

HERA_Imaging_Demo_Solutions

June 15, 2021

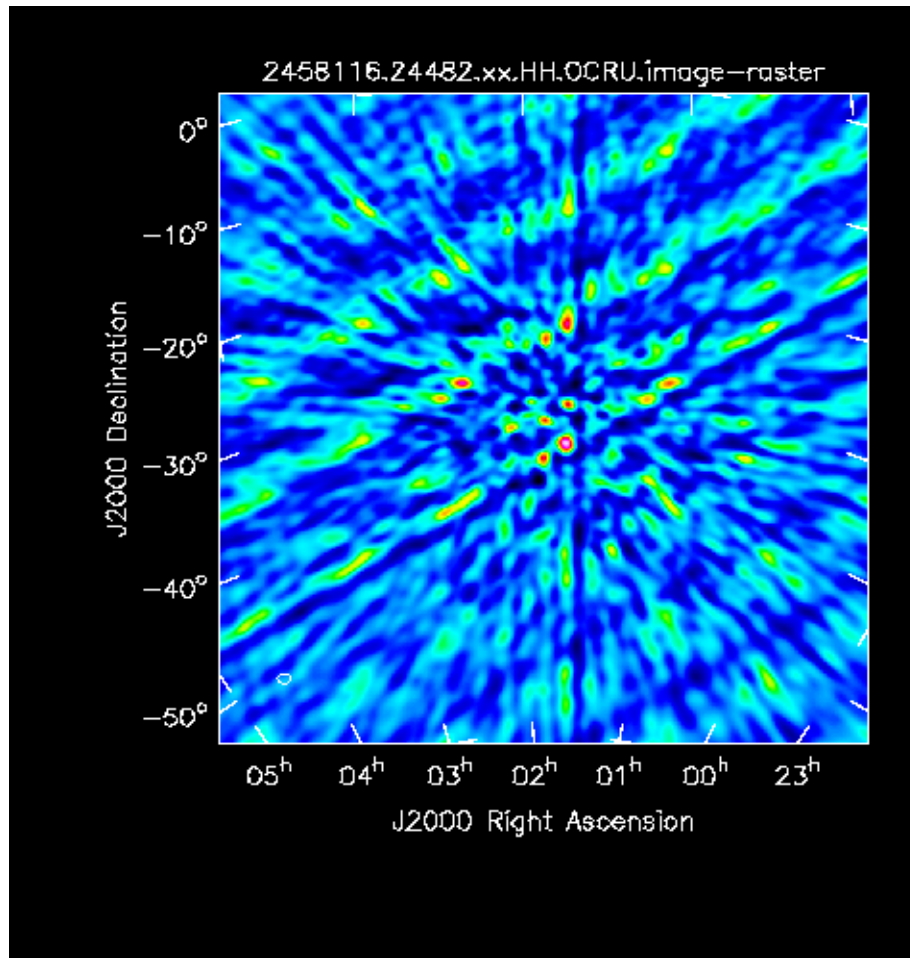
1 HERA Imaging Demo

CHAMP Bootcamp June 15, 2021

- This notebook will guide you along the general steps needed to image HERA data with the **CASA** software. Given you have introduced to **CASA**, it is assumed you have some familiarity with imaging and the CLEAN deconvolution algorithm.
- This notebook is *not* meant to be run interactively, and only contains instructions on how to use **CASA interactively from your command line**.
- Given that, all code in this notebook is meant to be run either from the bash shell (lines starting with `$`) or from a CASA session (lines starting with `>>>`)

2 A) : Imaging un-calibrated data

To begin, lets us have a look at the un-calibrated data.



3 B) Imaging calibrated data

4 1) Glimpse of the dataset

Use `data/zen.2458116.24482.xx.HH.uvOCR.ms`

You can enter a casa session by just typing into your command line

```
$ casa
```

which will enter you into a Python-looking session (and it is Python!) but it has some special pre-loaded modules that are specific to the CASA software.

One of these is the `listobs` function, which will give you a summary of the observation. Try running that on your measurement set and looking at your CASA logger for the output.

```

2021-06-15 12:46:07 INFO .obs::casa ##### Begin Task: listobs #####
2021-06-15 12:46:07 INFO .obs::casa listobs vis='ten.2458116.24482.xx.HH.OCR.ms', selectdata=True, spw='', field='', antenna='', uvrange='', timerange='', correlation='', scan='', i
2021-06-15 12:46:07 INFO .ms::summary =====
2021-06-15 12:46:07 INFO .s::summary+ MeasurementSet Name: /Users/Ridhina/Documents/teaching/CHAMP_Bootcamp/Lesson10_HERADataPartII/data/ten.2458116.24482.xx.HH.OCR.ms
2021-06-15 12:46:07 INFO .s::summary+
2021-06-15 12:46:07 INFO .s::summary+ Observation: Project:
2021-06-15 12:46:07 INFO .s::summary+ Observation: HERA
2021-06-15 12:46:07 INFO .Properties Computing scans and subscan properties...
2021-06-15 12:46:07 INFO .ms::summary+ Data records: 82680 Total elapsed time = 644.245 seconds
2021-06-15 12:46:07 INFO .s::summary+ Observed from 28-Dec-2017/17:52:32.8 to 28-Dec-2017/18:03:17.1 (TAI)
2021-06-15 12:46:07 INFO .ms::summary+
2021-06-15 12:46:07 INFO .s::summary+ ObservationID = 0 ArrayID = 0
2021-06-15 12:46:07 INFO .s::summary+ Date Timerange (TAI) Scan FlId FieldName nRows SpwIds Average Interval(s) ScanIntent
2021-06-15 12:46:07 INFO .ms::summary+ 28-Dec-2017/17:52:32.8 18:03:17.1 1 0 zenith 82680 [0] [10.7]
2021-06-15 12:46:07 INFO .ms::summary+ (nRows = Total number of rows per scan)
2021-06-15 12:46:07 INFO .s::summary+
2021-06-15 12:46:07 INFO .ms::summary+ Fields: 1
2021-06-15 12:46:07 INFO .s::summary+ ID Code Name RA Decl Epoch SrcId nRows
2021-06-15 12:46:07 INFO .ms::summary+ 0 26 zenith 01:52:23.612877 -30.48:16.87662 J2000 0 82680
2021-06-15 12:46:07 INFO .ms::summary+ Spectral Windows: (1 unique spectral windows and 1 unique polarization setups)
2021-06-15 12:46:07 INFO .s::summary+ SpwID Name #Chans Frame Ch0(MHz) ChanWid(kHz) TotBW(kHz) CtrFreq(MHz) Corrs
2021-06-15 12:46:07 INFO .s::summary+ 0 none 1024 TOPO 100.000 97.656 100000.0 149.9512 XX
2021-06-15 12:46:07 INFO .ms::summary+ Sources: 1
2021-06-15 12:46:07 INFO .s::summary+ ID Name SpwID RestFreq(MHz) SysVel(km/s)
2021-06-15 12:46:07 INFO .s::summary+ 0 zenith 0 0
2021-06-15 12:46:07 INFO .ms::summary+ Antennas: 52;
2021-06-15 12:46:07 INFO .s::summary+ ID Name Station Diam. Long. Lat. Offset from array center (m) ITRF Geocentric coordinates (m)
2021-06-15 12:46:07 INFO .s::summary+
2021-06-15 12:46:07 INFO .s::summary+ 0 1 HH0 14.0 m +021.25.39.0 -30.33.14.3 -53.6208 -142.1772 -477.4654 5109270.097595 2005130.056128 -3240024.087;
2021-06-15 12:46:07 INFO .s::summary+ 1 2 HH1 14.0 m +021.25.39.5 -30.33.14.2 -40.0288 -139.4090 -472.8806 5109270.117692 2005144.663971 -3240024.034;
2021-06-15 12:46:07 INFO .s::summary+ 2 3 HH2 14.0 m +021.25.40.0 -30.33.14.1 -26.4368 -136.6408 -468.2958 5109270.137760 2005159.271813 -3240023.981;
2021-06-15 12:46:07 INFO .s::summary+ 11 12 HH11 14.0 m +021.25.38.6 -30.33.13.9 -62.7736 -131.1444 -480.2674 5109276.415287 2005122.703911 -3240013.162;
2021-06-15 12:46:07 INFO .s::summary+ 12 13 HH12 14.0 m +021.25.39.2 -30.33.13.8 -49.1628 -128.3743 -475.7396 5109276.383819 2005137.311754 -3240013.079;
2021-06-15 12:46:07 INFO .s::summary+ 13 14 HH13 14.0 m +021.25.39.7 -30.33.13.7 -35.5551 -125.6044 -471.2022 5109276.360919 2005151.919597 -3240013.000;
2021-06-15 12:46:07 INFO .s::summary+ 14 15 HH14 14.0 m +021.25.40.2 -30.33.13.6 -22.0102 -122.8412 -466.4751 5109276.509920 2005166.527437 -3240013.024;
2021-06-15 12:46:07 INFO .s::summary+ 23 24 HH23 14.0 m +021.25.38.3 -30.33.13.6 -71.9315 -120.1022 -483.0603 5109282.746658 2005115.391655 -3240002.234;
2021-06-15 12:46:07 INFO .s::summary+ 24 25 HH24 14.0 m +021.25.38.8 -30.33.13.5 -58.3489 -117.3350 -478.4470 5109282.792573 2005129.959497 -3240002.197;
2021-06-15 12:46:07 INFO .s::summary+ 25 26 HH25 14.0 m +021.25.39.3 -30.33.13.4 -44.7569 -114.5669 -473.8622 5109282.812649 2005144.567339 -3240002.144;
2021-06-15 12:46:07 INFO .s::summary+ 26 27 HH26 14.0 m +021.25.39.8 -30.33.13.3 -31.1650 -111.7987 -469.2774 5109282.832737 2005159.175181 -3240002.091;
2021-06-15 12:46:07 INFO .s::summary+ 27 28 HH27 14.0 m +021.25.40.3 -30.33.13.2 -17.6076 -109.0341 -464.5882 5109282.947139 2005173.783021 -3240002.094;
2021-06-15 12:46:07 INFO .s::summary+ 36 37 HH36 14.0 m +021.25.38.0 -30.33.13.2 -81.0780 -109.0687 -485.8813 5109289.047098 2005107.994439 -3239991.299;
2021-06-15 12:46:07 INFO .s::summary+ 37 38 HH37 14.0 m +021.25.38.5 -30.33.13.1 -67.5174 -106.3039 -481.2016 5109289.153204 2005122.607279 -3239991.298;
2021-06-15 12:46:07 INFO .s::summary+ 38 39 HH38 14.0 m +021.25.39.0 -30.33.13.0 -53.9254 -103.5358 -476.6168 5109289.173315 2005137.215121 -3239991.245;
2021-06-15 12:46:07 INFO .s::summary+ 39 40 HH39 14.0 m +021.25.39.5 -30.33.12.9 -40.3272 -100.7670 -472.0509 5109289.176204 2005151.822963 -3239991.181;
2021-06-15 12:46:07 INFO .s::summary+ 40 41 HH40 14.0 m +021.25.40.0 -30.33.12.8 -26.7447 -97.9998 -467.4377 5109289.222047 2005166.430804 -3239991.144;
2021-06-15 12:46:07 INFO .s::summary+ 41 42 HH41 14.0 m +021.25.40.5 -30.33.12.8 -13.1371 -95.2299 -462.9003 5109289.199089 2005181.038646 -3239991.065;
2021-06-15 12:46:07 INFO .s::summary+ 50 51 HH50 14.0 m +021.25.37.6 -30.33.12.8 -90.2327 -98.0261 -488.6836 5109295.369815 2005100.647185 -3239980.365;
2021-06-15 12:46:07 INFO .s::summary+ 51 52 HH51 14.0 m +021.25.38.1 -30.33.12.8 -76.6470 -95.2586 -484.0798 5109295.407162 2005115.255026 -3239980.324;
2021-06-15 12:46:07 INFO .s::summary+ 52 53 HH52 14.0 m +021.25.38.6 -30.33.12.7 -63.0801 -92.4932 -479.4191 5109295.496060 2005129.862866 -3239980.311;
2021-06-15 12:46:07 INFO .s::summary+ 53 54 HH53 14.0 m +021.25.39.1 -30.33.12.6 -49.4819 -89.7244 -474.8533 5109295.498963 2005144.470708 -3239980.248;
2021-06-15 12:46:07 INFO .s::summary+ 54 55 HH54 14.0 m +021.25.39.7 -30.33.12.5 -35.8962 -86.9569 -470.2495 5109295.536224 2005159.078549 -3239980.206;
2021-06-15 12:46:07 INFO .s::summary+ 55 56 HH55 14.0 m +021.25.40.2 -30.33.12.4 -22.2980 -84.1881 -465.6836 5109295.539070 2005173.686390 -3239980.142;

```

Can you answer the following questions:

- When was this data observed?

28 Dec 2017 at 17:52:32.8

- How long did the observation last?

644.45 seconds

- How many antennas were used in taking this data?

52 antennas

- At which frequencies were the data observed?

Starting frequency = 100 MHz

Number of channels = 1024

Channel width = 97.656 kHz = 0.097656

Bandwidth = channel_with * number of channels

= 0.097656 * 1024

= 100 MHz

Observing frequency is between 100 to 200 MHz

- At what sky position was the array pointed during the observation?

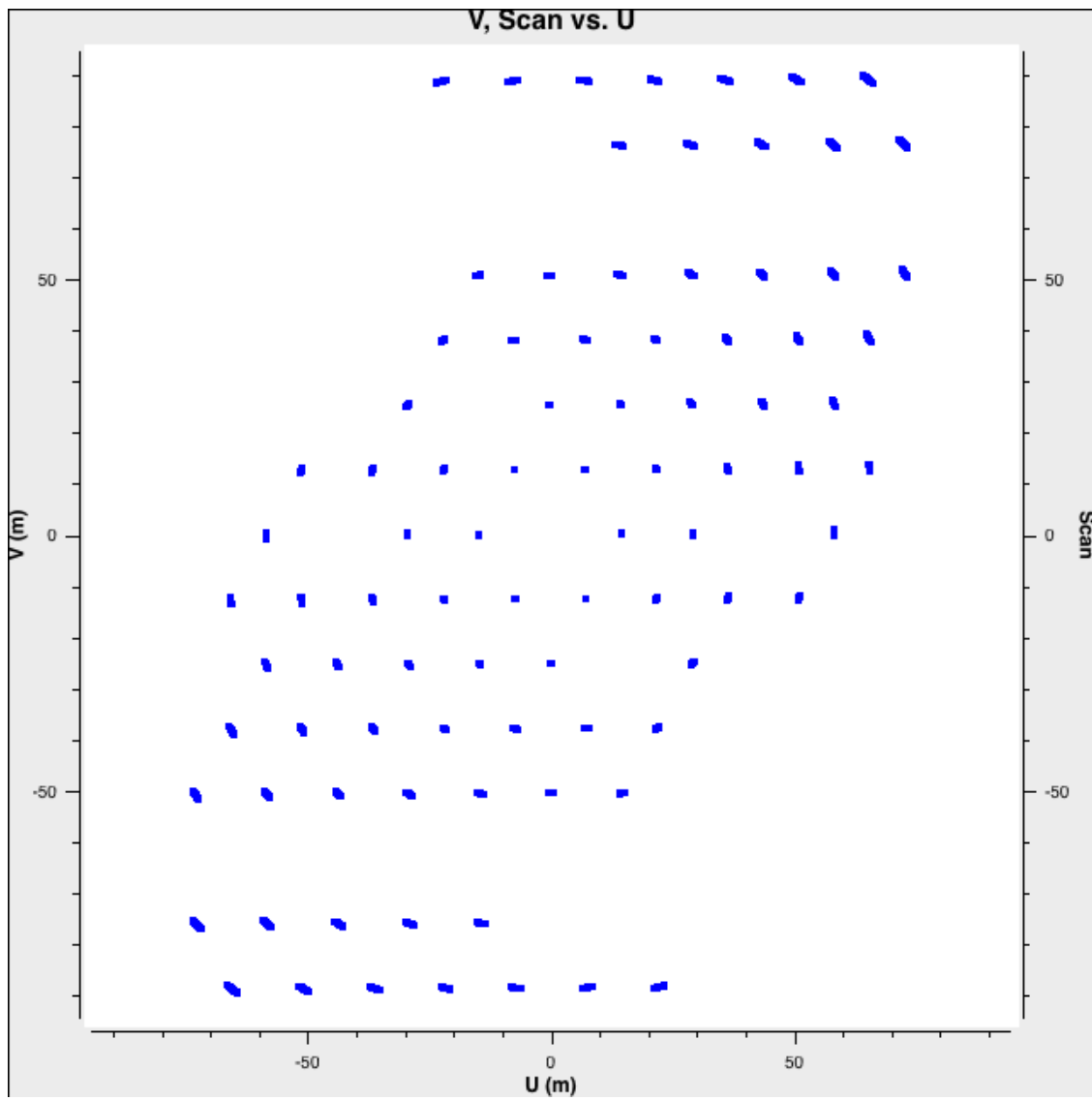
RA 01:52:32.8

DEC -30:48:16.87662

5 2) Plotting the uv-coverage

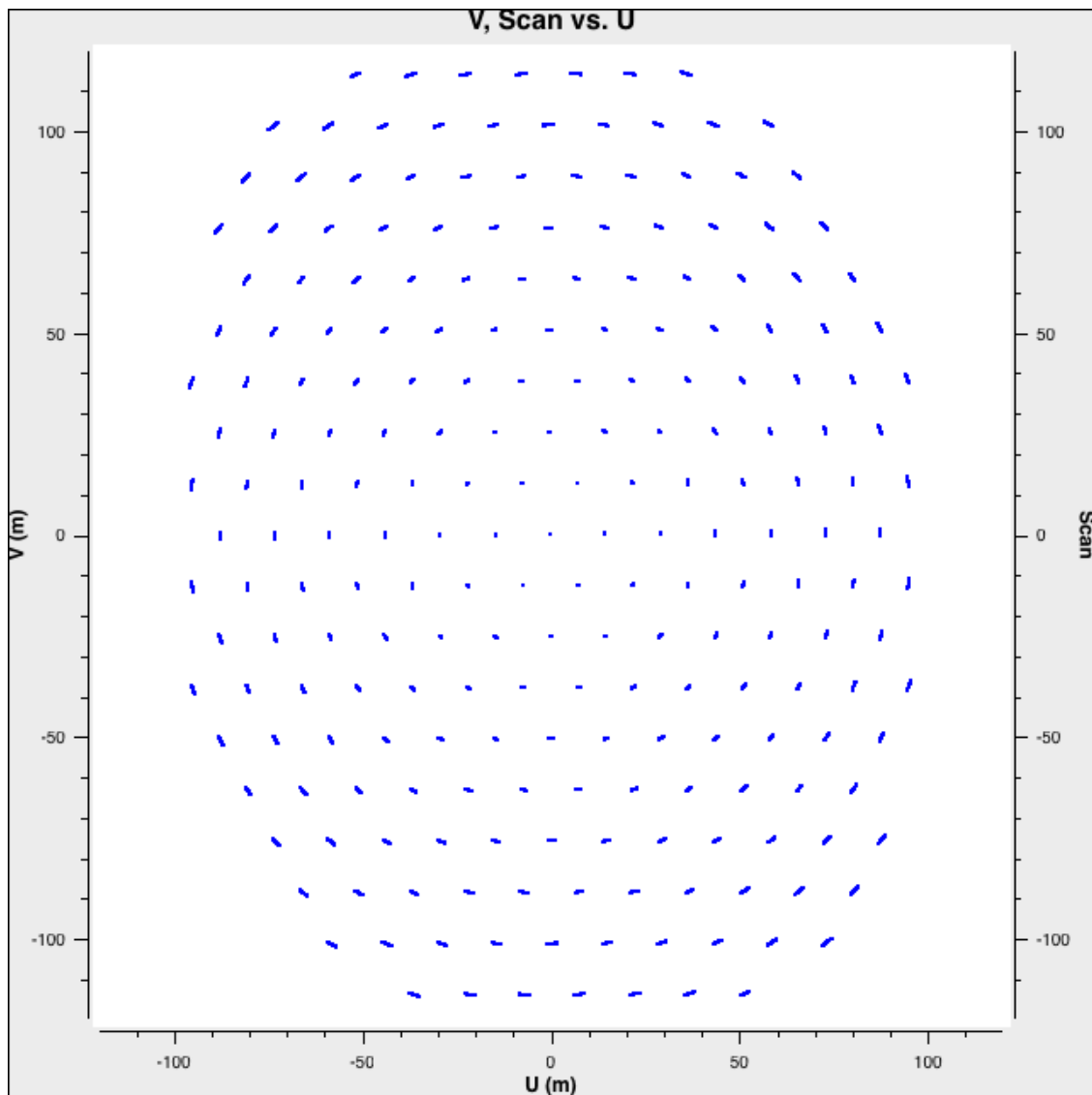
The uv-coverage represents the spatial frequencies the radio interferometer traces. The denser or compact the uv-coverage, the better is the image.

```
>>> plotms(vis, xaxis='U', yaxis='V', antenna='24', plotfile='uvcoverage_ant24.png')
```



- `antenna = ''` includes all the antennas.

```
>>> plotms(vis, xaxis='U', yaxis='V', antenna='', plotfile='uvcoverage.png')
```



- Does the uv-coverage change if you use single or subset of antennas?

Yes, with more antenna, the uv coverage is denser.

6 3) Make a “dirty” image of the data

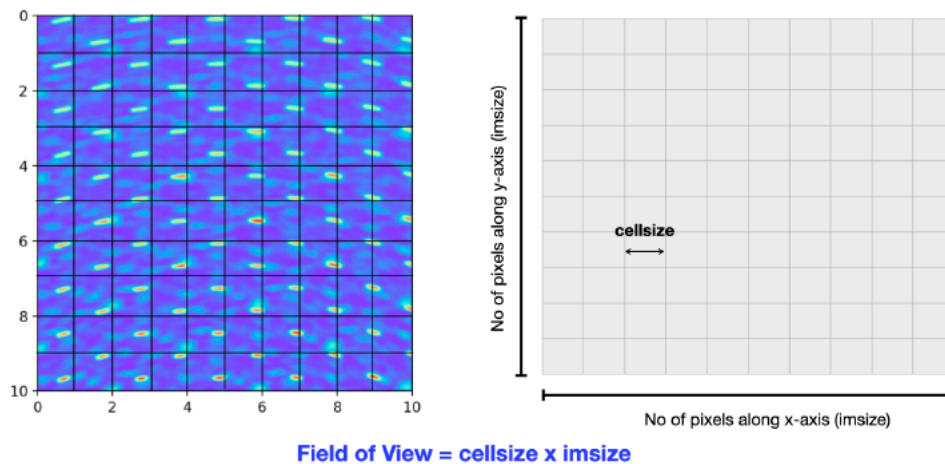
A dirty image is an image that has not been *deconvolved*, that is to say that the effects of incomplete uv-sampling distorts the image from the underlying “true” sky signal. That being the case, making and looking at dirty images is good way to get a “quick-look” at the data and diagnose possible problems.

To make a dirty image we will use the CASA `clean` function you used before, but this time we will set `niter=0`. This will mean that it will fourier transform the data to create an image, but it won’t attempt to deconvolve (or CLEAN) the image.

```
>>> tclean(visname, imagename, niter=0, cell='400arcsec', imsize=512,
spw='0:100~924', interactive=False)
```

Let's step through each of these parameters:

- `visname` is a string of the MS filename.
- `imagename` is a string for the output image. Something like `imagename = visname + 'nocal'` should work.
- `niter=0` means it **will not** attempt to deconvolve the data (which is what we want for now!)
- `cell='400arcsec'` this means that the image will have pixels that are 400 arcseconds in size.
- `imsize=512` this means that the image will contain 512 cells on each side, to make a 512 x 512 image.



- `spw='0:100~924'` means it will use the zeroth spectral window (only one exists anyways) and take channels 100 to 924. We ignore the first and last 100 channels because they are almost always subnominal.
- `interactive=False` this means we won't do an interactive deconvolution, but this doesn't matter because we won't be deconvolving anyways (hence the name "dirty" image).

Once that is completed, you can remove the mask0 to see the widefield image using

```
>>> ia.open(imagename)
>>> ia.maskhandler('delete', 'mask0')
>>> ia.close()
```

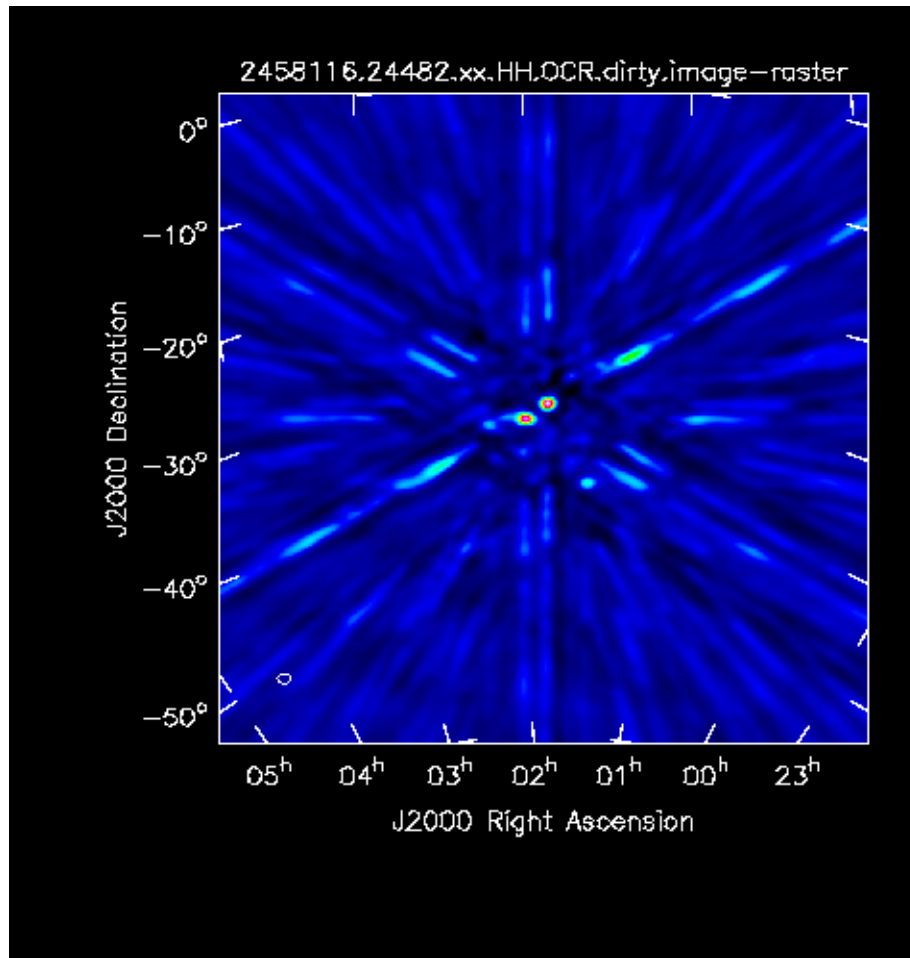
You can open the CASA viewer to look at the image via

```
>>> viewer
```

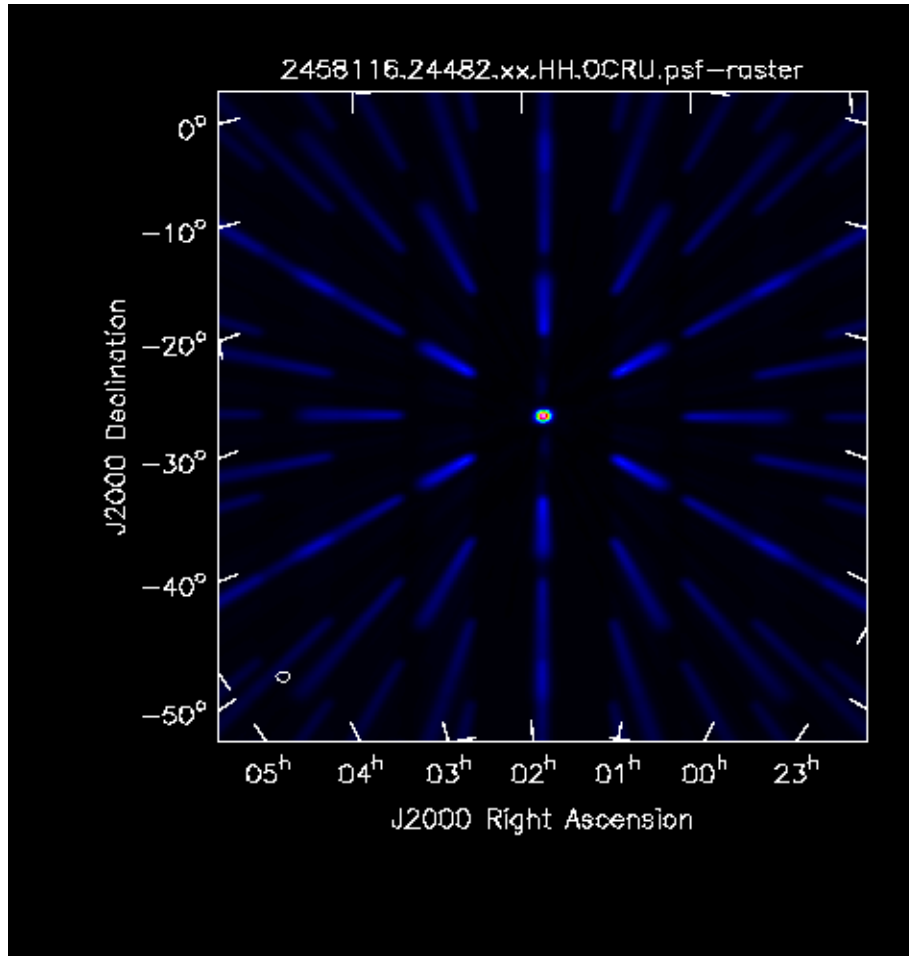
You can save the image to a .png using

```
>>> viewer(<imagename>, outfile=<output imagename>, gui=False)
```

- What does the image look like?



- How did the calibrated image change relative to the un-calibrated image? Did you expect this?
The sources in the images are more localised as compared to the uncalibrated one.
- Can you make any sense of why it might look the way it does? What does the PSF look like?



7 4) Use `clean` to deconvolve the image

Before we were making dirty images, which if you recall, means that we were not deconvolving the image. That is to say, point sources in the image are spreading their flux throughout the image in a way governed by the point spread function (PSF). Deconvolution is an attempt to correct for this. There are a few algorithms to do this, but we will stick to the CLEAN algorithm implemented in CASA's `clean` function.

We already did this interactively in the Interferometry lesson. If you recall, you perform an interactive clean by specifying the argument

```
>>> tclean(visname, imagename, niter=0, cell='400arcsec', imsize=512,
spw='0:100~924', interactive=True)
```

If you'd like to perform a non-interactive deconvolution (i.e. a one-shot attempt), you can do this by setting `interactive=False` and specifying parameters like `niter` and `threshold` to tell CLEAN when to stop the deconvolution.

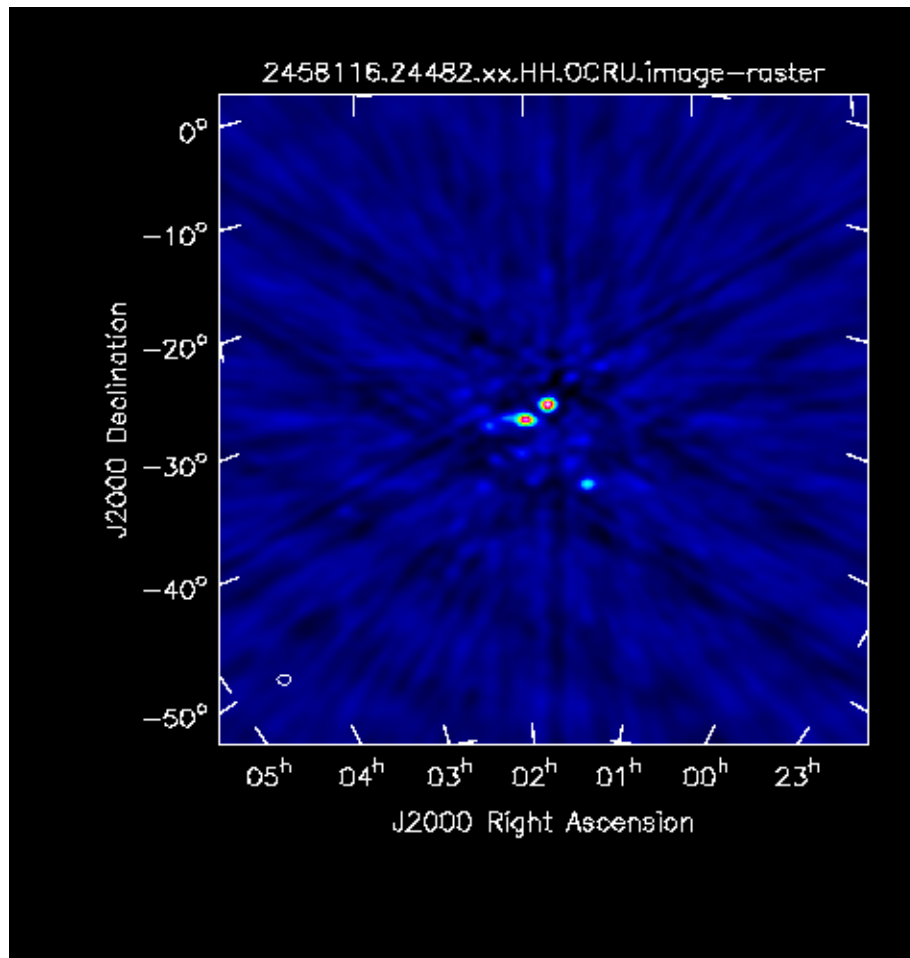
```
>>> tclean(visname, imagename, niter=100, cell='400arcsec', imsize=512,
spw='0:100~924')
```

You can also specify a `mask` to tell CLEAN where to put model point sources (similar to making

source boxes in an interactive CLEAN). The `mask` parameter takes the following form: `mask = circle([01h43m00s, -30d48m0s], 32000arcsec)` where the first two numbers tell where to center the circular mask in RA and Dec, and the third number is the size of the mask in arcseconds. **Note:** if you use a mask, don't use the RA Dec values shown here: figure out what the appropriate coordinates should be given your previous dirty image!

After making and inspecting the image, try to answer the following questions:

- How did the deconvolved/clean image change relative to the dirty image?



- How many sources can you see in your image?

3 sources

- What is the peak flux of the brightest source in the field?

18.6 Jy

- What is the rough RMS noise level of the image?

0.6 Jy

Congrats! You've made it to the end of the demo. By now you should have been able to make images from both un-calibrated and calibrated data! Hopefully this demonstrates the importance of calibration on all of the science that we do with the HERA instrument: good calibration is of utmost importance to yield science-quality data that we can then use to learn something about when and how the Epoch of Reionization took place.

[]: