NOEMA tutorials: IV. NGC 7027

by

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The datasets are not public as of Oct. 2018

⇒ We tampered with the datasets so that it's impossible to do quantitative science from them.

Scripts for this tutorixal are available in the following files

`pro/ngc7027-beginner.map`, `pro/ngc7027-beginner.class`, `pro/ngc7027-beginner.clic`, and `pro/ngc7027-selfcal.map`

The scripts assume that you use oct18 or a more recent version of `GILDAS`

IRAM Millimeter Interferometry Summer School
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Size of the problem: I. UV plane

From this slide on, please look into file pro/ngc7027-beginner.map

```
[imiss@reducv2 ngc7027]$ ls -lh lsb.uvt
-rw-r----- 1 imiss project 953M Sep 19 18:17 lsb.uvt
MAPPING> header lsb.uvt
File : lsb.uvt                                                    REAL*4
Size        Reference Pixel           Value                  Increment
     11617   2808.00000560259       97900.0000000000       2.00000011521782
     18078   0.00000000000000       0.00000000000000       1.00000000000000
Blanking value and tolerance      1.23455997E+34   0.0000000
Source name          NGC7027
Map unit             Jy
Axis type            UV-DATA      RANDOM
Coordinate system    EQUATORIAL          Velocity    LSR
Right Ascension   21:07:01.97000         Declination       42:14:10.7000
Lii         0.000000000000000            Bii       0.000000000000000
Equinox              2000.0000
Projection type      AZIMUTHAL           Angle     0.000000000000000
Axis 0     A0     21:07:01.97000         Axis 0     D0     42:14:10.7000
Baselines                0.0       0.0
Axis 1 Line Name     survey2             Rest Frequency   97900.00000000000
Resolution in Velocity   -6.1247368      in Frequency           2.0000894
Offset in Velocity        26.000000      Doppler Velocity       12.618164
Beam                    51.5                  0.00                  0.00
Tel: NOEMA           05:54:28.5   44:38:02.0 Alt.    2560.0 Diam    15.0
UV Data    Channels:   3870, Stokes: 1 None        Visibilities:        18078
Column             1 (Size 1) contains U
Column             2 (Size 1) contains V
Column             4 (Size 1) contains DATE
Column             5 (Size 1) contains TIME
Column             6 (Size 1) contains IANT
Column             7 (Size 1) contains JANT
Column             3 (Size 1) contains SCAN
```

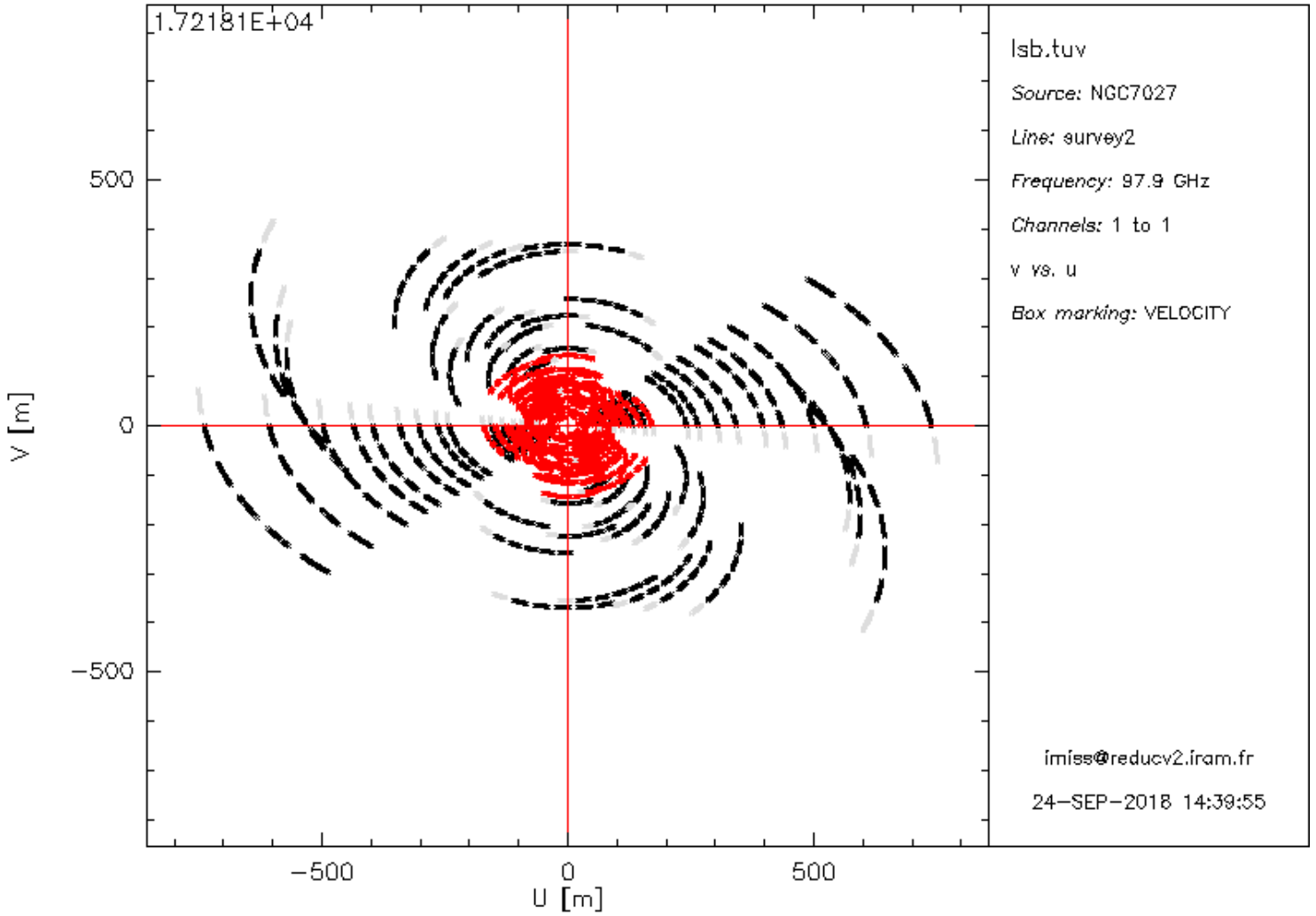
Size of the problem: II. Image plane

```
MAPPING> let name lsb
MAPPING> go setup
MAPPING> go setup
Input file: Interferometer (15m)  lsb.uvt

  Single field observation (18078 visibilities)

  Observed rest frequency       97.9 GHz
  Half power primary beam       51.5 arcsec
  Phase center RA and Dec       21:07:01.970 42:14:10.700
  Field of view / Largest Scale 51.5 x 51.5 arcsec

                               Recommended       Used
  Map size                     1024 x 1024     1024 x 1024 pixels
  Map cell                     0.17 x 0.17     0.17 x 0.17 arcsec
  Image Size                 171.4 x 171.4   171.4 x 171.4 arcsec

  Still to be imaged
  Still to be cleaned
```

$\Rightarrow$ One data cube will weight $\sim$ 16 GB!

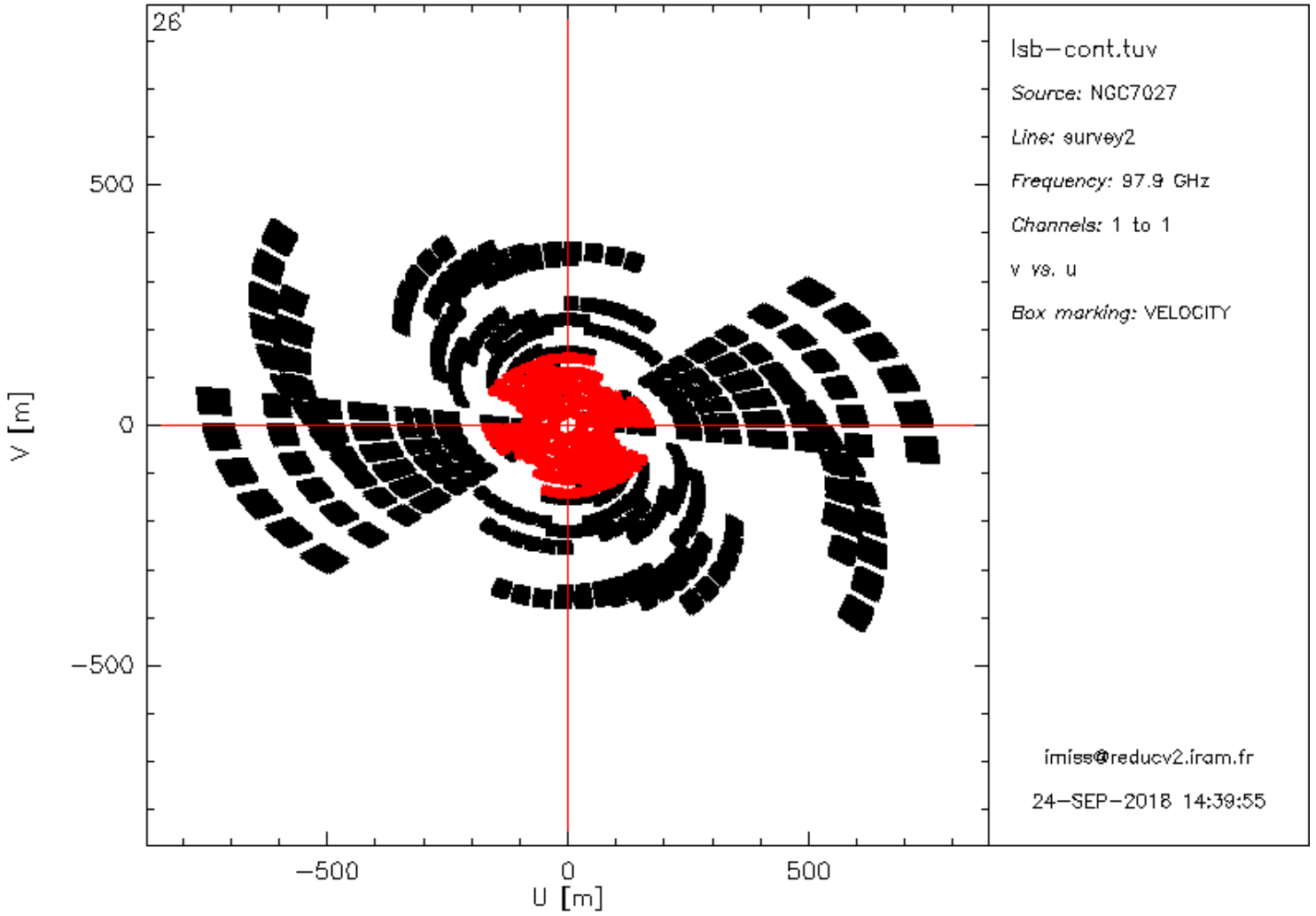
Size of the problem: III. Making a continuum image to check the actual source size. 1. Original uv coverage

```
MAPPING> let name lsb
MAPPING> go uvcov
```



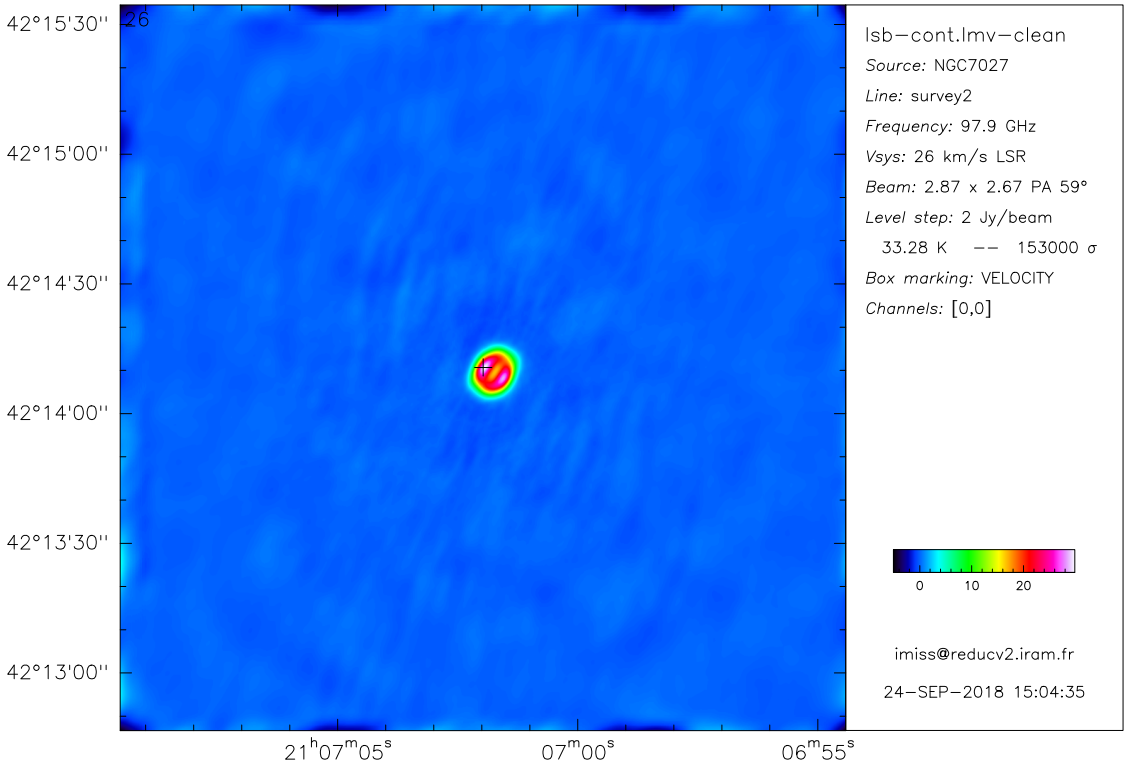
Size of the problem: III. Making a continuum image to check the source size. 2. New uv coverage

```
MAPPING> read uv lsb
MAPPING> uv_cont
MAPPING> write uv lsb-cont
MAPPING> let name lsb-cont
MAPPING> go uvcov
```



Size of the problem: III. Making a continuum image to check the source size. 3. Creating the image

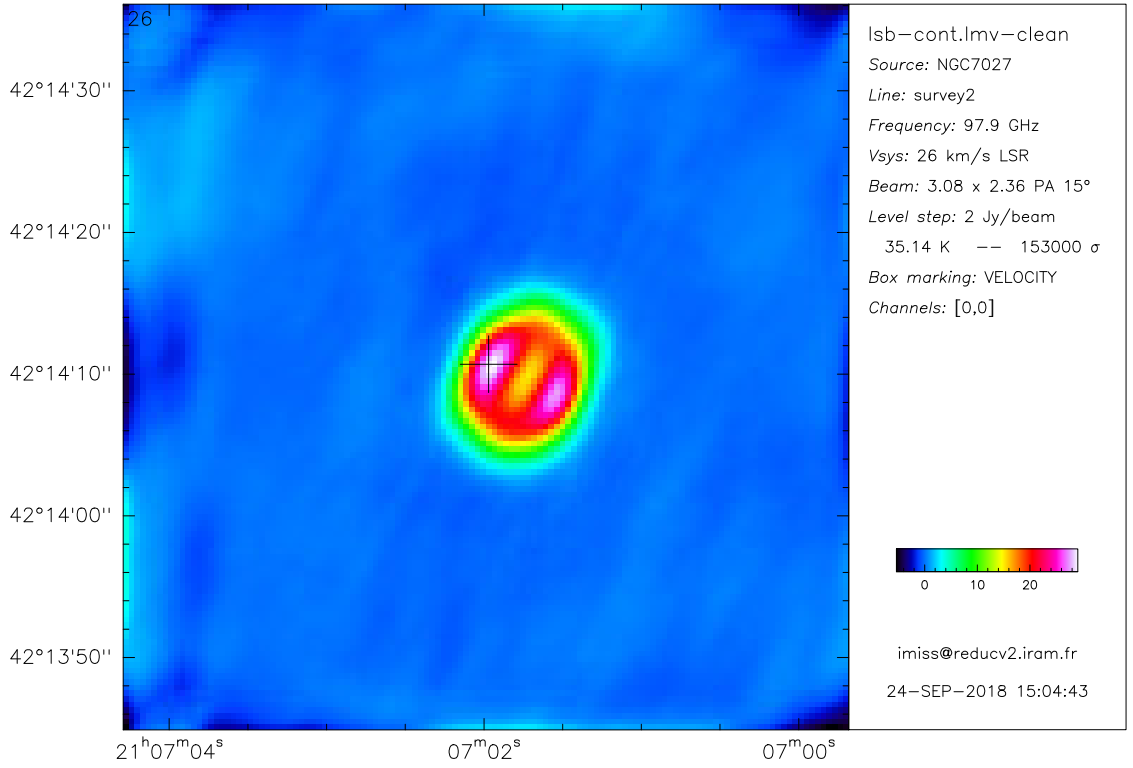
```
MAPPING> let name lsb-cont
MAPPING> go uvmap
  I-CLEAN,  Beam is     2.87" by     2.67" at PA    59.23 deg.
  I-CLEAN,  Errors (    0.05)   (    0.02)      (    0.16)
  W-CLEAN,  Dubious beam fit, please increase pixel size
  I-UVMAP,  Set type variable to lmv
MAPPING> go clean
MAPPING> go plot
```



⇒ Pixel size too small. Field of view too large.

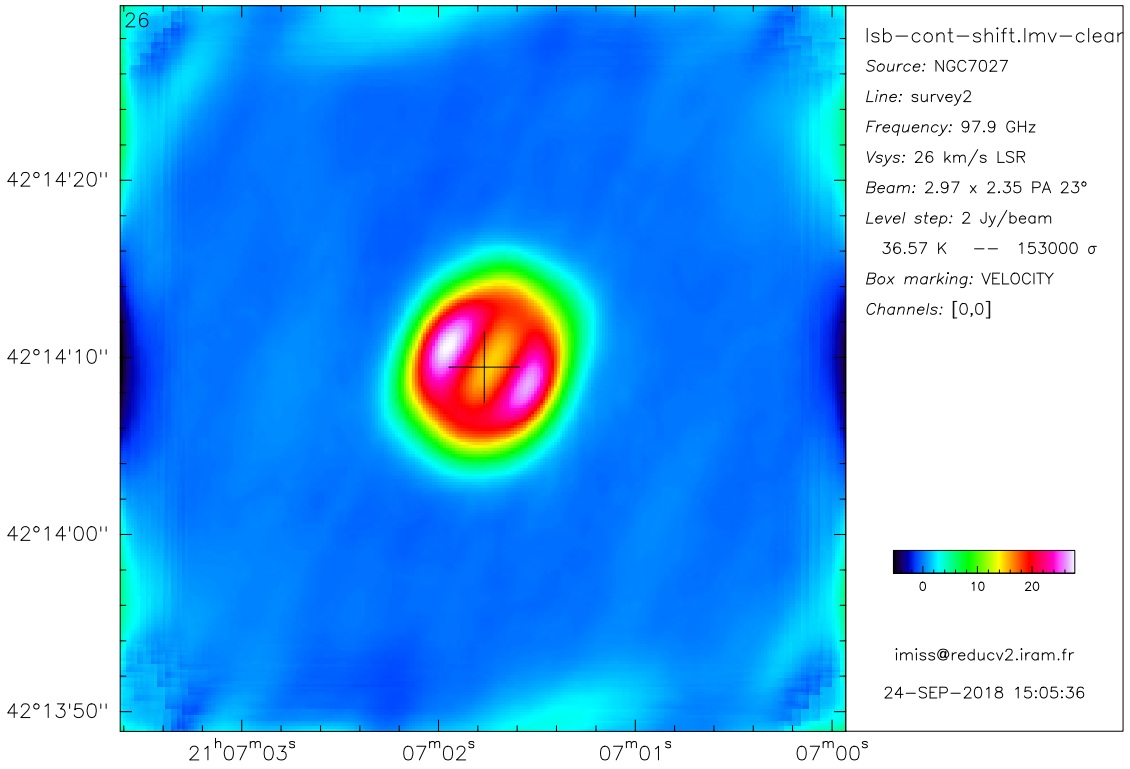
Size of the problem: IV. Adapting

```
MAPPING> let map_size 128 ! [pixels]
MAPPING> let map_cell 0.4 ! [arcsec]
MAPPING> go uvmap
MAPPING> go clean
MAPPING> go plot
```



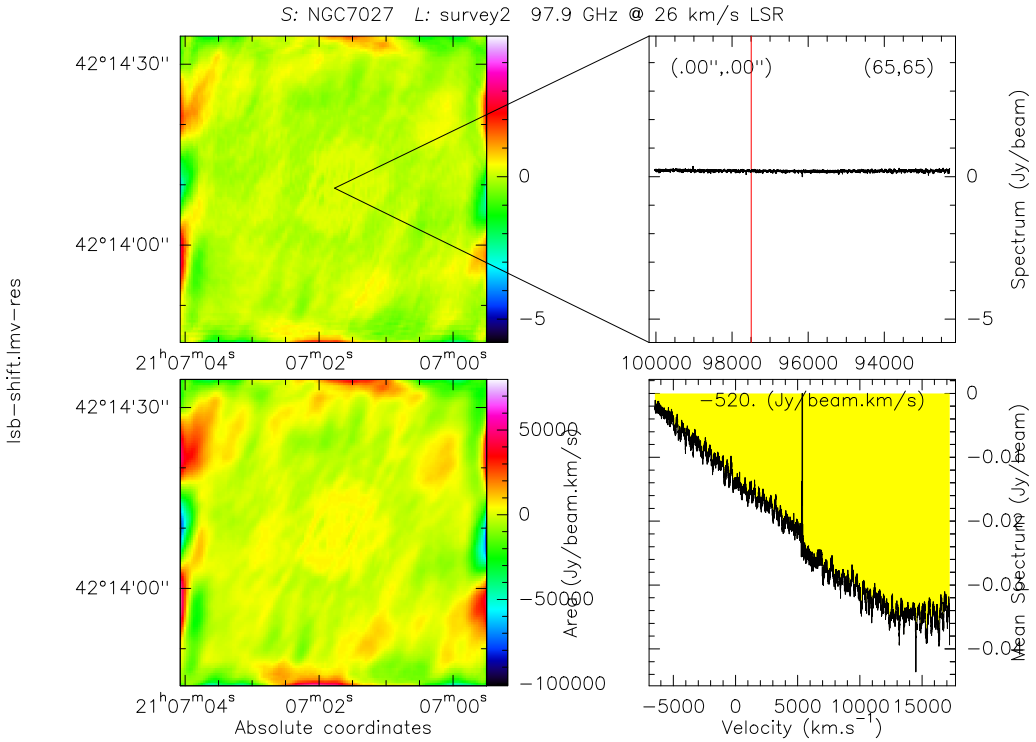
Size of the problem: V. Centering

```
MAPPING> read uv lsb-cont
MAPPING> uv_shift -2.25 -1.25
MAPPING> write uv lsb-cont-shift
MAPPING> let name lsb-cont-shift
MAPPING> go uvmap
MAPPING> go clean
MAPPING> go plot
```



Size of the problem: VI. Getting back to the original uv table

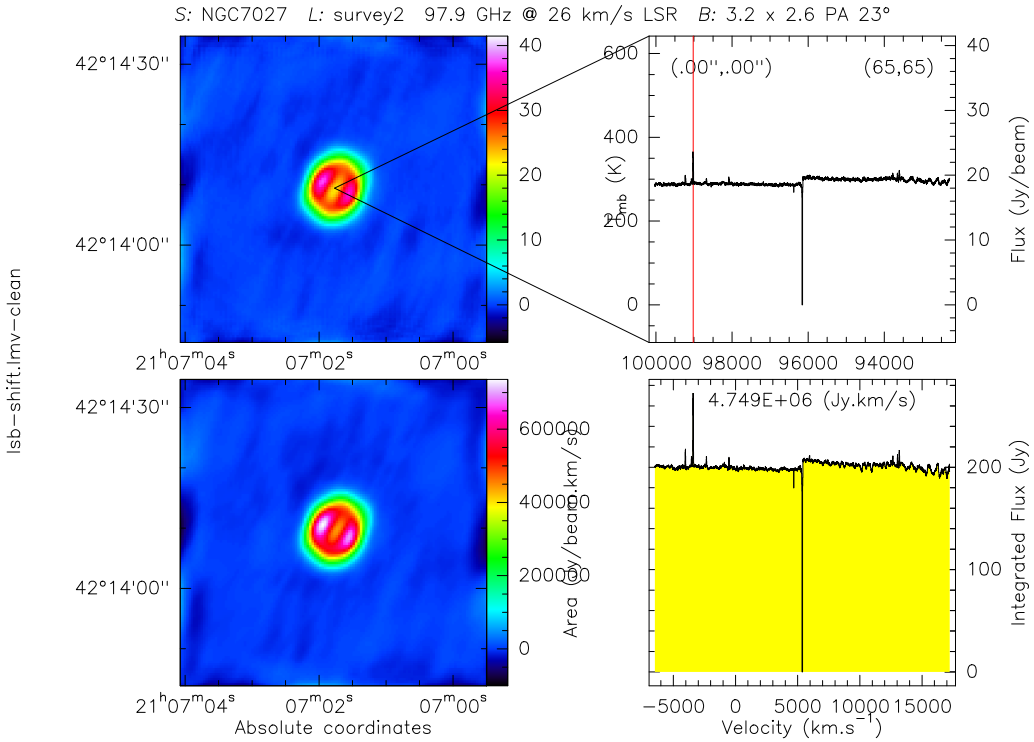
```
MAPPING> read uv lsb
MAPPING> uv_shift -2.25 -1.25
MAPPING> write uv lsb-shift
MAPPING> let name lsb-shift
MAPPING> let map_size 128 ! [pixels]
MAPPING> let map_cell 0.4 ! [arcsec]
MAPPING> go uvmap
MAPPING> let fres 0
MAPPING> let niter 100
MAPPING> go clean
MAPPING> go plot res
```



⇒ One data cube will weight ∼ 256 MB!

Size of the problem: VI. Getting back to the original uv table

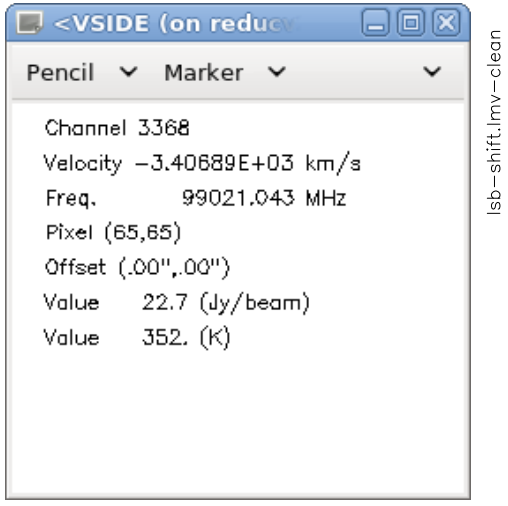
```
MAPPING> read uv lsb
MAPPING> uv_shift -2.25 -1.25
MAPPING> write uv lsb-shift
MAPPING> let name lsb-cont-shift
MAPPING> let map_size 128 ! [pixels]
MAPPING> let map_cell 0.4 ! [arcsec]
MAPPING> go uvmap
MAPPING> let fres 0
MAPPING> let niter 100
MAPPING> go clean
MAPPING> go plot clean
```



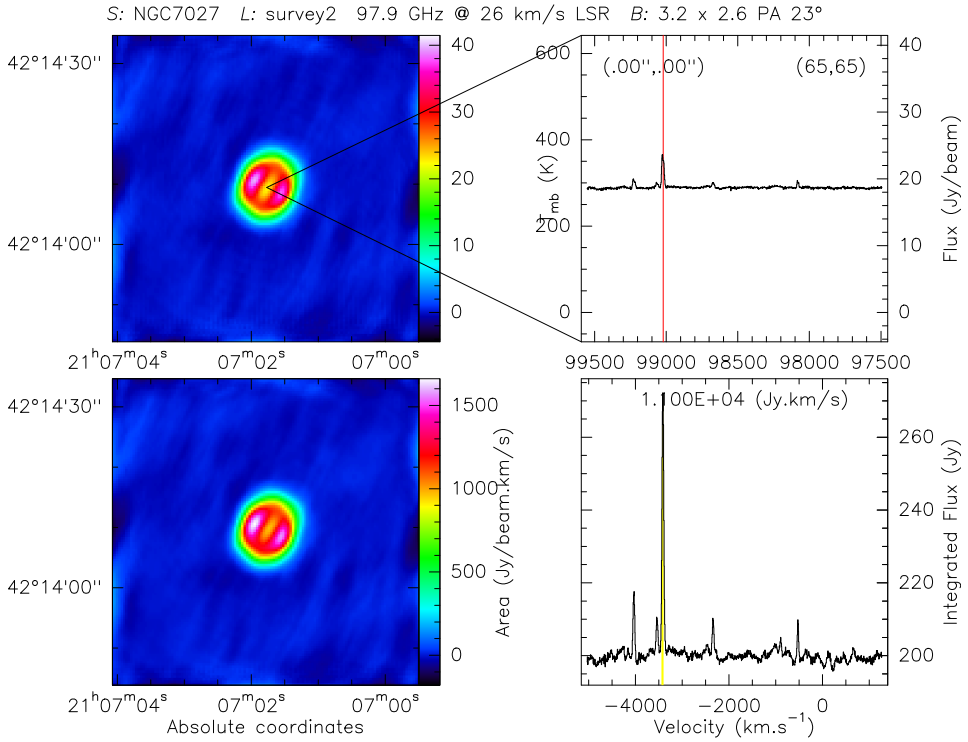
⇒ There are both continuum and lines!

Imaging the continuum: I. Making a list of contaminating lines

```
MAPPING> let name lsb-cont-shift
MAPPING> go plot clean
```



lsb−shift.lmv−clean

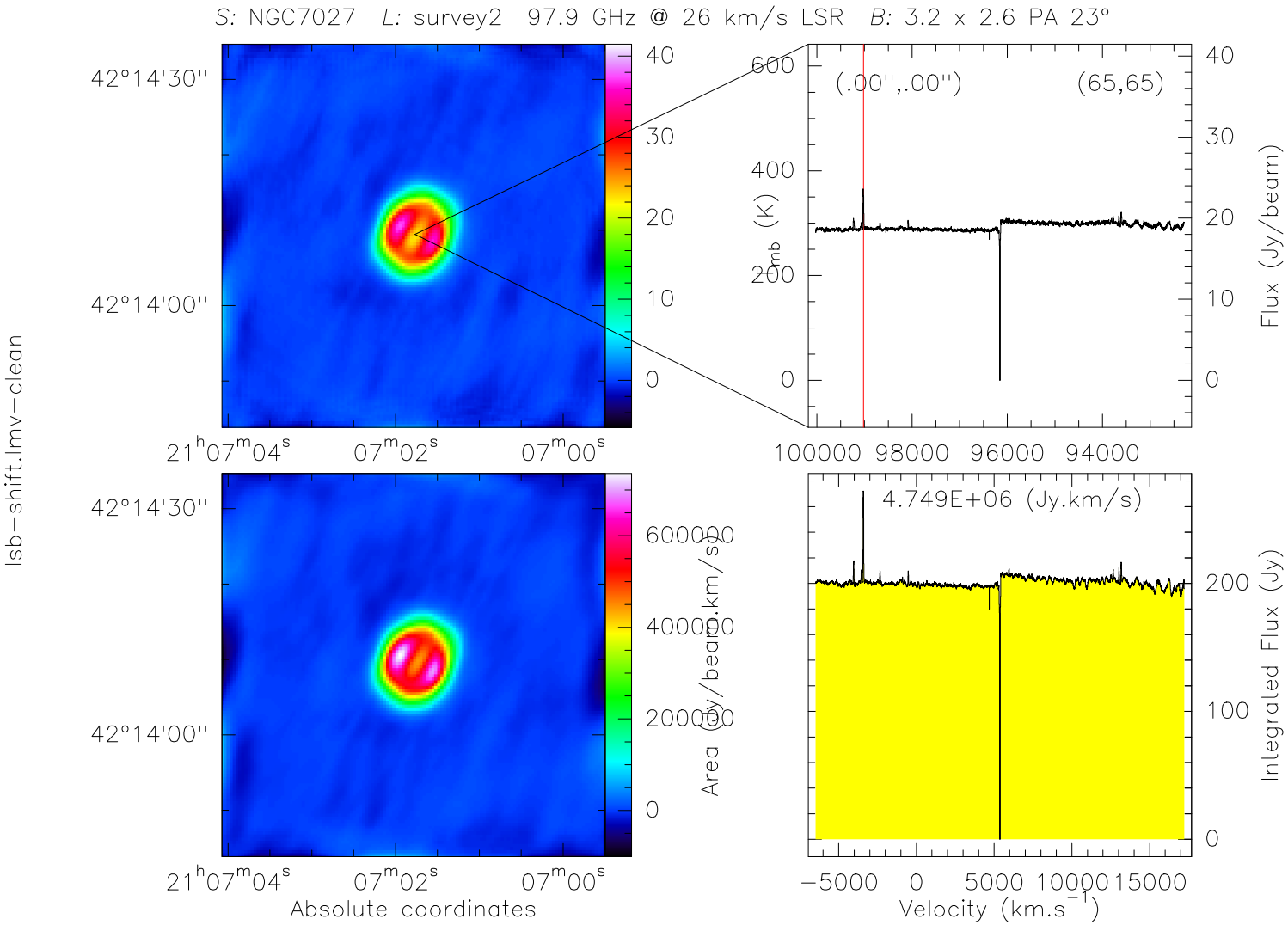


⇒ One line at 99021 MHz.

⇒ Now iterate to get the following list: 93603.5 93779.8 98084.5 98667.8 99021.5 99231.9

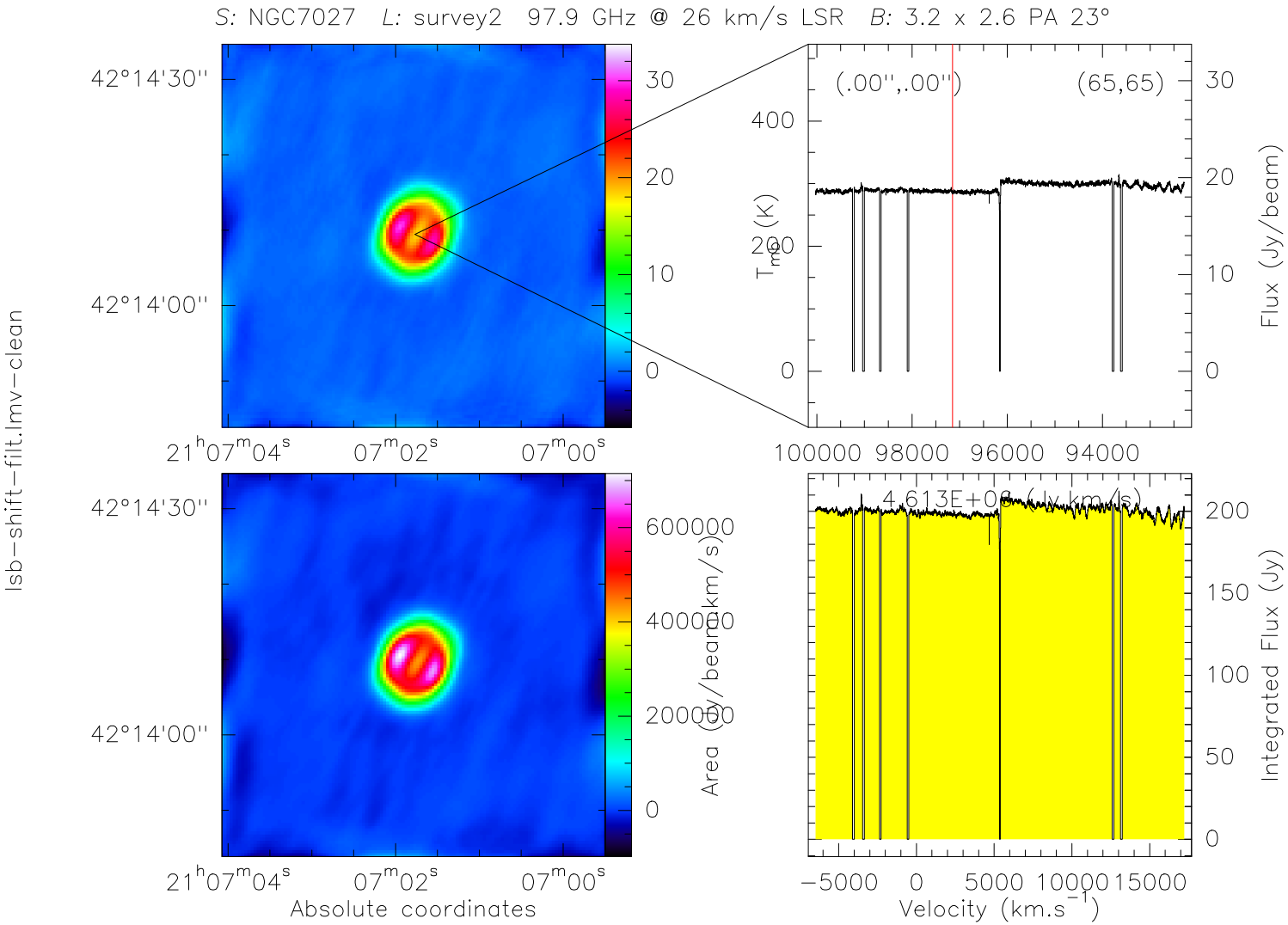
Imaging the continuum: II. Before setting a 100 km/s velocity range around each line to zero

```
MAPPING> read uv lsb-shift
MAPPING> uv_filter /zero /frequency 93603.5 93779.8 98084.5 98667.8 99021.5 99231.9 /width 100 velo
MAPPING> write uv lsb-shift-filt
Imaging and deconvolution...
```



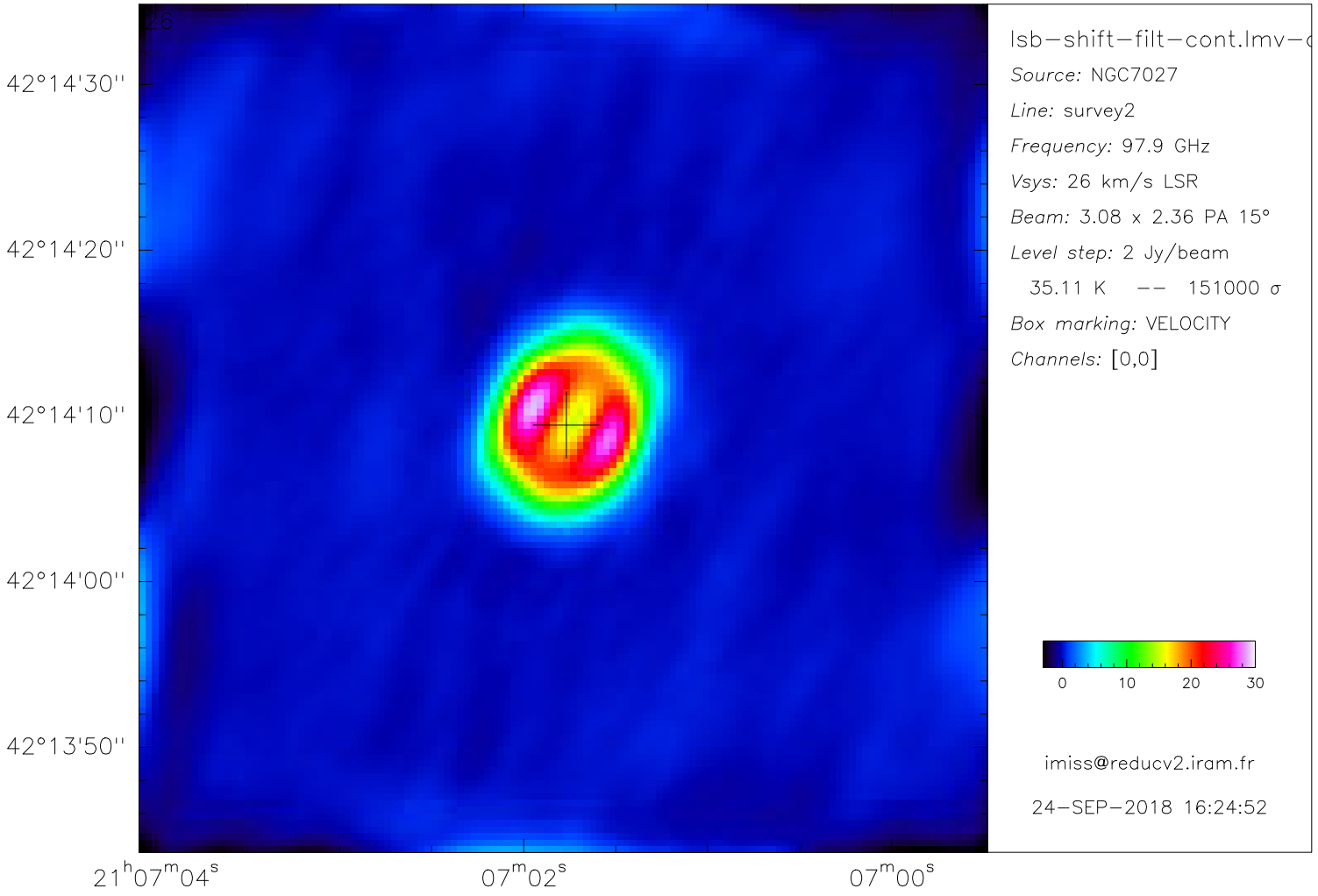
Imaging the continuum: II. After setting a 100 km/s velocity range around each line to zero

```
MAPPING> read uv lsb-shift
MAPPING> uv_filter /zero /frequency 93603.5 93779.8 98084.5 98667.8 99021.5 99231.9 /width 100 velo
MAPPING> write uv lsb-shift-filt
Imaging and deconvolution...
```



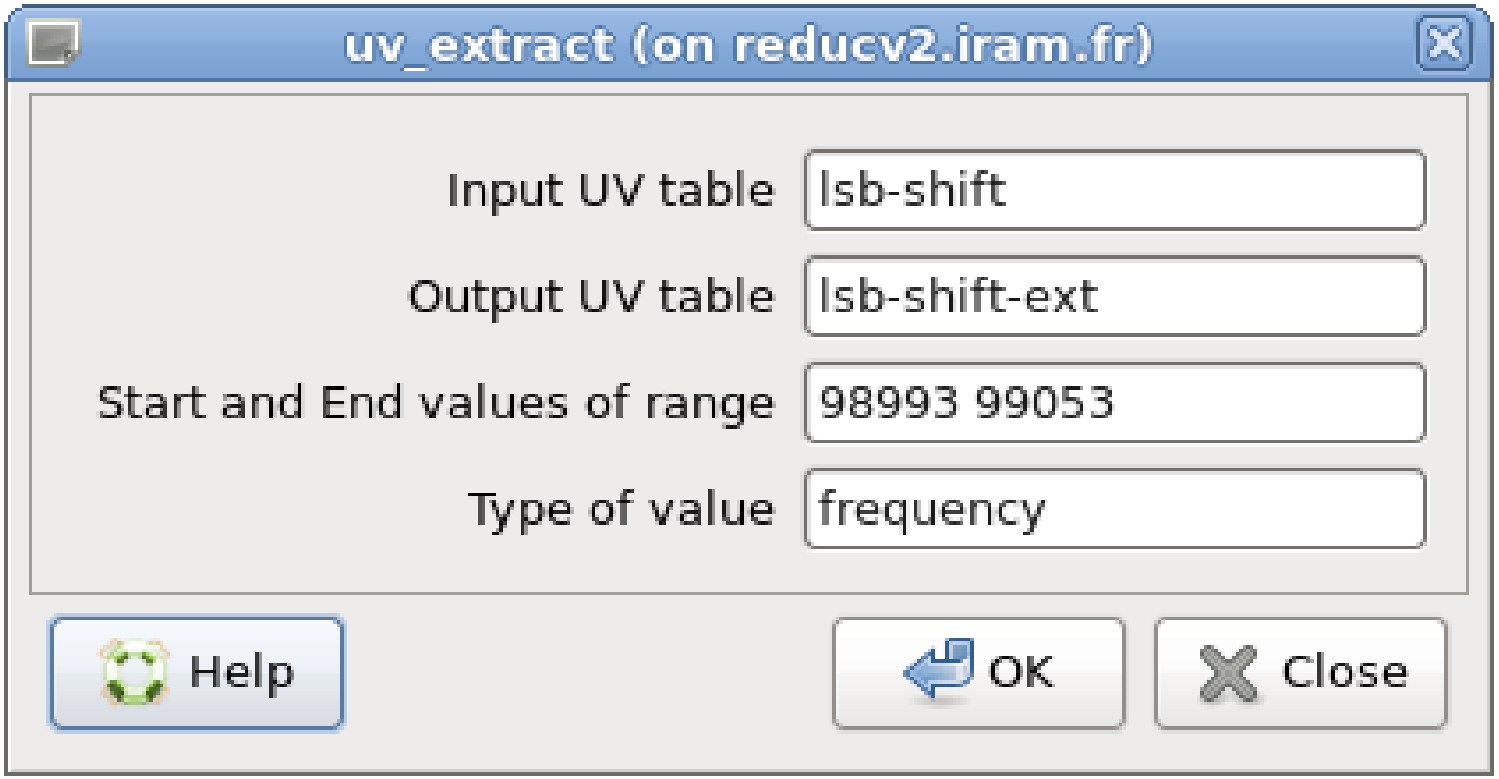
Imaging the continuum: III. From a line uv table to a continuum uv table

```
MAPPING> read uv lsb-shift-filt
MAPPING> uv_cont
MAPPING> write uv lsb-shift-filt-cont
Imaging and deconvolution...
```



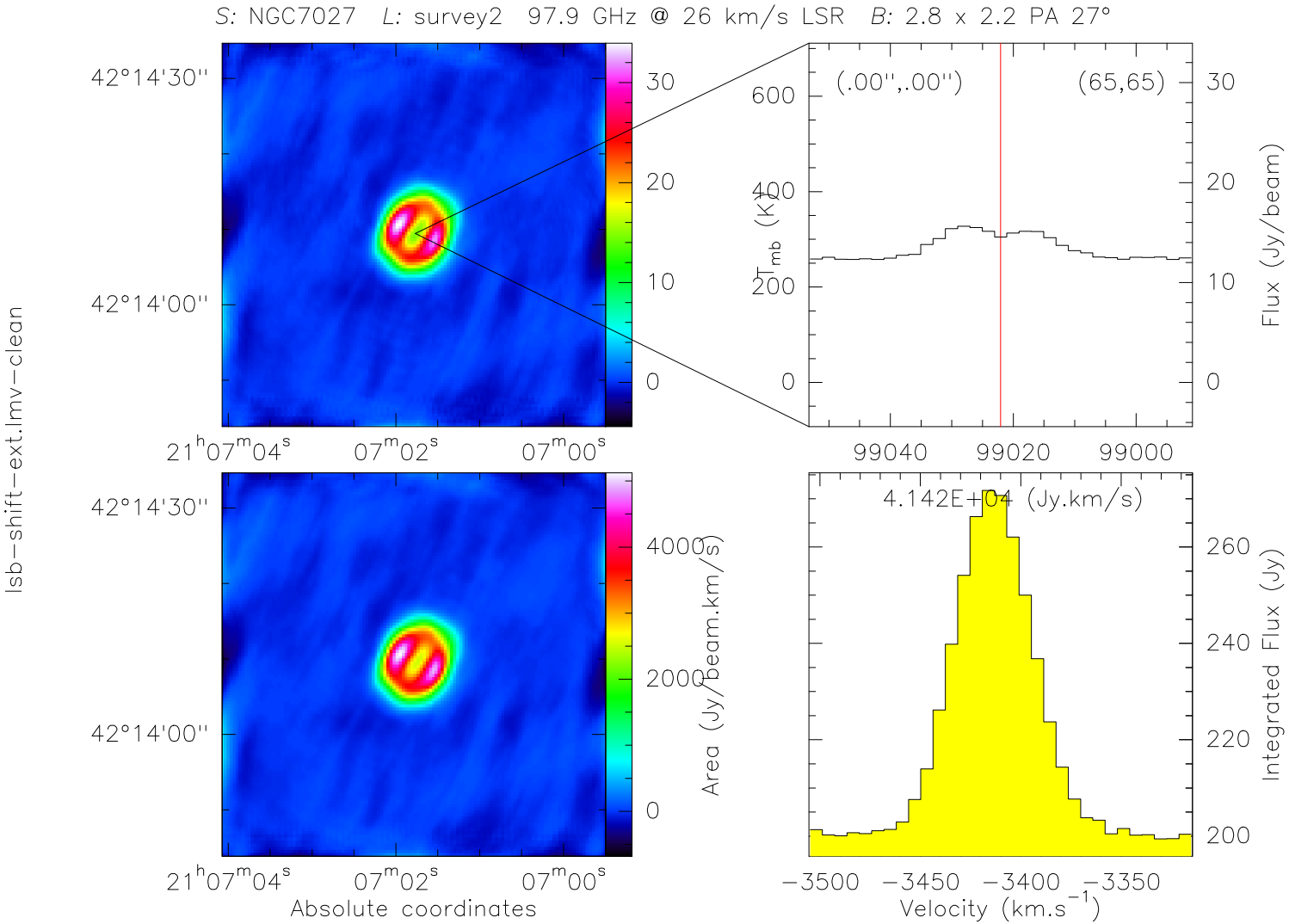
Imaging a line: I. Extracting the 100 MHz around the H40α frequency at 99020 MHz. 1. Task input

```
MAPPING> run uv_extract
Imaging and deconvolution...
```



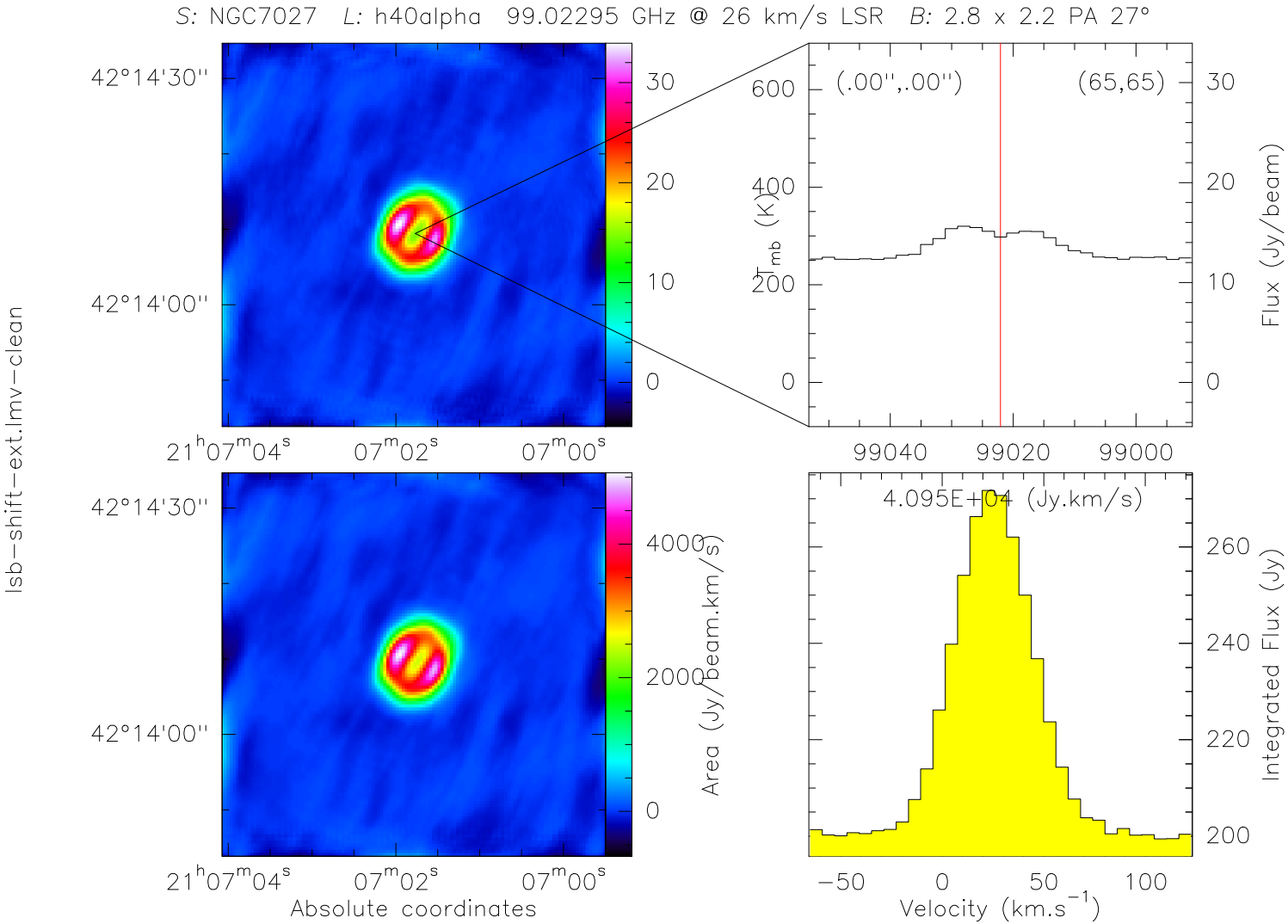
Imaging a line: I. Extracting the 100 MHz around the H40α frequency at 99020 MHz. 2. Result

```
MAPPING> run uv_extract
Imaging and deconvolution...
```



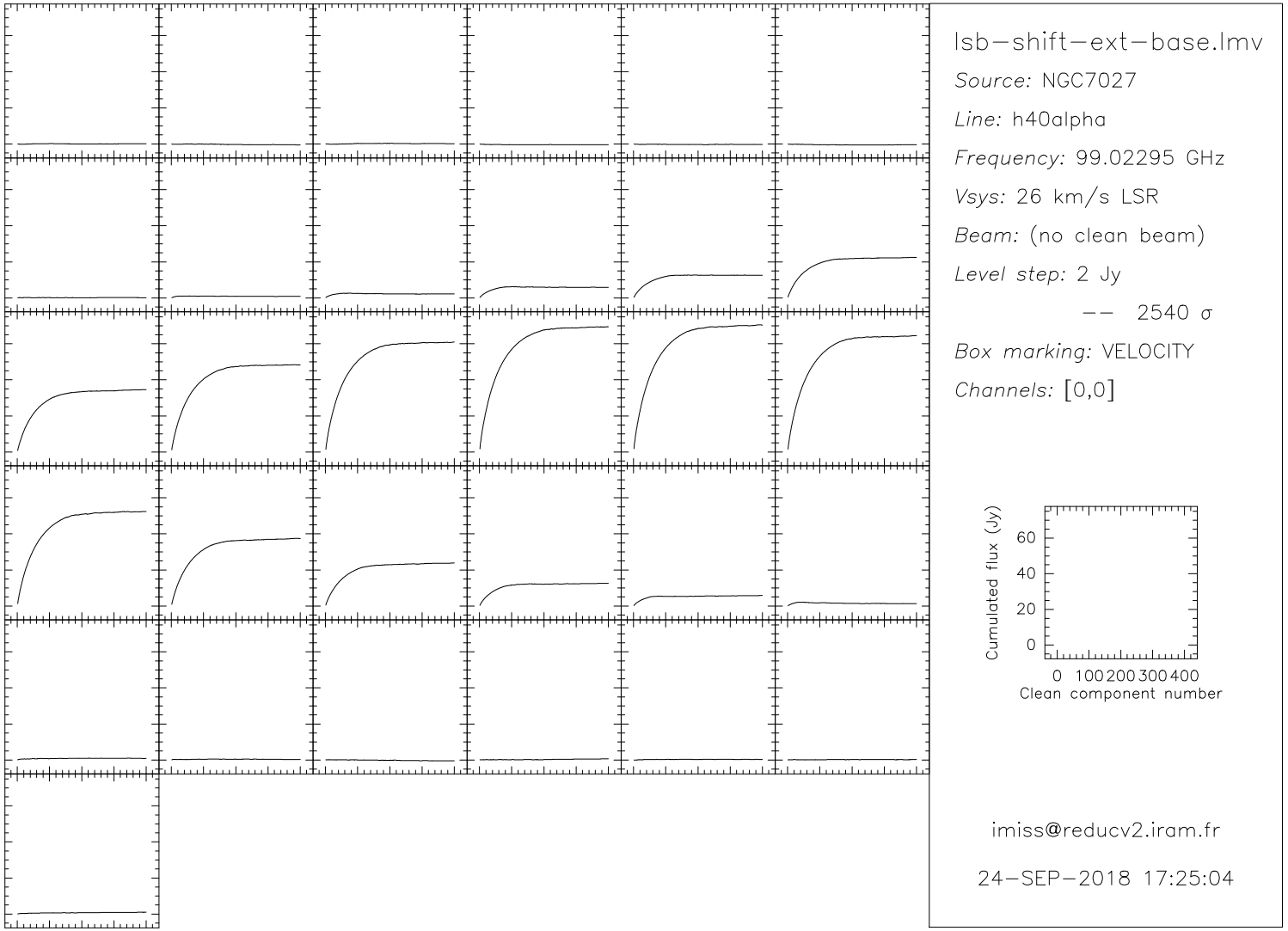
Imaging a line: II. Modifying the rest frequency in order to get the right velocity axis

```
MAPPING> modify lsb-shift-ext.uvt /freq h40alpha 99022.95
Imaging and deconvolution...
```



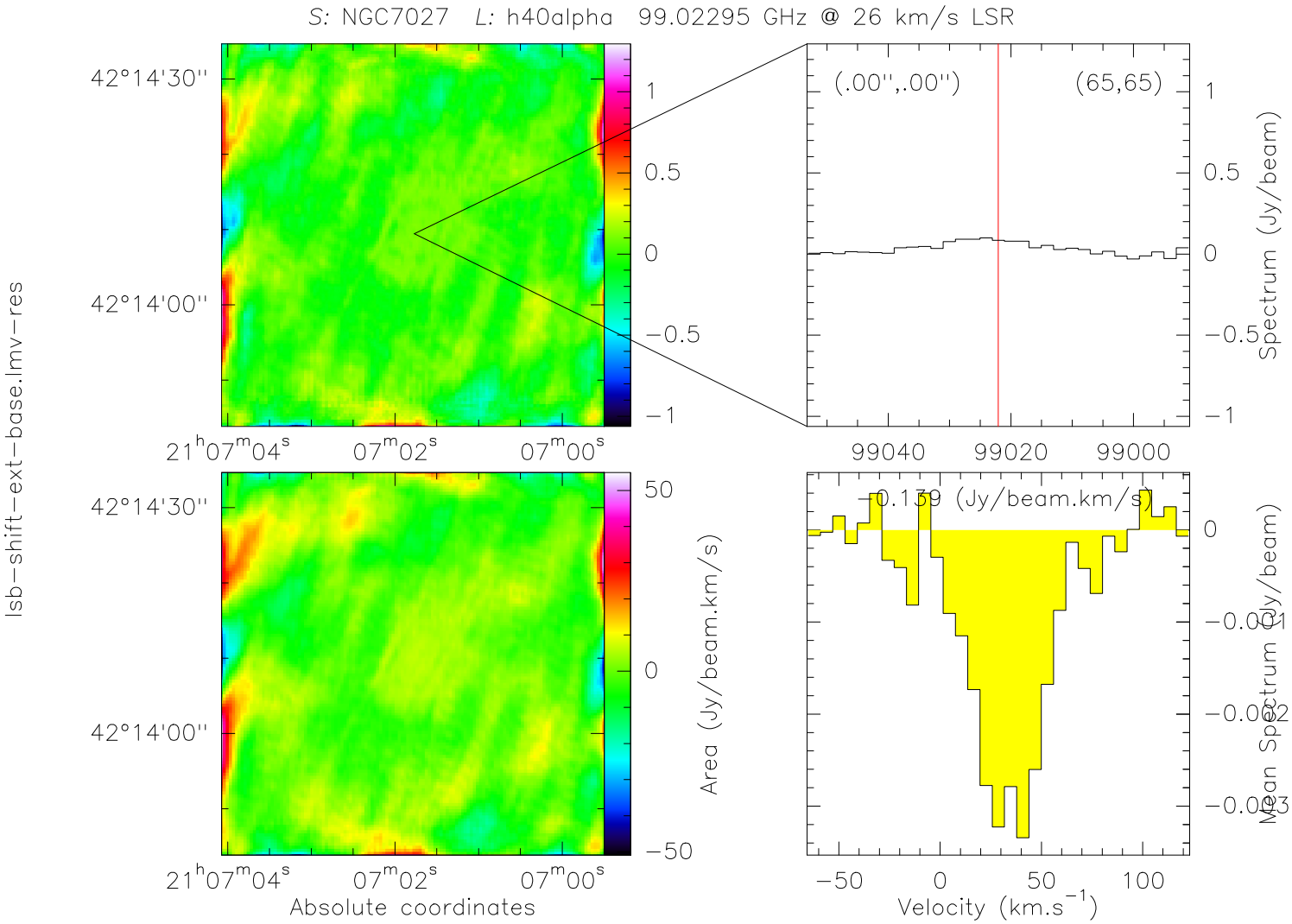
Imaging a line: III. Subtracting a baseline out of each visibility

```
MAPPING> read uv lsb-shift-ext
MAPPING> uv_base 0 /frequency 99022.95 /width 100 velo
MAPPING> write uv lsb-shift-ext-base
Imaging and deconvolution...
MAPPING> go cct
```



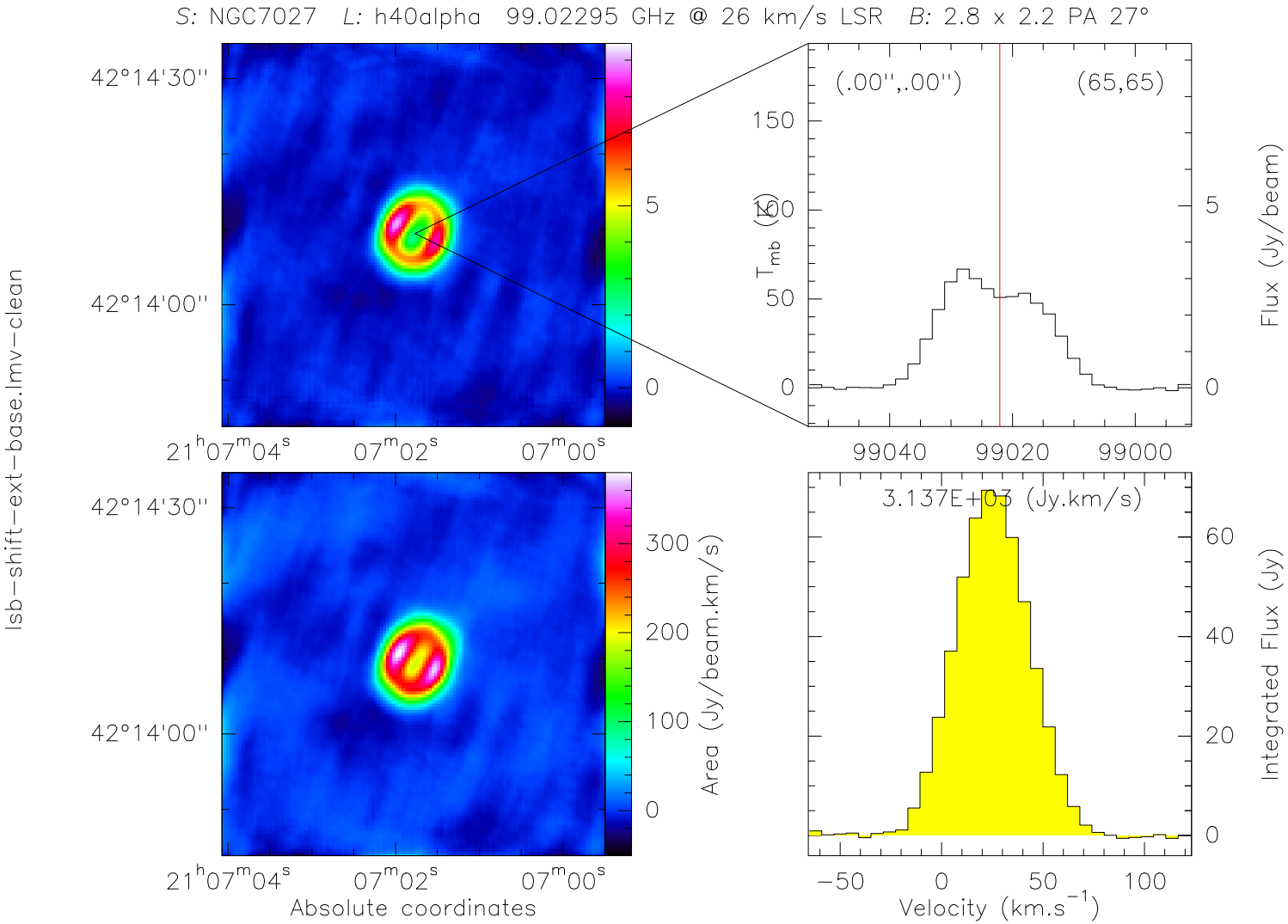
Imaging a line: III. Subtracting a baseline out of each visibility

```
MAPPING> read uv lsb-shift-ext
MAPPING> uv_base 0 /frequency 99022.95 /width 100 velo
MAPPING> write uv lsb-shift-ext-base
Imaging and deconvolution...
MAPPING> go plot res
```



Imaging a line: III. Subtracting a baseline out of each visibility

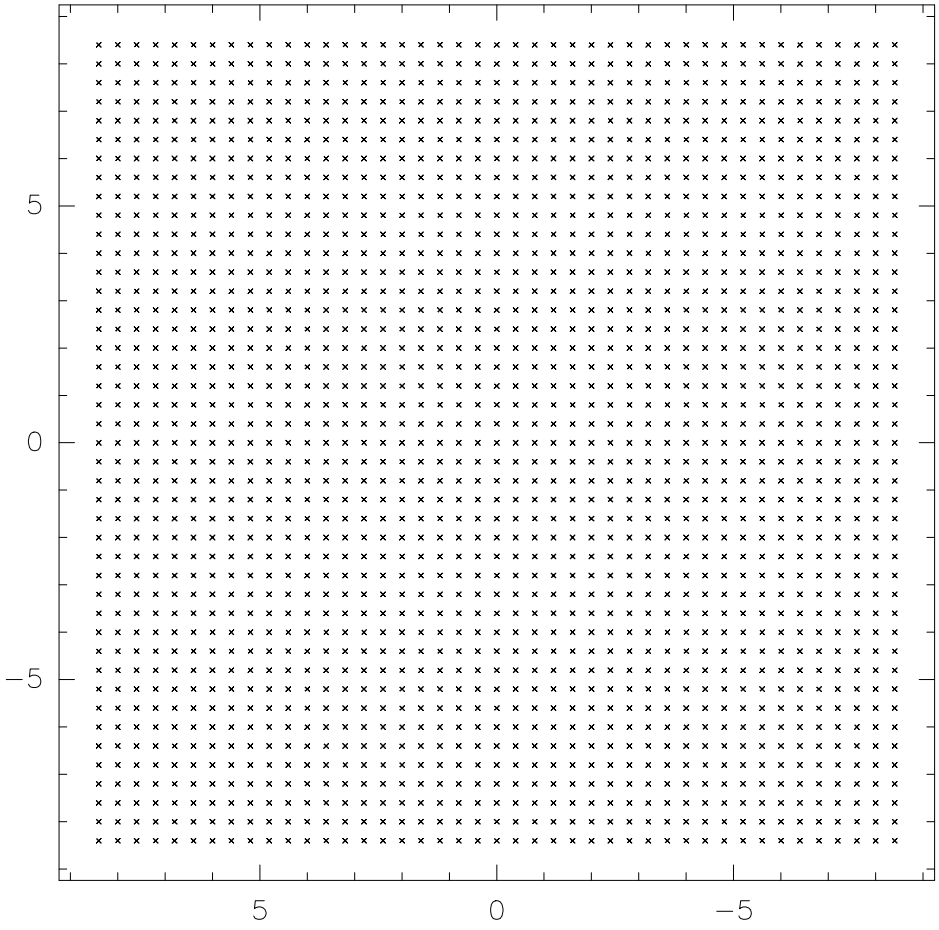
```
MAPPING> read uv lsb-shift-ext
MAPPING> uv_base 0 /frequency 99022.95 /width 100 velo
MAPPING> write uv lsb-shift-ext-base
Imaging and deconvolution...
MAPPING> go plot clean
```



Going to CLASS: I. Importing and finding everything inside a square of 17”-side

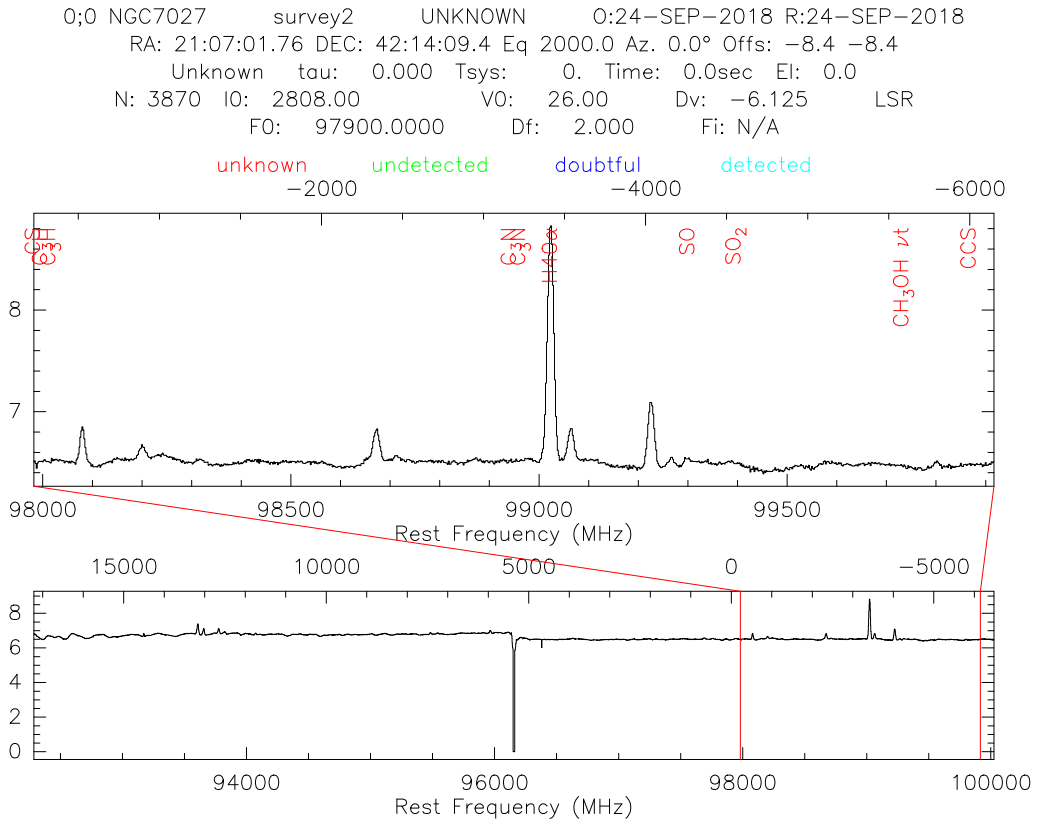
From this slide on, please look into file pro/ngc7027-beginner.class

```
LAS> file out lsb-shift single /overwrite
LAS> lmv lsb-shift.lmv-clean
LAS> set match 0 ! [arcsec]
LAS> set range -8.5 8.5 -8.5 8.5 ! [arcsec]
LAS> file in lsb-shift
LAS> find
LAS> go where
```



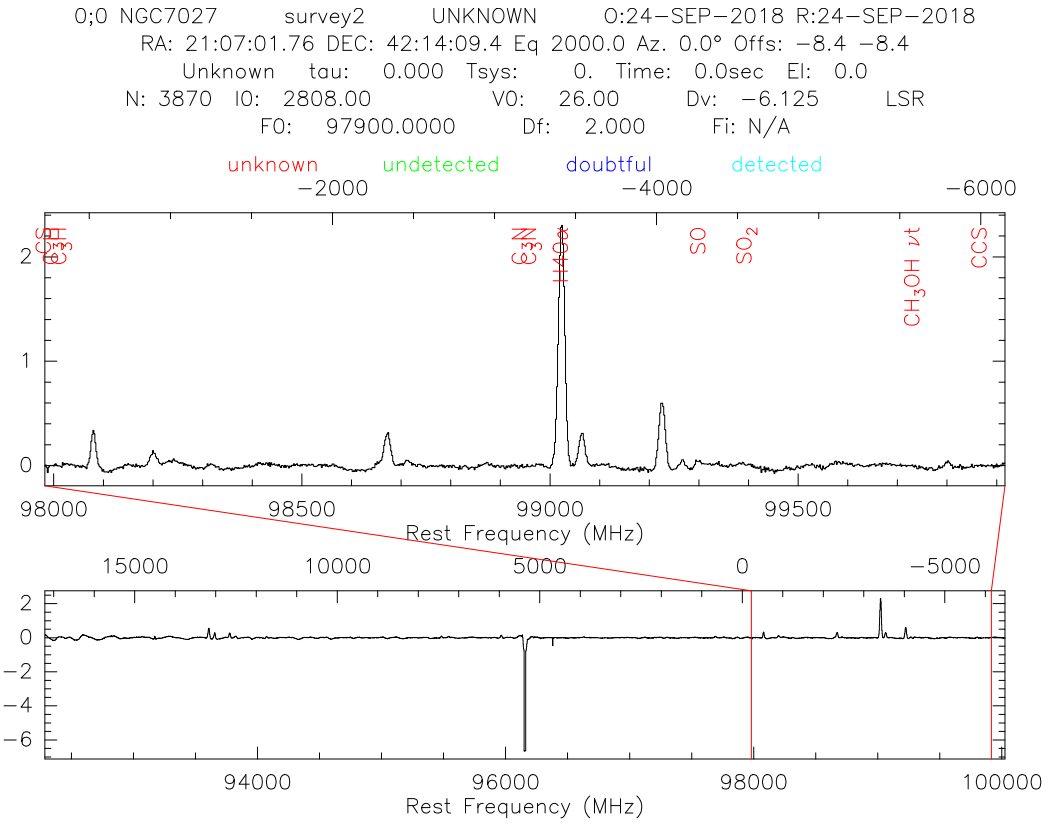
Going to CLASS: II. Averaging

```
LAS> set match 0 ! [arcsec]
LAS> set range -8.5 8.5 -8.5 8.5 ! [arcsec]
LAS> file in lsb-shift
LAS> find
LAS> average /resample /nocheck position /weight equal
LAS> go browse
```



Going to CLASS: III. Baselining through a running median

```
LAS> set match 0 ! [arcsec]
LAS> set range -8.5 8.5 -8.5 8.5 ! [arcsec]
LAS> file in lsb-shift
LAS> find
LAS> average /resample /nocheck position /weight equal
LAS> median 200
LAS> let ry ry-r%assoc%baseline%data
LAS> go browse
```



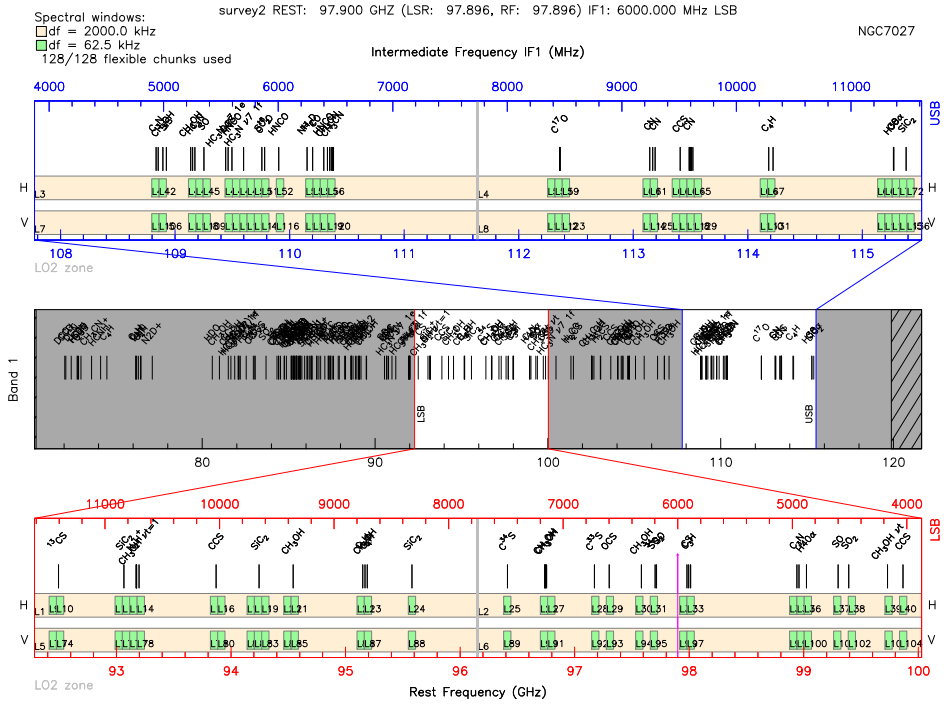
Producing the UV tables in CLIC: I. Tuning CLIC defaults

From this slide on, please look into file pro/ngc7027-beginner.clic

```
CLIC> set default ! Reset all global settings to their natural default
CLIC> set rf_passband on frequency antenna file
CLIC> show rf_passband
  RF Passband Calibration is applied
  RF Passband Calibration is frequency dependent
  RF Passband Calibration is antenna-based
  RF Passband Calibration from input file
CLIC> set phase relative antenna internal atmosphere
CLIC> show phase
  Phases are relative to calibrator phase
  Phase Calibration is antenna-based
  Phase reference is internal (same receiver)
  Using real-time atmospheric phase correction, antennas  1 2 3 4 5 6 7 8 9 :
  (according to validation by STORE CORRECTION)
  Using no off-line atmospheric phase correction, antennas  1 2 3 4 5 6 7 8 9 :
CLIC> set amplitude relative antenna jansky
CLIC> show amplitude
  Amplitudes are relative to calibrator amplitude
  Amplitude Calibration is antenna-based
  Amplitudes are expressed in janskys
```

Producing the UV tables in CLIC: II. Looking at the frequency setup

```
CLIC> sic log ipb_data: "./" ! Tell CLIC the directory where IPB files are.
CLIC> file in 19-feb-2018-d17id001.hpb
CLIC> show file
  Input file 19-feb-2018-d17id001.hpb [Native]
  No output file opened
  Raw data files are searched in:
     ./
CLIC> find /proc corr /source ngc7027 /offset 0 0
CLIC> if (found.ne.0) then
CLIC>    list
CLIC>    get first
CLIC>    header /plot
CLIC> endif
```



Producing the UV tables in CLIC: III. LSB low res. windows

```
CLIC> sic delete lsb.uvt
CLIC> set selection line LSB L1 and L2 and L5 and L6
CLIC> set drop 0.002 0.0472 ! Drop channels at edges of the basebands (low resolution spectral windows)
CLIC> file in 19-feb-2018-d17id001.hpb
CLIC> find /proc corr /source ngc7027 /offset 0 0
CLIC> if (found.ne.0) then
CLIC>    table lsb.uvt new /freq lsb 96200
CLIC> endif
CLIC> file in 10-may-2018-d17id001.hpb
CLIC> find /proc corr /source ngc7027 /offset 0 0
CLIC> if (found.ne.0) then
CLIC>    table lsb.uvt
CLIC> endif
CLIC> v\header lsb.uvt
File : lsb.uvt                                                    REAL*4
Size        Reference Pixel           Value                  Increment
     11620   1958.03800186507       96195.7059654815       2.00000011521782
     18078   0.00000000000000       0.00000000000000       1.00000000000000
Blanking value and tolerance      1.23455997E34   0.0000000
Source name          NGC7027
Map unit             Jy
Axis type            UV-DATA      RANDOM
Coordinate system    EQUATORIAL          Velocity    LSR
Right Ascension   21:07:01.97000         Declination       42:14:10.7000
Lii         0.000000000000000            Bii        0.000000000000000
Equinox              2000.0000
Projection type      AZIMUTHAL           Angle      0.000000000000000
Axis 0     A0     21:07:01.97000         Axis 0     D0     42:14:10.7000
Axis 1 Line Name     lsb                 Rest Frequency   96200.00000000000
Resolution in Velocity   -6.2329702      in Frequency           2.0000894
Offset in Velocity        26.000000      Doppler Velocity       0.0000000
Beam                    52.4                  0.00                  0.00
UV Data    Channels:   3871, Stokes: 1 None         Visibilities:        18078
```

Producing the UV tables in CLIC: IV. USB low res. windows

```
CLIC> sic delete usb.uvt
CLIC> set drop 0.002 0.0472
CLIC> set selection line USB L3 and L4 and L7 and L8
CLIC> file in 19-feb-2018-d17id001.hpb
CLIC> find /proc corr /source ngc7027 /offset 0 0
CLIC> if (found.ne.0) then
CLIC>    table usb.uvt new /freq usb 111600
CLIC> endif
CLIC> file in 10-may-2018-d17id001.hpb
CLIC> find /proc corr /source ngc7027 /offset 0 0
CLIC> if (found.ne.0) then
CLIC>    table usb.uvt
CLIC> endif
CLIC> v\header usb.uvt
File : usb.uvt                                                    REAL*4
Size        Reference Pixel           Value                  Increment
     11620   1913.69127782547       111594.974287318       1.99999999593899
     18078   0.00000000000000       0.00000000000000       1.00000000000000
Blanking value and tolerance      1.23455997E34   0.0000000
Source name          NGC7027
Map unit             Jy
Axis type            UV-DATA      RANDOM
Coordinate system    EQUATORIAL          Velocity    LSR
Right Ascension   21:07:01.97000         Declination       42:14:10.7000
Lii         0.000000000000000            Bii        0.000000000000000
Equinox              2000.0000
Projection type      AZIMUTHAL           Angle      0.000000000000000
Axis 0     A0     21:07:01.97000         Axis 0     D0     42:14:10.7000
Axis 1 Line Name     usb                 Rest Frequency   111600.0000000000
Resolution in Velocity   -5.3728671      in Frequency           2.0000901
Offset in Velocity        26.000000      Doppler Velocity       0.0000000
Beam                    45.2                  0.00                  0.00
UV Data    Channels:   3871, Stokes: 1 None         Visibilities:        18078
```

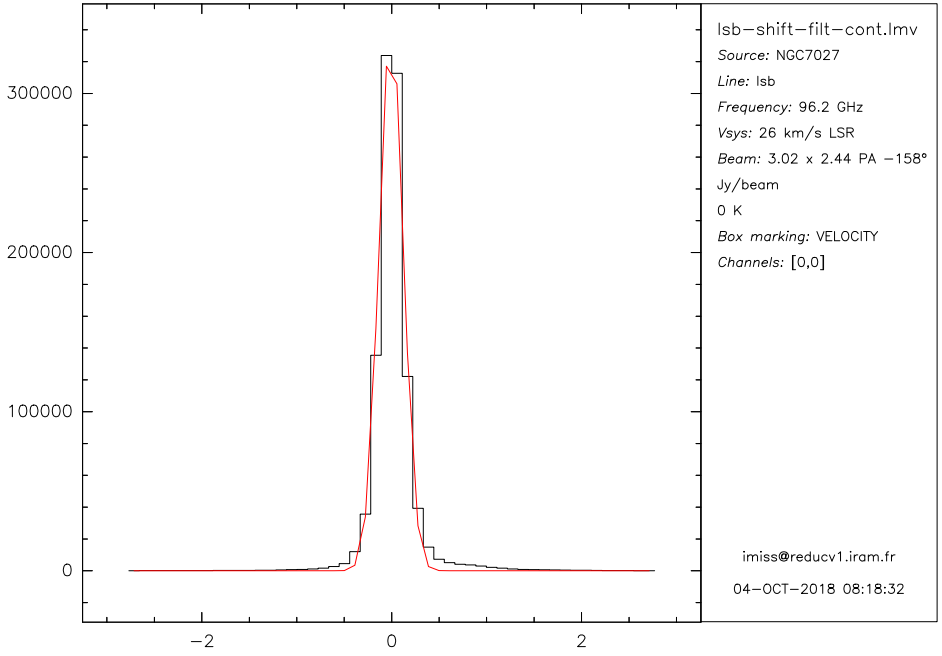
Producing the UV tables in CLIC: V. H40α high res. window

```
CLIC> sic delete h40alpha.uvt
CLIC> set drop 0.0 0.0
CLIC> set selection line LSB L35 and L36 and L99 and L100
CLIC> file in 19-feb-2018-d17id001.hpb
CLIC> find /proc corr /source ngc7027 /offset 0 0
CLIC> if (found.ne.0) then
CLIC>    table h40alpha.uvt new  /freq h40alpha 99022.95 /resample 400 200.00 26.00 0.4 v
CLIC> endif
CLIC> file in 10-may-2018-d17id001.hpb
CLIC> find /proc corr /source ngc7027 /offset 0 0
CLIC> if (found.ne.0) then
CLIC>    table h40alpha.uvt
CLIC> endif
CLIC> v\header h40alpha.uvt
File : h40alpha.uvt                                              REAL*4
Size        Reference Pixel           Value                  Increment
      1207   200.000000000000       99018.4909956920     -0.132116055396140
     18078   0.00000000000000       0.00000000000000       1.00000000000000
Blanking value and tolerance      1.23455997E34   0.0000000
Source name          NGC7027
Map unit             Jy
Axis type            UV-DATA      RANDOM
Coordinate system    EQUATORIAL          Velocity    LSR
Right Ascension   21:07:01.97000         Declination       42:14:10.7000
Lii         0.000000000000000             Bii       0.000000000000000
Equinox              2000.0000
Projection type      AZIMUTHAL           Angle     0.000000000000000
Axis 0     A0     21:07:01.97000         Axis 0     D0     42:14:10.7000
Axis 1 Line Name     h40alpha            Rest Frequency   99022.95000000000
Resolution in Velocity   0.40000001      in Frequency         -0.13212200
Offset in Velocity         26.000000     Doppler Velocity       0.0000000
Beam                    50.9                  0.00                  0.00
UV Data    Channels:    400, Stokes: 1 None         Visibilities:       18078
```

Phase self-calibration of the continuum: I. Get a correctly imaged, deconvolved, and analyzed data

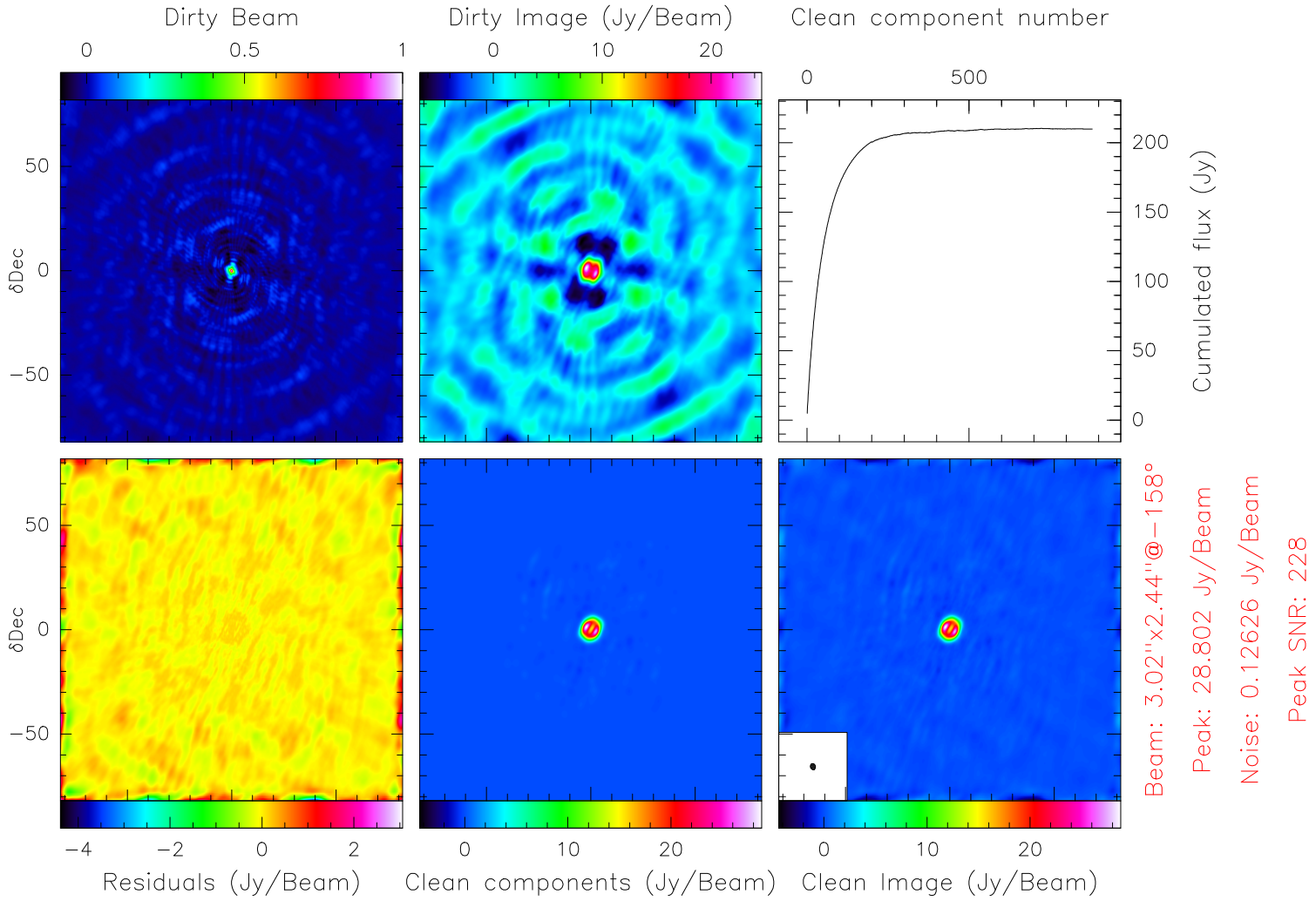
From this slide on, please look into file pro/ngc7027-selfcal.map

```
MAPPING> read uv lsb
MAPPING> uv_shift -2.25 -1.25
MAPPING> uv_filter /zero /frequency 93603.5 93779.8 98084.5 98667.8 99021.5 99231.9 /width 100 velo
MAPPING> uv_cont
MAPPING> write uv lsb-shift-filt-cont
MAPPING> let name lsb-shift-filt-cont
MAPPING> let map_size 1024
MAPPING> let map_cell 0.16
MAPPING> go uvmap
MAPPING> let ares 0
MAPPING> let fres 0
MAPPING> let niter 880
MAPPING> go clean
MAPPING> go noise
```



Phase self-calibration of the continuum:
I. Get a correctly imaged, deconvolved, and analyzed data

```
MAPPING> @ deconvolution-tools
MAPPING> @ deconv-plot 0 0
```

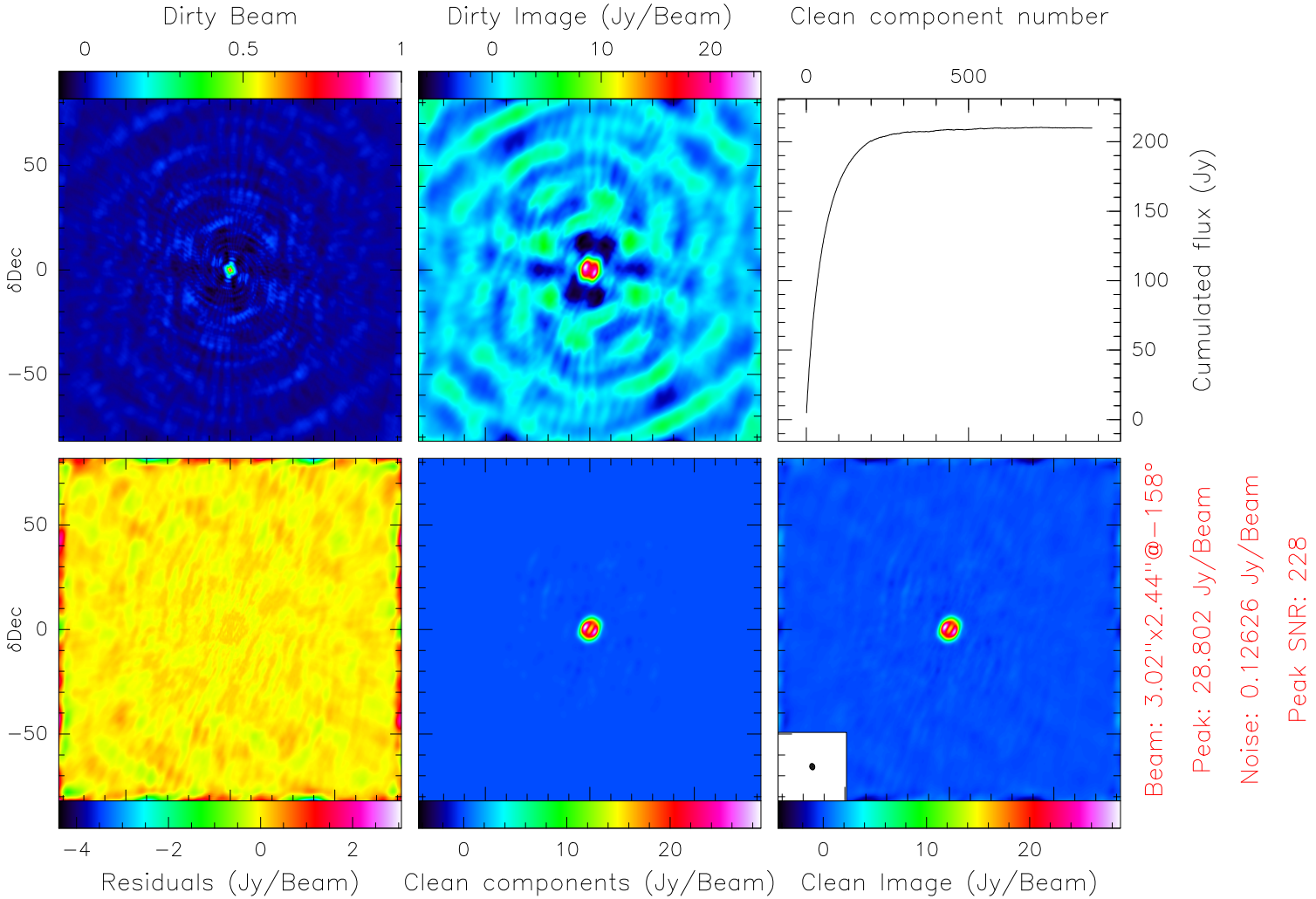


Phase self-calibration of the continuum: II. A bit of preparation

```
begin procedure my-selfcal
  !------------------------------------------------------------------------
  ! This procedure sets reasonable defaults for the self-calibration tool.
  ! It then executes the self-calibration and plot the result.
  ! &1: uv table name without extension
  ! &2: number of selfcal iteration
  ! &3: number of clean components during each selfcal step in double quote
  !     for instance, "10 15" 10 and then 15 clean components.
  ! &4: Integration time used during each selfcal step in double quote
  !     for instance, "180 45" means 180 and then 45 seconds.
  !------------------------------------------------------------------------
  let self%iname &1         ! input uv table
  let self%oname &1-selfcal ! output uv table
  let self%loop  &2         ! number of self cal loops
  let self%niter &3 /resize ! number of selected components
  let self%times &4 /resize ! integration time for solution
  let self%channel  0 0     ! channel range
  let self%refant     0     ! reference antenna
  let self%sname &1-sol     ! solution table
  let self%flux       0     ! maximum flux for display
  let self%restore   no     ! use uv_restore at end
  let self%display  yes     ! display clean image at each loop
  go selfcal
  @ deconv-plot 0 0
  ha ha/lsb-after-selfcal-plot-'niter' /dev epdf /over
  pause
end procedure my-selfcal
```

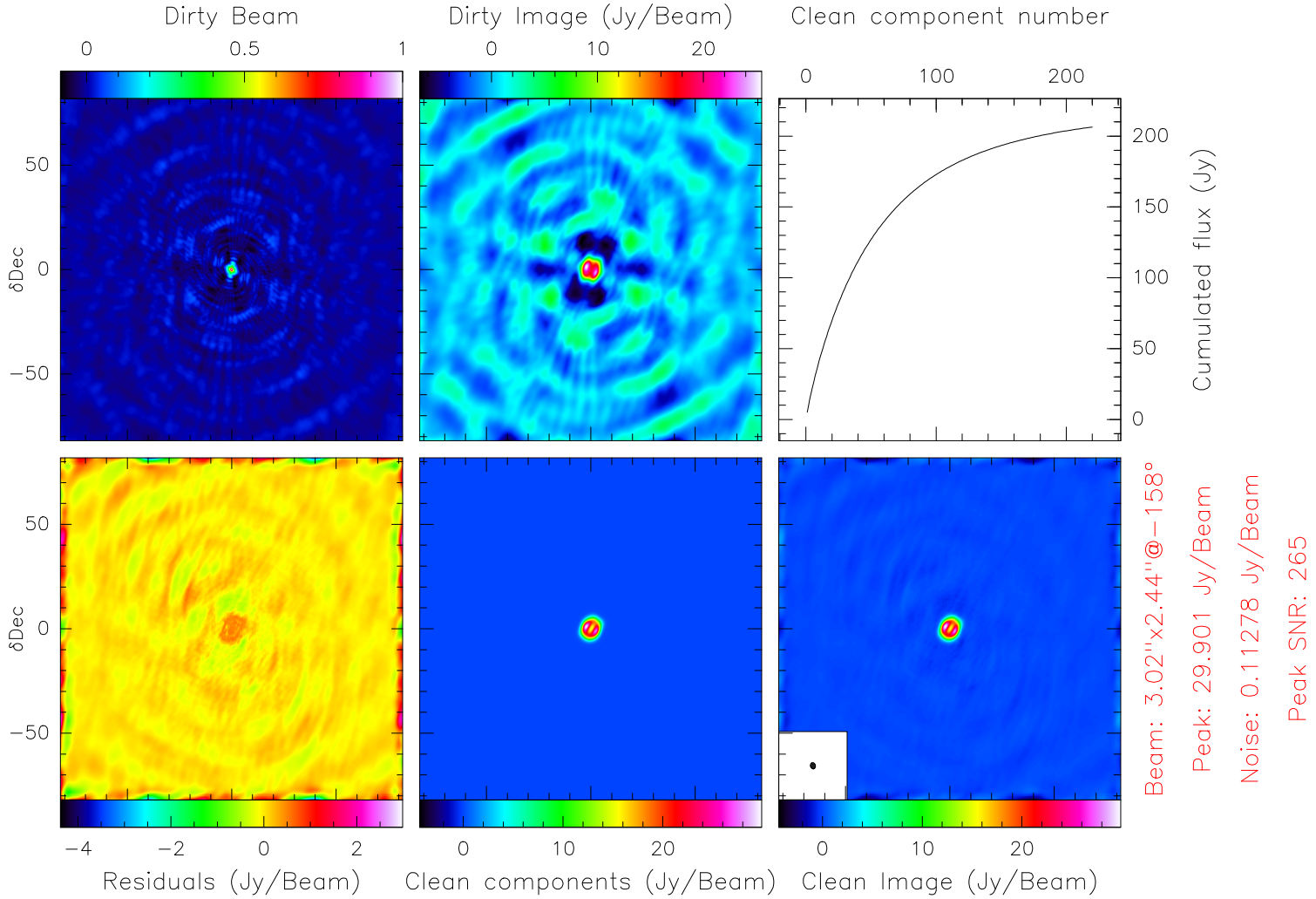
Phase self-calibration of the continuum: III. Test #1: Before self-calibration

```
MAPPING> let name lsb-shift-filt-cont
MAPPING> let niter 880
MAPPING> go clean
MAPPING> @ deconv-plot 0 0
```



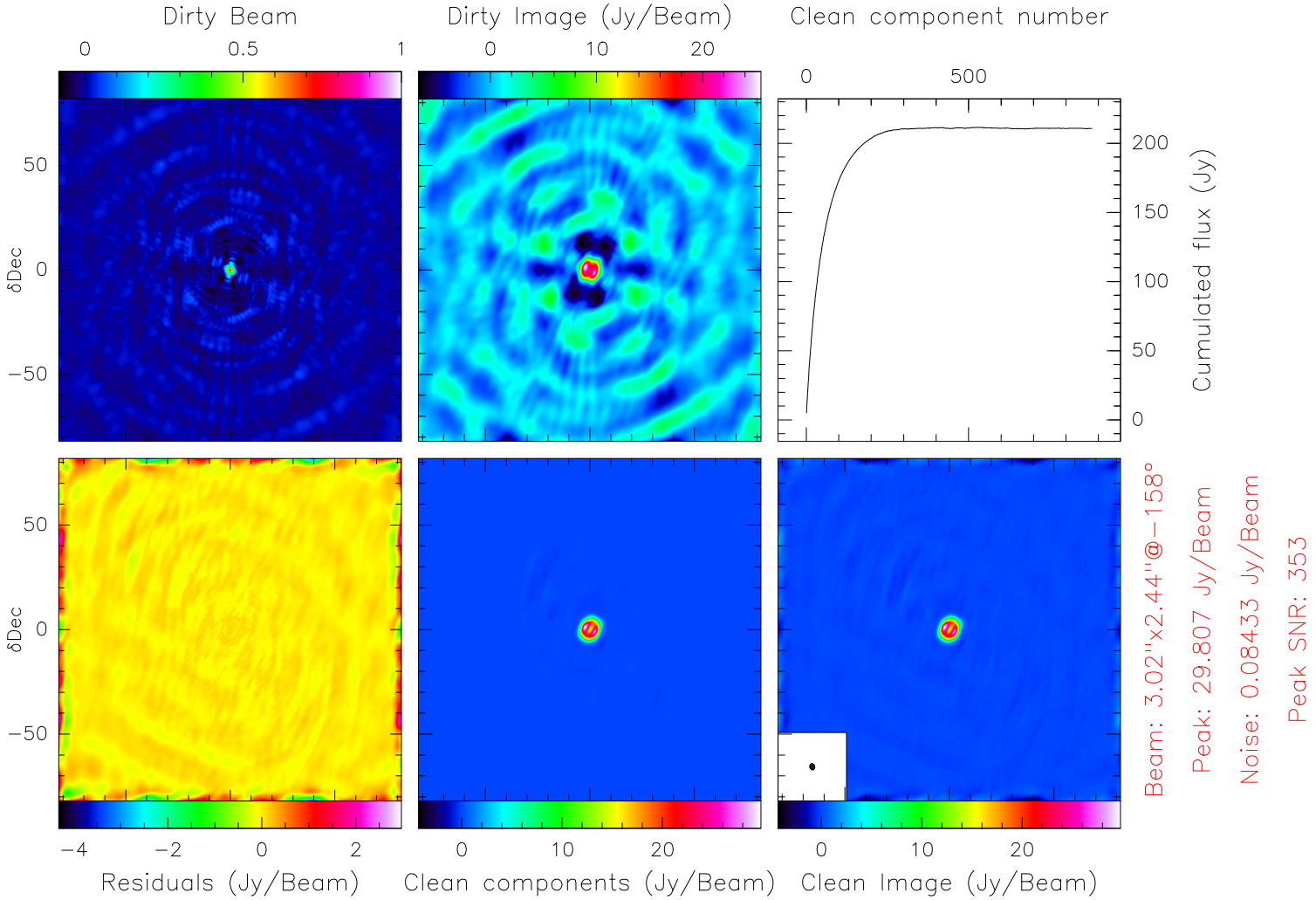
Phase self-calibration of the continuum: III. Test #1: During self-calibration.

```
MAPPING> let name lsb-shift-filt-cont
MAPPING> @ my-selfcal lsb-shift-filt-cont 1 "220" "45"
MAPPING>
MAPPING>
```



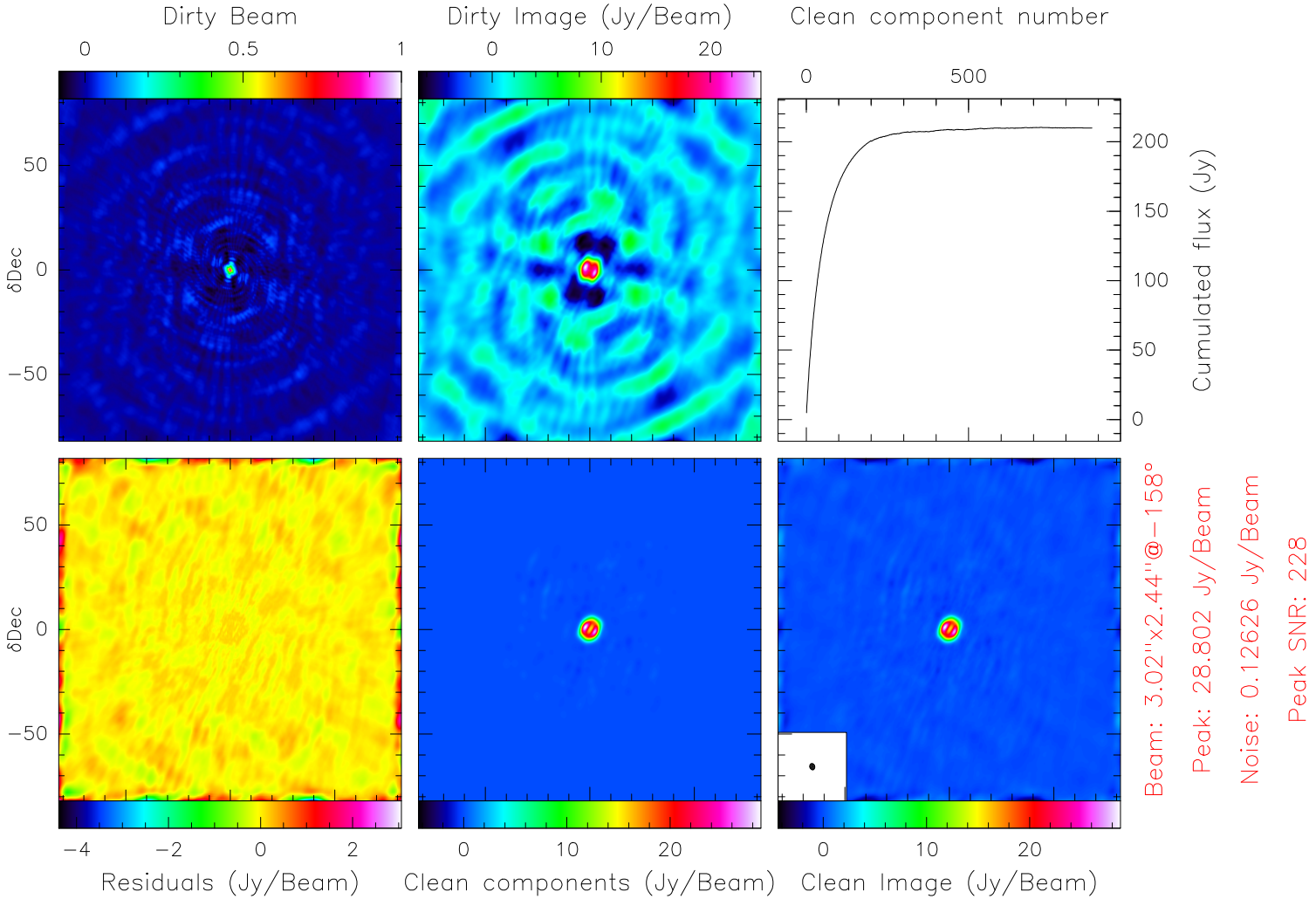
Phase self-calibration of the continuum: III. Test #1: After self-calibration

```
MAPPING> let name lsb-shift-filt-cont-selfcal
MAPPING> let niter 30
MAPPING> go clean
MAPPING> @ deconv-plot 0 0
```



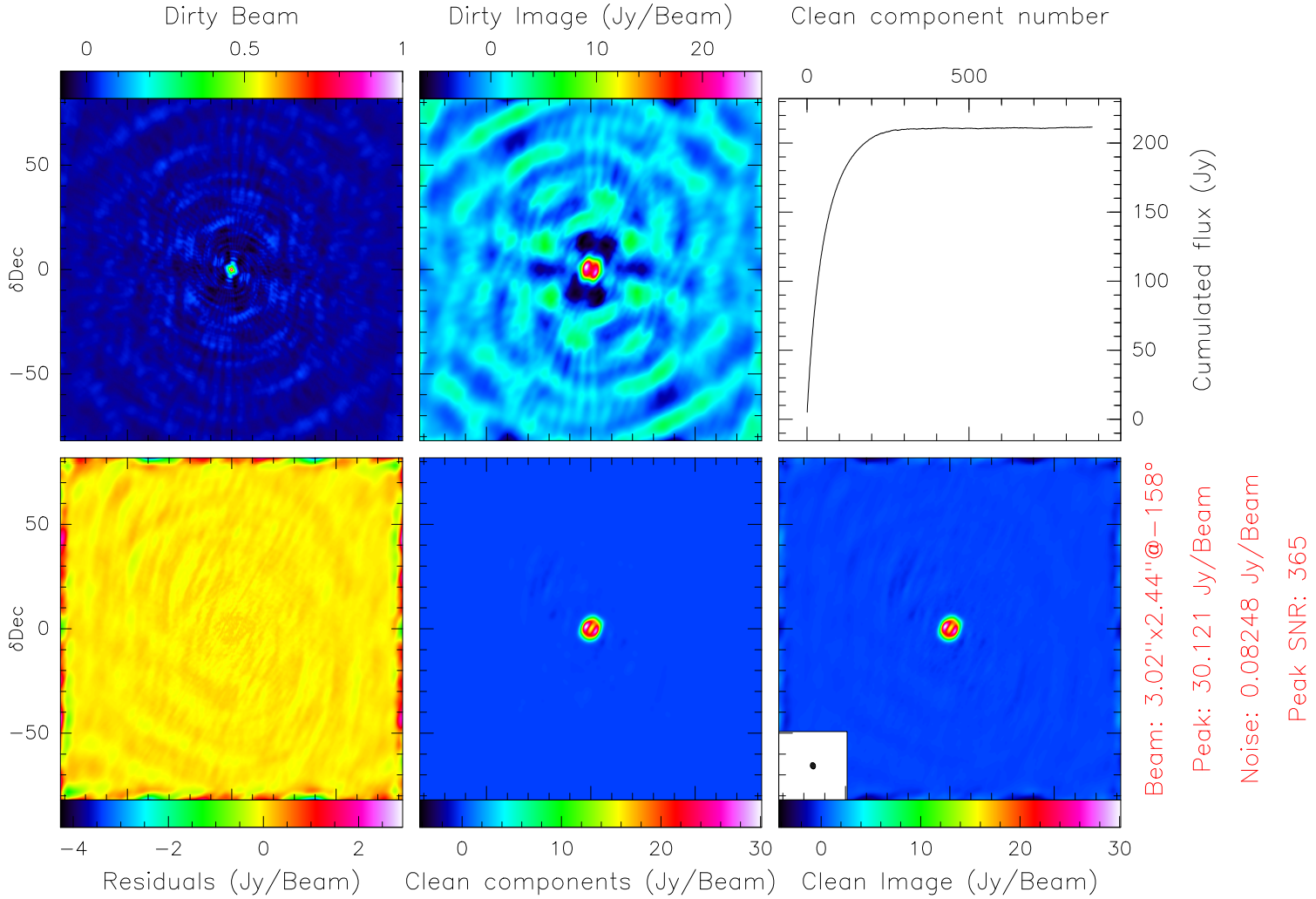
Phase self-calibration of the continuum: III. Test #2: Before self-calibration

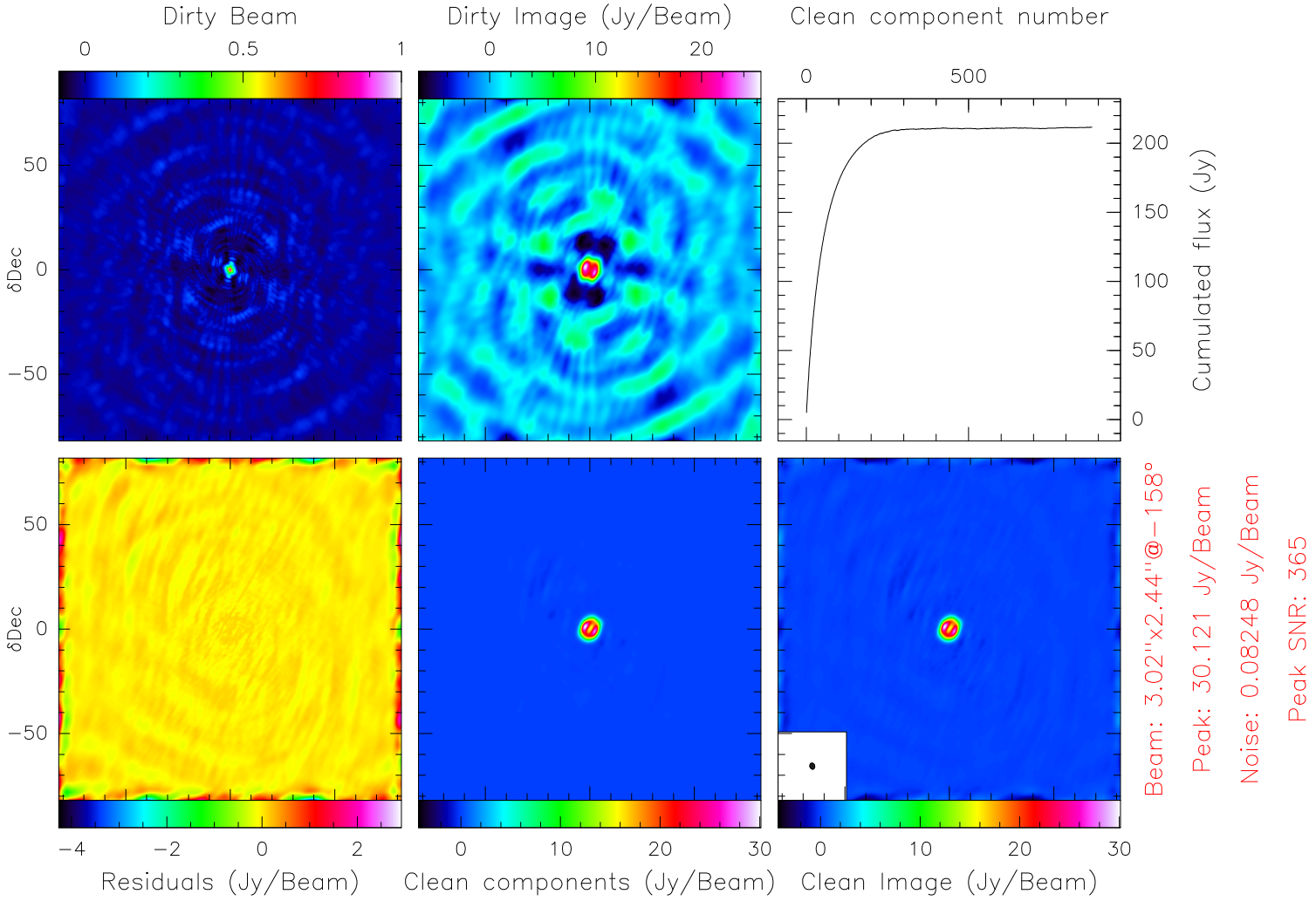
```
MAPPING> let name lsb-shift-filt-cont
MAPPING> let niter 880
MAPPING> go clean
MAPPING> @ deconv-plot 0 0
```



Phase self-calibration of the continuum: III. Test #2: During self-calibration.

```
MAPPING> let name lsb-shift-filt-cont
MAPPING> @ my-selfcal lsb-shift-filt-cont 3 "220 440 880" "45 45 45"
MAPPING>
MAPPING>
```



Phase self-calibration of the continuum: III. Test #2: After self-calibration

```
MAPPING> let name lsb-shift-filt-cont-selfcal
MAPPING> let niter 30
MAPPING> go clean
MAPPING> @ deconv-plot 0 0
```