofar-astron/factor
- Relatively modest resources required: 6 CPUs, 32 GB memory, 1 TB of disk space

Factor Overview

- Divide field into facets based on bright direction-dependent calibrators
- Cycle over facets:
  - Self calibrate the calibrator sources (`facetselfcal`)
  - Improve the subtraction with new model and calibration (`facetsub`)
- Image the facets (`facetimage`)
- Make a mosaic of all facets and correct for the primary beam attenuation (`fieldmosaic`)

Factor Overview

- Divide fiel … ent calibrator…
- Cycle ove…
  - Self ca…)
  - Improv… n (`face…`
- Image the…
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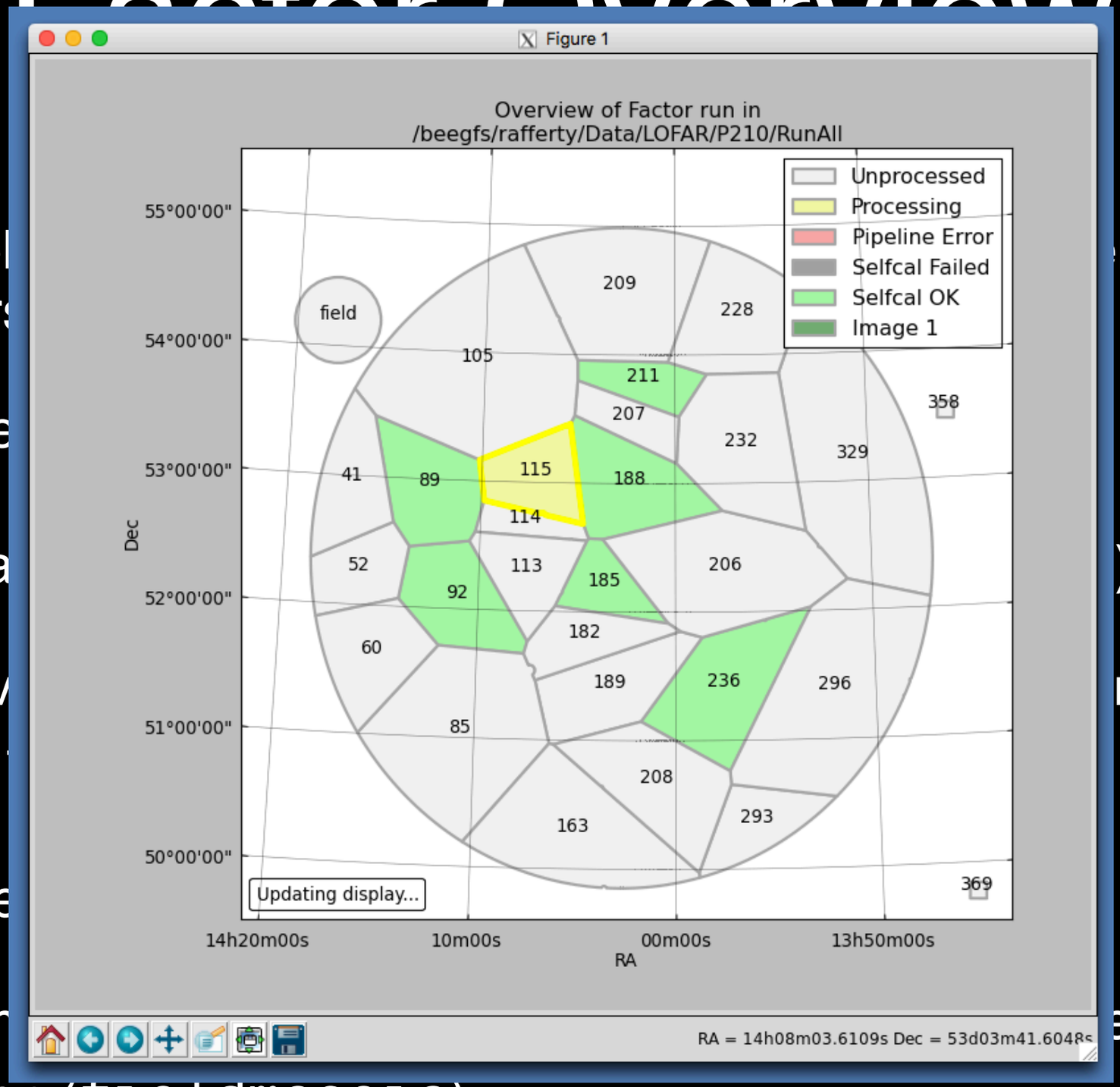

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Data Preparation

- Data should first be processed through Prefactor (https://github.com/lofar-astron/prefactor)
  - Input MS files (uv data) consist of concatenated bands of 10 subbands each (= 2 MHz); typical observations will have 24 bands (= 48 MHz total)
- The initial-subtract Prefactor pipeline must be run to:
  - Image the field at medium and low resolution to make initial models of the sources
  - Subtract these models of the sources from the uv data

Input Data

- Collect input data in a single directory
- For this tutorial, the data are located on CEP3 in: **`/data/scratch/rafferty/Tutorial/Input_data`**

```
$ ls /data/scratch/rafferty/Tutorial/Input_data

L091539_SB244_uv_12A0F95E8t_127MHz.pre-cal.merge
L091539_SB244_uv_12A0F95E8t_127MHz.pre-cal.ms
…
```

sky model for 2-MHz band at 127 MHz

measurement set for 2-MHz band at 127 MHz

- Data are 40 subbands (= 8 MHz) of an 8-hour HBA observation of the Toothbrush relic
  - **A**veraged by Prefactor to 0.1 MHz per channel and 10 seconds per timeslot

The Factor Parset

- Make a directory in your area to hold the parset and Factor output:

```
$ mkdir /data/scratch/yourname/DDCal
```

- For this tutorial, copy the tutorial parset to the directory you made above:

```
$ cd /data/scratch/yourname/DDCal
$ cp /data009/scratch/rafferty/Tutorial/factor.parset .
```

- Edit your copy of the parset:

```
$ emacs /data/scratch/yourname/DDCal/factor.parset
```

  - and change the path of `dir_working` to your new directory:

```
[global]
dir_working = /data/scratch/yourname/DDCal/Factor_output
```

Starting Factor

- Run Factor in a screen with the parset you made:

```
$ cd /data/scratch/yourname/DDCal
$ screen
[Hit ENTER]
$ source ~rafferty/init_factor
$ runfactor -v factor.parset
```

initializes your CEP3 environment for Factor

= use verbose mode

- Factor will copy the input data to its working directory and analyze the sky models to find suitable calibrators. It will then stop to allow you to check that these calibrators are OK

The Factor Parset

- The parset is divided into sections ([global], [calibration], etc.)
- See http://www.astron.nl/citt/facet-doc/parset.html for a full description of all the parameters
- An example parset that you can use as a basis for your reduction is available at https://github.com/lofar-astron/factor/tree/master/examples
- For most parameters, the default values will be fine

DDE Calibrators

- Factor will select calibrators automatically using the constraints specified in your parset. Typical values are:

```
[directions]
max_radius_deg = 5.0
flux_min_jy = 0.3
size_max_arcmin = 2.0
separation_max_arcmin = 7.5
```

- You can also specify a target area to ensure that a facet edge does not cross it. For this tutorial, we specify a region around the Toothbrush relic:

```
[directions]
target_ra = 6h03m26.884
target_dec = +42d14m44.52
target_radius_arcmin = 12
```

Directions File

- Factor records all DDE calibrators that it finds in a file called **`factor_directions.txt`** in the working directory (**`dir_working`** in the parset)

```
$ more Factor_output/factor_directions.txt


# name position atrous_do mscale_field_do cal_imsize solint_ph solint_amp dynamic_range region_selfcal region_facet
peel_skymodel outlier_source cal_size_deg cal_flux_mJy

# LSMTool history:
…

facet_patch_428 6h06m58.2663s,41d41m05.4364s empty empty 0 0 0 LD empty empty empty False 0.0630167432052 5164.902
facet_patch_465 6h05m32.0635s,41d32m35.2269s empty empty 0 0 0 LD empty empty empty False 0.119815831353  3983.052
facet_patch_219 6h14m55.3294s,42d51m52.9319s empty empty 0 0 0 LD empty empty empty False 0.0871275710808 3064.898
facet_patch_181 6h16m21.593s,41d30m51.753s   empty empty 0 0 0 LD empty empty empty False 0.0849659868304 1977.998
facet_patch_646 5h58m58.3629s,39d48m37.4551s empty empty 0 0 0 LD empty empty empty False 0.167902036169  1965.264
facet_patch_728 5h56m52.6856s,41d44m42.1425s empty empty 0 0 0 LD empty empty empty False 0.0915769725428 1920.065
facet_patch_758 5h55m43.7777s,42d01m48.5151s empty empty 0 0 0 LD empty empty empty False 0.080999745687  1492.178
facet_patch_314 6h10m45.2455s,42d21m02.7874s empty empty 0 0 0 LD empty empty empty False 0.0744974807579 1389.868
…
```

direction name

direction RA,Dec

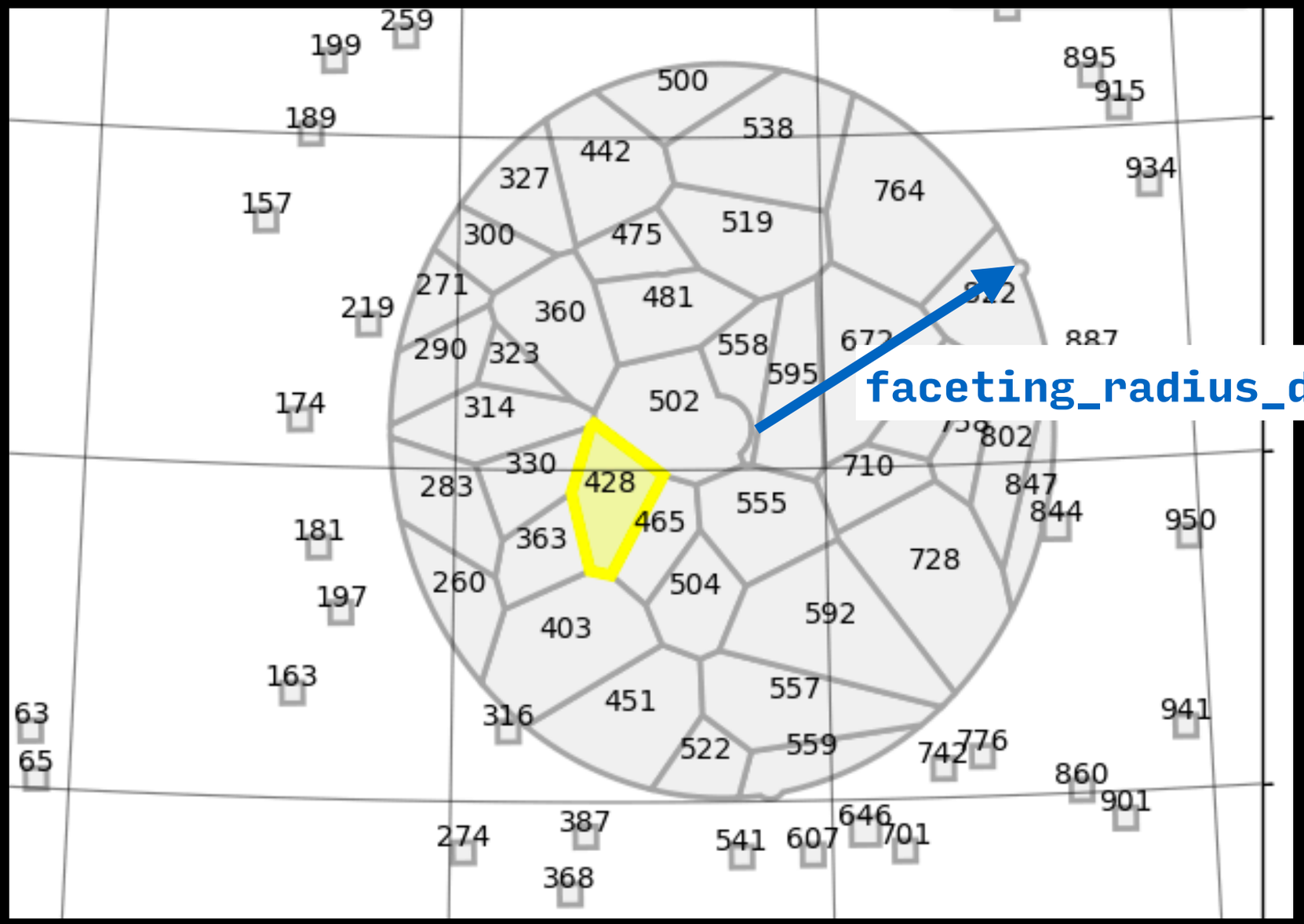
approximate flux density

Editing the Directions File

- Directions can be added or removed to improve facet layout
- Directions can be reordered (e.g., in order to process only a subset of directions); they are processed in order from the top of the directions file downward
- Other, advanced options can be activated on a per-direction basis (see documentation)
- Warning: after the first direction has completed for a run, changes to the facet layout will result in incorrect results!

Facets

- Factor will divide the field into facets (one for each DDE calibrator) inside of **`faceting_radius_deg`** (under the **`[directions]`** section of the parset). Outside of this radius, boxes are used instead (to speed up processing):



Check Calibrators and Facets

- Exit from the screen (CTRL-A CTRL-D) and load a wide-field image of the field in ds9 (e.g., one made by initial subtract Prefactor pipeline). There is one provided here:

```
$ ds9 /data009/scratch/rafferty/Tutorial/
L091539_SB244_uv_12A0F95E8t_133MHz.pre-cal.wsclean_high-image.fits
```

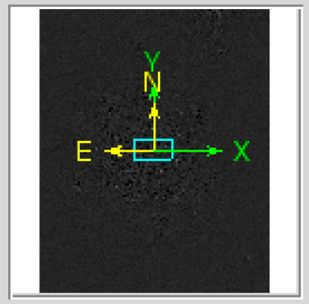
- Adjust the contrast and load (under the “Region” menu) **`calimages_ds9.reg`** and **`facets_ds9.reg`** from **`/data/scratch/yourname/DDCal/Factor_output/regions`**

- If you find any problems, change **`[directions]`** parameters in parset or edit **`factor_directions.txt`** (in the Factor working directory)

SAOImage ds9

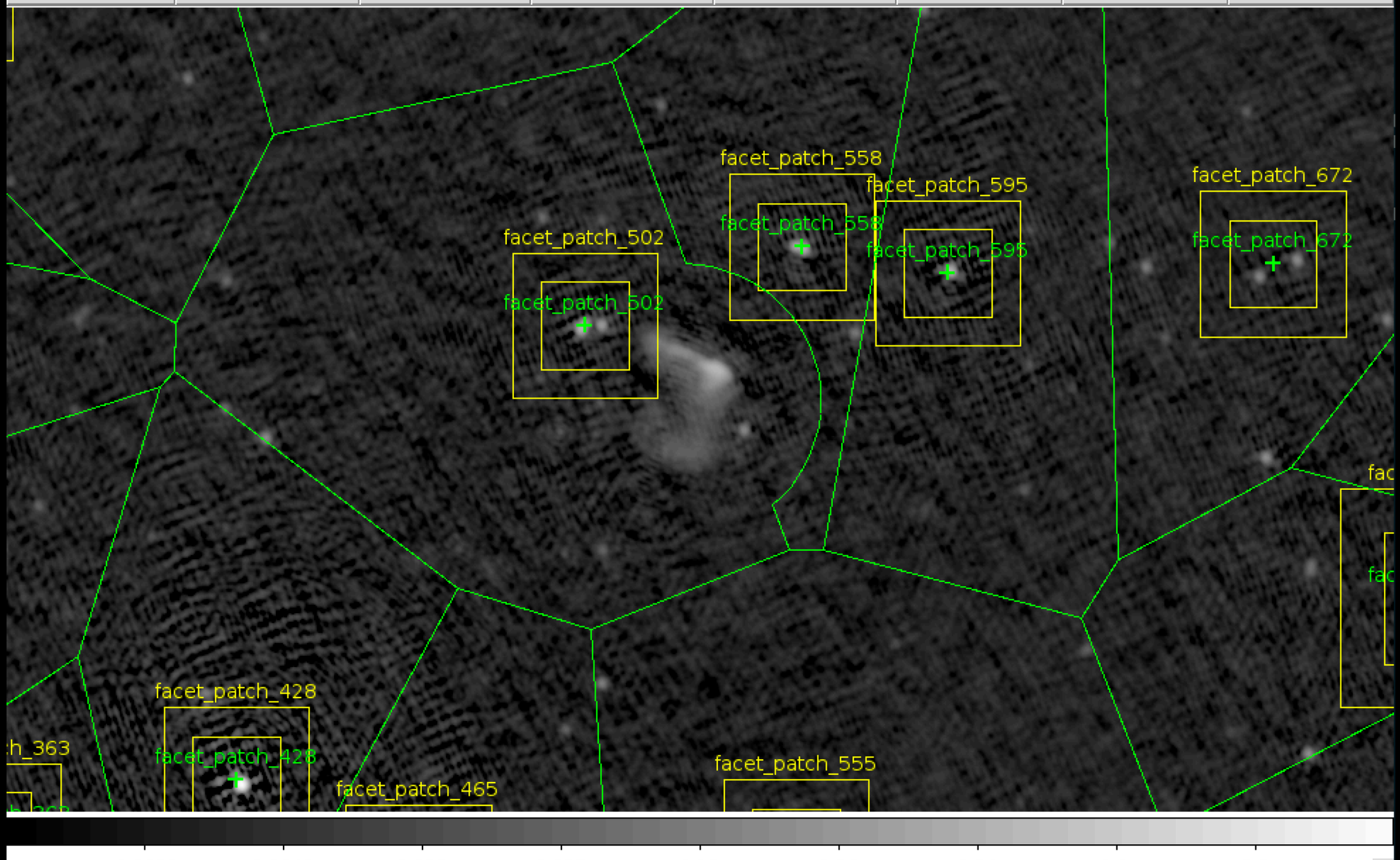
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help

File	L091539_SB244_uv_12A0F95E8t_133MHz.pre-cal.wsclean_high-image.fits			
Object	BEAM_0			
Value				
WCS				
Physical	X		Y	
Image	X		Y	
Frame 1	x	1		0 °



file edit view frame bin zoom scale color region wcs analysis help

zoom in | zoom out | zoom fit | zoom 1/4 | zoom 1/2 | zoom 1 | zoom 2 | zoom 4



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