

Sunspot Band6 Feathering for CASA 4.7

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1. Overview

This portion of the Sunspot Band6 CASA Guide for CASA 4.7 covers the combine process between the synthesized solar image and the full-sun image obtained with TP array. It begins where the calibration of the visibility data and single-dish data, image synthesis, and creating of the full-sun map are completed. If you do not complete them, at first,

- 1) Download the file of the un-calibrated data package ‘Sunspot_Band6_UncalibratedData.tgz’, do the calibration of the data, and create the images from the interferometric data and single-dish data, along the ‘Sunspot_Band6*_for_CASA_4.7’ tutorials.

or

- 2) Download the file of the calibrated data package ‘Sunspot_Band6_CalibratedData.tgz’, and synthesize the image from interferometric data along the ‘Sunspot_Band6_Imaging_for_CASA_4.7’ tutorial.

In case 1), we assume that you are working on the working directory ‘Sunspot_Band6_UncalibratedData’. On the other hand, when you started the tutorial from the calibrated package (case 2), we assume that the

working directory is 'Sunspot_Band6_CalibratedData.'

From next, we will show all commands for combining the images. If you do not want to cut-&-paste the commands, you can use the script as described in section 6 "Alternative way of Combining Images".

2. Obtaining the RA/Dec coordinate of the sun center at the reference time

Before starting the combination process on CASA, we need to know the RA/Dec coordinate of the sun center at the reference time that is used for the image synthesis¹, because the observing time of the TP-array is not the same as the reference time exactly. The Sun was moving on the RA/Dec coordinate frame during the gap between the times. To combine the synthesized image with the full-sun image obtained from the TP array, we need to shift the coordinate of the full-sun image based on the coordinate of the sun center at the reference time. Hence, we obtain the solar coordinate from the JPL's HORIZONS system².

The reference time in this tutorial is 19:49:00UT, December 18 2015. At the time, the RA/Dec coordinate of the sun center estimated by JPL's HORIZONS system is RA: 266.01898 degree, Dec: -23.38648 degree.

3. Preparation for Feathering task: The Single-Dish data

We start the process on CASA by defining some names of the data.

¹ see. 'Sunspot_Band6_Imaging_for_CASA_4.7'

² <http://ssd.jpl.nasa.gov/horizons.cgi>

Sunspot_Band6_Feathering_for_CASA_4.7

```
# In Casa
int_base = 'AR12470_B6AllSpw_I' # basename of the synthesized image
sd_img_base = 'uid___A002_Xae00c5_X2e6b.PM03.StkI.Spw3'
    # basename of the full-sun map
out_base = 'AR12470_B6AllSpe_I_Feather' # basename of the final products
```

We shift the coordinate of the full-sun map created from the single-dish data, based on the RA/Dec coordinate obtained in the previous section, as follows.

```
# In Casa
sun_ra = str(266.01898 * pi/180.)
sun_dec = str(-23.38648 * pi/180.)
imhead(imagename = sd_img_base+'.im', mode = 'put',
        hdkey = 'crval1', hdvalue = sun_ra)
imhead(imagename = sd_img_base+'.im', mode = 'put',
        hdkey = 'crval2', hdvalue = sun_dec)
```

The unit of the full-sun map is Kelvin. On the other hand, the unit of the synthesized image is Jy/beam. So, the conversion of the unit has to be done. In the tutorial, we convert the unit of the full-sun image to Jy/beam, using the following commands.

Sunspot_Band6_Feathering_for_CASA_4.7

```
# In Casa
crval4S= imhead(sd_img_base+'.im', mode='get',hdkey='crval4')
freqSD = crval4S.values()[0]
sbema = imhead(sd_img_base+'.im', mode='get',hdkey='beammajor')
sbemi = imhead(sd_img_base+'.im', mode='get',hdkey='beamminor')
sbmajor = sbema.values()[0]
sbminor = sbemi.values()[0]
convKJb = str(13.6 * (300./(freqSD/1.e9))**2. * (1./sbmajor)*(1./sbminor))

immath(imagename=sd_img_base+'.im', expr='IM0/'+convKJb,
        outfile=sd_img_base+'.jyb.im')

imhead(imagename = sd_img_base+'.jyb.im', mode = 'put',
        hdkey = 'crval3', hdvalue = ['I'])
imhead(imagename = sd_img_base+'.jyb.im', mode = 'put',
        hdkey = 'bunit', hdvalue = 'Jy/beam')
```

The result of the process is shown in Figure 1. A look of image is not changed, but you can find the changing of the values and unit from the Figure 1 in ‘Sunspot_Band6_SingleDish_for_CASA_4.7’ tutorial.

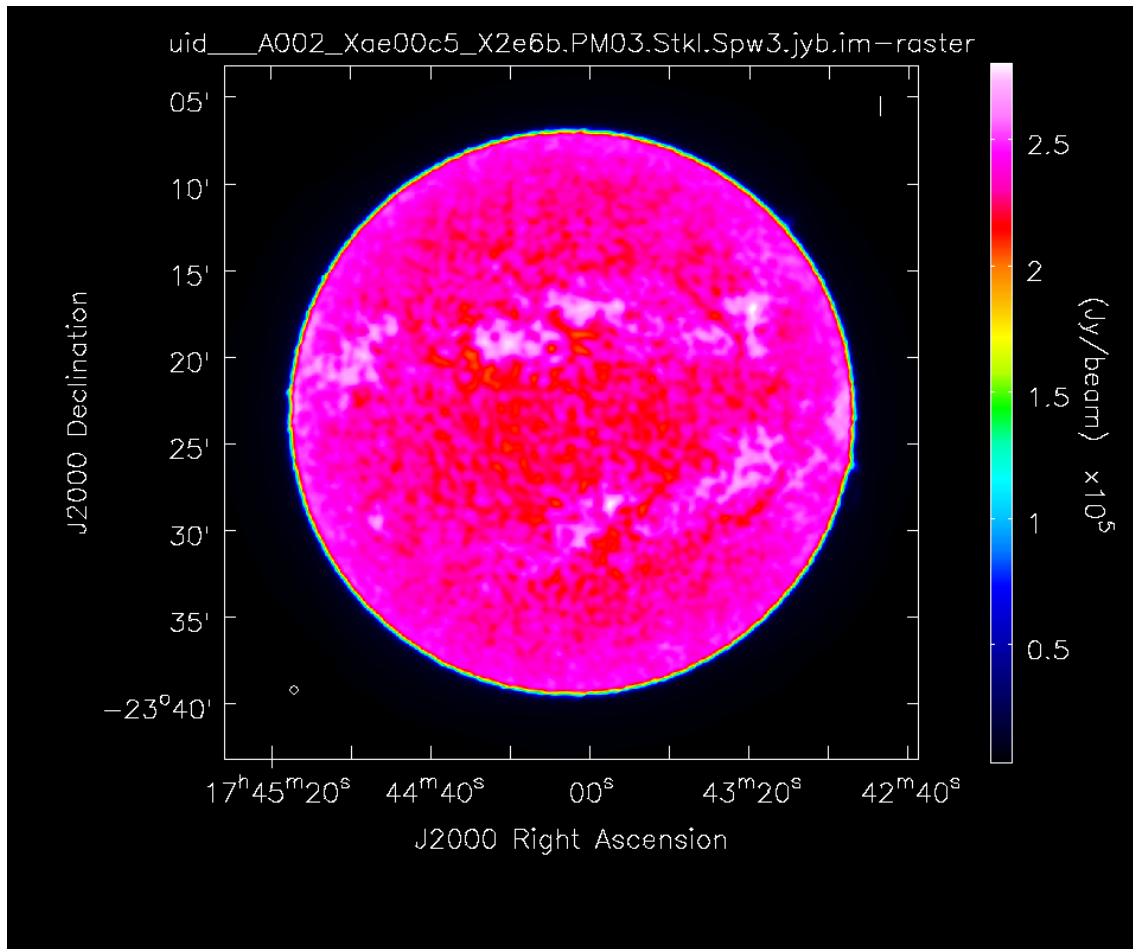


Figure 1. The full-sun map with 'Jy/beam' unit.

Then we do the re-gridding and trimming to fit the map area to that of the synthesized image. The area of the trimming is set to the same as the CLEAN box, in the tutorial.

```
# In Casa
#re-gridding of SD data
imregrid(imagename=sd_img_base+'.jyb.im', template=int_base+'.image',
         axes=[0, 1], output=sd_img_base+'.jyb.regrid')

# Trimming to exclude noisy edge regions in the TP image
imsubimage(imagename=sd_img_base+'.jyb.regrid',
           outfile=sd_img_base+'.jyb.regrid.subim', box='555,565,1505,1490')
```

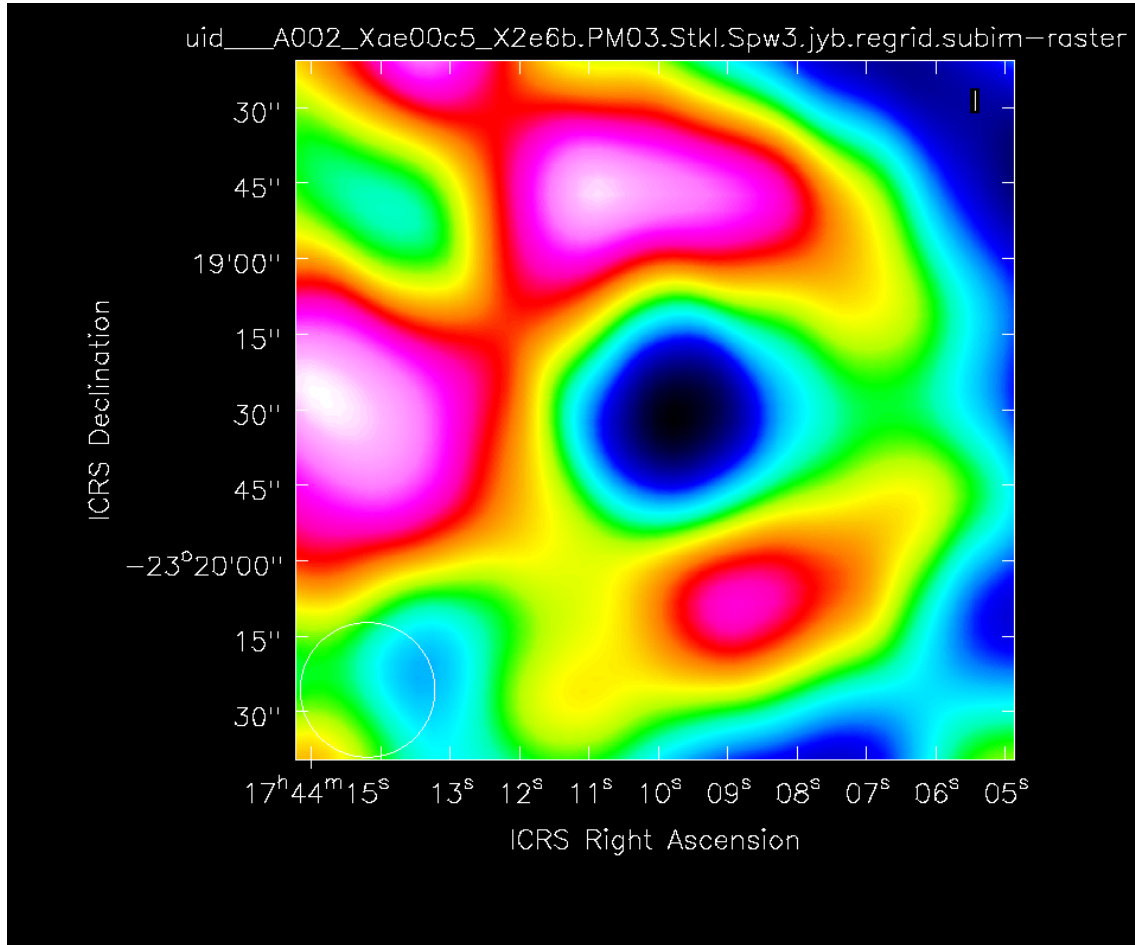


Figure 2. The trimmed map from the full-sun map.

As the final process of the preparation of the single-dish data, we multiply the trimmed image by the primary beam response, as follows.

```
# In Casa
imsubimage(imagename=int_base+'.flux',outfile=int_base+'.flux.subim',
           box='555,565,1505,1490')

immath(imagename=[sd_img_base+'.jyb.regrid.subim',int_base+'.flux.subim'],
       expr='IM0*IM1', outfile=sd_img_base+'.jyb.regrid.subim.depb')
```

4. Preparation for Feathering task: The Synthesized image

To fit the map area to that of the trimmed single-dish image, we do the trimming for the synthesized image.

```
# In Casa
imsubimage(imagename=int_base+'.image', outfile=int_base+'.image.subim',
            box='555,565,1505,1490')
```

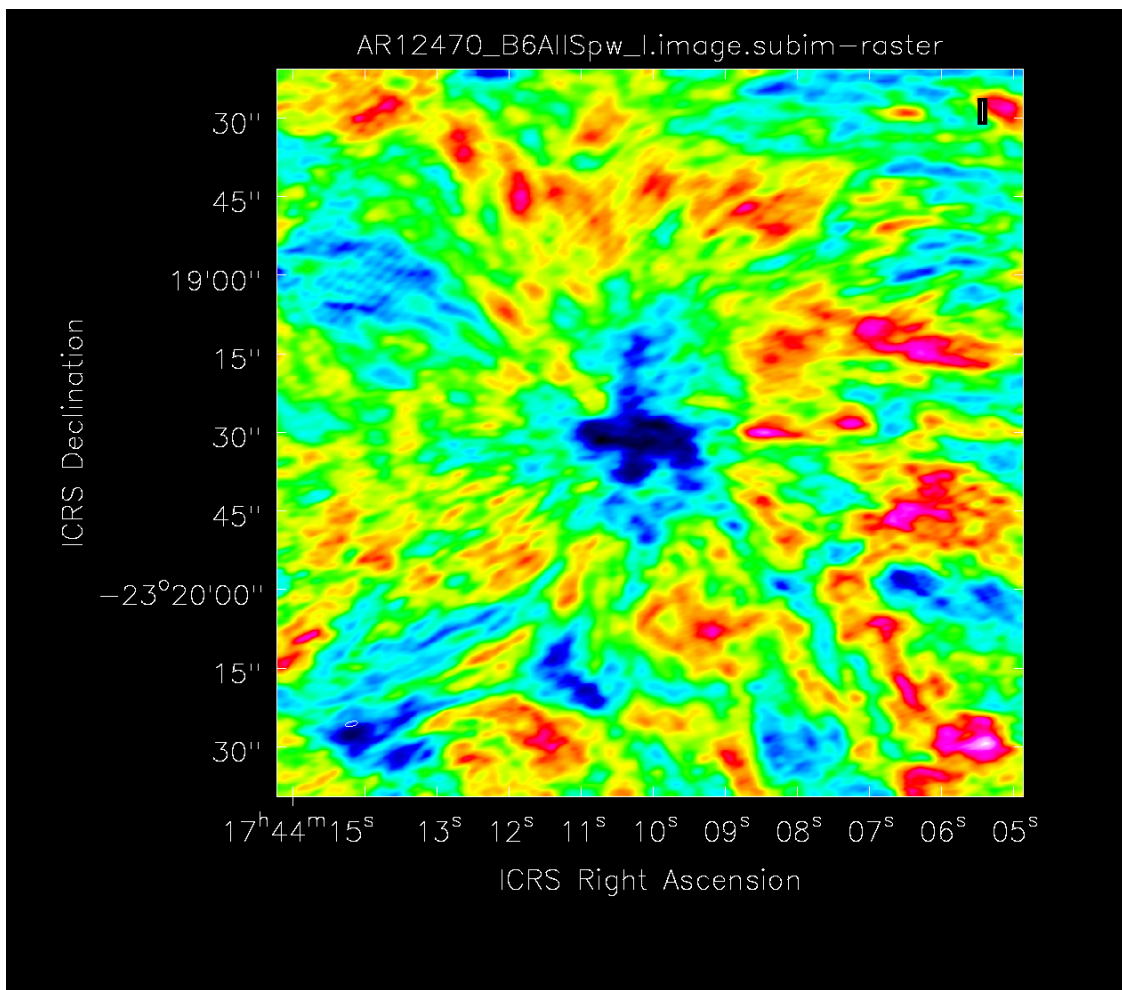


Figure 3. The trimmed map from the synthesized image.

5. Combining, primary beam correction, and creating of the FITS file.

The combining of the maps can be done using ‘feathering’ task, as the same as the non-solar data.

```
# In Casa  
feather(imagename=out_base+'.image', highres=int_base+'.image.subim',  
        lowres=sd_img_base+'.jyb.regrid.subim.dep'))
```

CAUTION: In this tutorial and the packages of the solar SV data released on [????/??/??](#), we use the default parameters of the task, as shown above. As a result, the averaged brightness temperature of the combined image is always larger a few % than the temperature brightness at the same position in the single-dish map, although the values have to be the same basically. It means that you need to tune the “sdfactor” parameter of the task for obtaining consistent images, before using combined images for your science. The detail of the parameter is described in Section 5.6 of “CASA User Reference & Cookbook Release 4.7.0”³.

After the feathering process, we do the primary beam correction, as follows.

```
# In Casa  
impbcor(imagename=out_base+'.image', pbimage=int_base+'.flux.subim',  
        outfile=out_base+'.pbcpr', mode='divide')
```

³ <https://casa.nrao.edu/docs/cookbook/index.html>

To convert the unit from Jy/beam to Kelvin, we use the following commands.

```
# In Casa
crval4I= imhead(int_base+'.image', mode='get',hdkey='crval4')
freq = crval4I.values()[0]
fbema = imhead(out_base+'.image', mode='get',hdkey='beammajor')
fbemi = imhead(out_base+'.image', mode='get',hdkey='beamminor')
fbmajor = fbema.values()[0]
fbminor = fbemi.values()[0]

convKJb2 = str(13.6 * (300./(freq/1.e9))**2. * (1./fbmajor)*(1./fbminor))

immath(imagename=out_base+'.pbcor',expr='IM0*'+convKJb2,
        outfile= out_base+'_K.pbcor')

imhead(imagename = out_base+'_K.pbcor',
        mode = 'put', hdkey = 'bunit', hdvalue = 'K')
```

Finally, we create the FITS file of the combined and primary corrected map.

```
# In Casa
exportfits(imagename=out_base+'_K.pbcor', fitsimage=out_base+'_K.fits')
```

The result of the combining is shown in Figure 4.

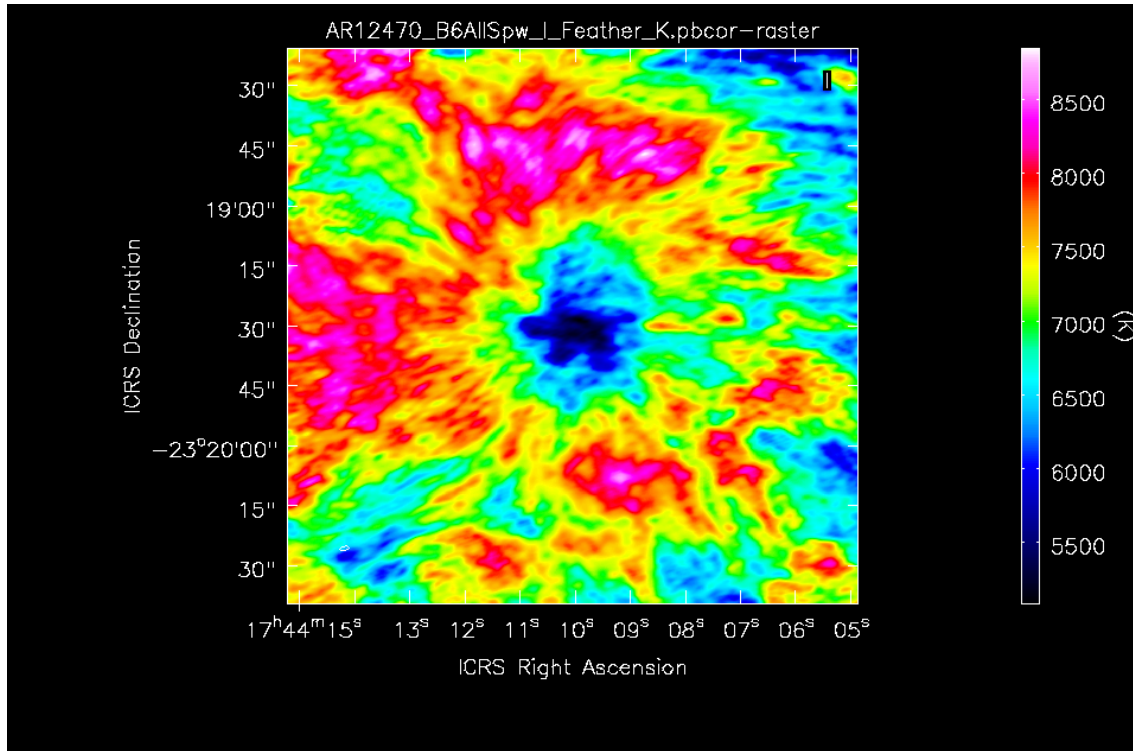


Figure 4. Combined image. It is the final product of the guide.

Note: The FITS file can be imported to the data-analysis environment based on SolarSoftWare (SSW) + IDL without any modification, but the coordinate system is the RA/Dec coordinate. You have to convert the coordinate from the RA/Dec coordinate system to the heliocentric coordinate system (X-cen/Y-cen) for the co-alignment with the other instrument's data.

6. Alternative way of Combining Images

Sunspot_Band6_Feathering_for_CASA_4.7

If you do not want to cut-&-paste all commands shown in above, you can use the script included in the file Sunspot_Band6_CalibratedData.tgz. The script can be executed as follows, after downloading the file.

```
# In a terminal outside CASA
tar -xvzf Sunspot_Band6_CalibratedData.tgz

cd Sunspot_Band6_CalibratedData

#Start CASA
casa

#In CASA
execfile("SunspotBand6Img.py")
execfile("SunspotBand6Cmb.py")
```

Or the script can be executed as follows, after downloading the file of uncalibrated data package 'Sunspot_Band6_UncalibratedData.tgz' and installing the Analysis Utilities package.

```
# In a terminal outside CASA
tar -xvzf Sunspot_Band6_UncalibratedData.tgz
cd Sunspot_Band6_UncalibratedData

#Start CASA
casa

#In CASA
execfile("SunRedUtil.py")
execfile("SunspotBand6Cal.py")
execfile("SunspotBand6SD.py")
execfile("SunspotBand6Img.py")
execfile("SunspotBand6Cmb.py")
```