Imaging with CASA

Sarrvesh S. Sridhar

ASTRON, the Netherlands

April 12, 2019

Session objectives

1. We have already seen the theory behind imaging. We will see how it works in practice.
2. How to image with CASA?
3. Overview of the different parameters used in imaging.

Data preparation

- For this session, we will use a data that has already been calibrated.
- The dataset is from a telescope called Westerbork Synthesis Radio Telescope.

Data preparation

- For this session, we will use a data that has already been calibrated.
- The dataset is from a telescope called Westerbork Synthesis Radio Telescope.
- We want to know what is in the dataset:
  - Hint: use casa task **listobs**.

Data preparation

- For this session, we will use a data that has already been calibrated.
- The dataset is from a telescope called Westerbork Synthesis Radio Telescope.
- We want to know what is in the dataset:
  - Hint: use casa task **listobs**.
  - How many antennas do we have?

Data preparation

- For this session, we will use a data that has already been calibrated.
- The dataset is from a telescope called Westerbork Synthesis Radio Telescope.
- We want to know what is in the dataset:
  - Hint: use casa task **listobs**.
  - How many antennas do we have?
  - What is the name of the source(s) in this dataset?

Data preparation

- For this session, we will use a data that has already been calibrated.
- The dataset is from a telescope called Westerbork Synthesis Radio Telescope.
- We want to know what is in the dataset:
  - Hint: use casa task **listobs**.
  - How many antennas do we have?
  - What is the name of the source(s) in this dataset?
  - How many spectral windows and channels are there?

Data preparation

- For this session, we will use a data that has already been calibrated.
- The dataset is from a telescope called Westerbork Synthesis Radio Telescope.
- We want to know what is in the dataset:
  - Hint: use casa task **listobs**.
  - How many antennas do we have?
  - What is the name of the source(s) in this dataset?
  - How many spectral windows and channels are there?
- Can you use **plotants** to see the layout of the array?

Westerbork Synthesis Radio Telescope (WSRT)

- East-West interferometer located in the Netherlands.

Image credit: ASTRON

Data inspection

- We have 4 measurement sets. What is the difference between them?

Data inspection

- We have 4 measurement sets. What is the difference between them?
- What is the UV-coverage of this observation?

Data inspection

- We have 4 measurement sets. What is the difference between them?
- What is the UV-coverage of this observation?
  - Recall from the lecture: We do not measure the entire uv-plane.

ASTRON

Data inspection

- We have 4 measurement sets. What is the difference between them?
- What is the UV-coverage of this observation?
  - Recall from the lecture: We do not measure the entire uv-plane.
  - Hint: Use **plotms**

Data inspection

- We have 4 measurement sets. What is the difference between them?
- What is the UV-coverage of this observation?
  - Recall from the lecture: We do not measure the entire uv-plane.
  - Hint: Use **plotms**
  - From the UV coverage, can you find the resolution of this observation?

Imaging with CASA

- We will use a task called **tclean** to make images.
- Can you see the parameters of **tclean** using **inp tclean**?

Imaging with CASA

- We will use a task called **tclean** to make images.
- Can you see the parameters of **tclean** using **inp tclean**?
- A lot of parameters to set. Key parameters for a first image:
  - **vis** → Names of the input MS
  - **imagename** → Output name
  - **imsize** → Size of the output image
  - **cell** → Size of a pixel in the output image

Imaging with CASA

- We will use a task called **tclean** to make images.
- Can you see the parameters of **tclean** using **inp tclean**?
- A lot of parameters to set. Key parameters for a first image:
  - **vis** → Names of the input MS
  - **imagename** → Output name
  - **imsize** → Size of the output image
  - **cell** → Size of a pixel in the output image
- Run **tclean** with

```
default tclean
vis=['M101_final_1_obs_0.ms','M101_final_1_obs_3.ms']
imagename='test1'
imsize=1024
cell='10arcsec'
datacolumn='DATA'
go
```

Imaging with CASA

- **tclean** would have produced several new files
  - test1.image
  - test1.model
  - test1.pb
  - test1.psf
  - test1.residual
  - test1.sumwt

Imaging with CASA

- **tclean** would have produced several new files
  - **test1.image** → Open with **viewer()**
  - test1.model
  - test1.pb
  - test1.psf
  - test1.residual
  - test1.sumwt

Imaging with CASA

- **tclean** would have produced several new files
  - **test1.image** → Open with **viewer()**
  - test1.model
  - test1.pb
  - test1.psf
  - test1.residual
  - test1.sumwt

- **Is this what the sky looks like?**

Imaging with CASA

- **tclean** would have produced several new files
  - **test1.image** → Open with **viewer()**
  - test1.model
  - test1.pb
  - test1.psf
  - test1.residual
  - test1.sumwt

- **Is this what the sky looks like?**

- Why are there circles around bright sources? Have you seen this pattern before?

Deconvolution

- From the lecture, we saw

$$\mathrm{I}_{\mathrm{True}}(l, m) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} V_{\mathrm{True}}(u, v)\ \mathrm{e}^{i2\pi(ul+vm)}\ \mathrm{d}u\ \mathrm{d}v \tag{1}$$

Deconvolution

- From the lecture, we saw

$$\mathrm{I}_{\mathrm{True}}(l, m) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} V_{\mathrm{True}}(u, v)\ \mathrm{e}^{i2\pi(ul+vm)}\ \mathrm{d}u\ \mathrm{d}v \tag{1}$$

- But, we do not measure $V(u, v)$ for all values of u and v.

Deconvolution

- From the lecture, we saw

$$\mathrm{I}_{\mathrm{True}}(l, m) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} V_{\mathrm{True}}(u, v)\ \mathrm{e}^{i2\pi(ul+vm)}\ \mathrm{d}u\ \mathrm{d}v \tag{1}$$

- But, we do not measure $V(u, v)$ for all values of u and v.
- So, we define a window function $W(u, v)$

$$\mathrm{I}_{\mathrm{Obs}}(l, m) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} W(u, v)\ V_{\mathrm{True}}(u, v)\ \mathrm{e}^{i2\pi(ul+vm)}\ \mathrm{d}u\ \mathrm{d}v \tag{2}$$

Deconvolution

- From the lecture, we saw

$$\mathrm{I}_{\mathrm{True}}(l, m) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} V_{\mathrm{True}}(u, v)\ \mathrm{e}^{i2\pi(ul+vm)}\ \mathrm{d}u\ \mathrm{d}v \tag{1}$$

- But, we do not measure $V(u, v)$ for all values of u and v.
- So, we define a window function $W(u, v)$

$$\mathrm{I}_{\mathrm{Obs}}(l, m) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} W(u, v)\ V_{\mathrm{True}}(u, v)\ \mathrm{e}^{i2\pi(ul+vm)}\ \mathrm{d}u\ \mathrm{d}v \tag{2}$$

$$\mathrm{I}_{\mathrm{Obs}}(l, m) = \mathcal{F}^{-1}[W(u, v)\ V(u, v)] \tag{3}$$

ASTRON

Deconvolution

- From the lecture, we saw

$$\mathrm{I}_{\mathrm{True}}(l, m) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} V_{\mathrm{True}}(u, v)\ \mathrm{e}^{i2\pi(ul+vm)}\ \mathrm{d}u\ \mathrm{d}v \tag{1}$$

- But, we do not measure $V(u, v)$ for all values of u and v.
- So, we define a window function $W(u, v)$

$$\mathrm{I}_{\mathrm{Obs}}(l, m) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} W(u, v)\ V_{\mathrm{True}}(u, v)\ \mathrm{e}^{i2\pi(ul+vm)}\ \mathrm{d}u\ \mathrm{d}v \tag{2}$$

$$\mathrm{I}_{\mathrm{Obs}}(l, m) = \mathcal{F}^{-1}[W(u, v)\ V(u, v)] \tag{3}$$

$$\mathrm{I}_{\mathrm{Obs}}(l, m) = \mathcal{F}^{-1}[W(u, v)]\ \circledast\ \mathcal{F}^{-1}[V(u, v)] \tag{4}$$

Deconvolution

- From the previous slide,

$$\mathrm{I}_{\mathrm{Obs}}(l, m) = \mathcal{F}^{-1}[W(u, v)] \circledast \mathcal{F}^{-1}[V(u, v)] \tag{5}$$

  - $\mathcal{F}^{-1}[W(u, v)]$ is called "dirty beam"
  - $\mathrm{I}_{\mathrm{Obs}}(l, m)$ is called the "dirty image"
  - $\mathcal{F}^{-1}[V(u, v)]$ is the "true sky"

- The "dirty image" is the "true sky" convolved by the "dirty beam".
- To get the "true" sky image $\rightarrow$ we deconvolve our "dirty image" with the "dirty beam"

Simple deconvolution in practice

- Input image:

2	4	4	3	2
2	4	8.5	4	2
2	4	4	3	2
1	3	4	3	1
2	4	10	5	2
2	3	5	3	2
2	2	3	2	2

- Gain = 0.1
- Threshold = 8.2
- niter = 5

- Dirty beam:

0.1	0.5	0.1
0.5	1.0	0.5
0.1	0.5	0.1

- Model:

ASTRON

Simple deconvolution in practice (iter 1)

- Input image:

2	4	4	3	2
2	4	8.5	4	2
2	4	4	3	2
1	3	4	3	1
2	4	10	5	2
2	3	5	3	2
2	2	3	2	2

- Gain = 0.1
- Threshold = 8.2
- niter = 5

- Dirty beam:

0.1	0.5	0.1
0.5	1.0	0.5
0.1	0.5	0.1

Peak × gain = 1

- Model:

		1		

ASTRON

Simple deconvolution in practice (iter 1)

- Input image:

2	4	4	3	2
2	4	8.5	4	2
2	4	4	3	2
1	3-0.1	4-0.5	3-0.1	1
2	4-0.5	10-1	5-0.5	2
2	3-0.1	5-0.5	3-0.1	2
2	2	3	2	2

- Gain = 0.1
- Threshold = 8.2
- niter = 5

- Dirty beam:

0.1	0.5	0.1
0.5	1.0	0.5
0.1	0.5	0.1

Peak × gain = 1
Subtract Peak × gain × PSF

- Model:

		1		

Simple deconvolution in practice (iter 1)

- Input image:

2	4	4	3	2
2	4	8.5	4	2
2	4	4	3	2
1	2.9	3.5	2.9	1
2	3.5	9	4.5	2
2	2.9	4.5	2.9	2
2	2	3	2	2

- Gain = 0.1
- Threshold = 8.2
- niter = 5

- Dirty beam:

0.1	0.5	0.1
0.5	1.0	0.5
0.1	0.5	0.1

Peak × gain = 1
Subtract Peak × gain × PSF

- Model:

		1		

Simple deconvolution in practice (iter 2)

- Input image:

2	4	4	3	2
2	4	8.5	4	2
2	4	4	3	2
1	2.9	3.5	2.9	1
2	3.5	9	4.5	2
2	2.9	4.5	2.9	2
2	2	3	2	2

- Gain = 0.1
- Threshold = 8.2
- niter = 5

- Dirty beam:

0.1	0.5	0.1
0.5	1.0	0.5
0.1	0.5	0.1

Peak × gain = 0.9

- Model:

		1.9		

Simple deconvolution in practice (iter 2)

- Input image:

2	4	4	3	2
2	4	8.5	4	2
2	4	4	3	2
1	2.9-0.09	3.5-0.45	2.9-0.09	1
2	3.5-0.45	9-0.9	4.5-0.45	2
2	2.9-0.09	4.5-0.45	2.9-0.09	2
2	2	3	2	2

- Gain = 0.1
- Threshold = 8.2
- niter = 5
- Dirty beam:

0.1	0.5	0.1
0.5	1.0	0.5
0.1	0.5	0.1

Peak × gain = 0.9
Subtract Peak × gain × PSF

- Model:

		1.9		

Simple deconvolution in practice (iter 2)

- Input image:

2	4	4	3	2
2	4	8.5	4	2
2	4	4	3	2
1	2.01	3.05	2.01	1
2	3.05	8.1	4.05	2
2	2.01	4.05	2.01	2
2	2	3	2	2

- Gain = 0.1
- Threshold = 8.2
- niter = 5

- Dirty beam:

0.1	0.5	0.1
0.5	1.0	0.5
0.1	0.5	0.1

Peak × gain = 0.9
Subtract Peak × gain × PSF

- Model:

		1.9		

Simple deconvolution in practice (iter 3)

- Input image:

2	4	4	3	2
2	4	8.5	4	2
2	4	4	3	2
1	2.01	3.05	2.01	1
2	3.05	8.1	4.05	2
2	2.01	4.05	2.01	2
2	2	3	2	2

- Gain = 0.1
- Threshold = 8.2
- niter = 5

- Dirty beam:

0.1	0.5	0.1
0.5	1.0	0.5
0.1	0.5	0.1

Peak × gain = 0.85

- Model:

		0.85		
		1.9		

Simple deconvolution in practice (iter 3)

- Input image:

2	4-0.085	4-0.425	3-0.085	2
2	4-0.425	8.5-0.85	4-0.425	2
2	4-0.085	4-0.425	3-0.085	2
1	2.01	3.05	2.01	1
2	3.05	8.1	4.05	2
2	2.01	4.05	2.01	2
2	2	3	2	2

- Gain = 0.1
- Threshold = 8.2
- niter = 5

- Dirty beam:

0.1	0.5	0.1
0.5	1.0	0.5
0.1	0.5	0.1

Peak × gain = 0.85
Subtract Peak × gain × PSF

- Model:

		0.85		
		1.9		

ASTRON

Simple deconvolution in practice (iter 3)

- Input image:

2	3.915	3.575	3.915	2
2	3.575	7.65	3.575	2
2	3.915	3.575	2.915	2
1	2.01	3.05	2.01	1
2	3.05	8.1	4.05	2
2	2.01	4.05	2.01	2
2	2	3	2	2

- Gain = 0.1
- Threshold = 8.2
- niter = 5
- Dirty beam:

0.1	0.5	0.1
0.5	1.0	0.5
0.1	0.5	0.1

Peak $\times$ gain = 0.85
Subtract Peak $\times$ gain $\times$ PSF

- Model:

		0.85		
		1.9		

ASTRON

Simple deconvolution in practice (iter 4)

- Input image:

2	3.915	3.575	3.915	2
2	3.575	7.65	3.575	2
2	3.915	3.575	2.915	2
1	2.01	3.05	2.01	1
2	3.05	8.1	4.05	2
2	2.01	4.05	2.01	2
2	2	3	2	2

- Gain = 0.1
- Threshold = 8.2
- niter = 5

- Dirty beam:

0.1	0.5	0.1
0.5	1.0	0.5
0.1	0.5	0.1

- Model:

		0.85		
		1.9		

Peak (8.1) $<$ Threshold (8.2). So, we stop.

Simple deconvolution in practice (iter 4)

- Input image → .residual :

2	3.915	3.575	3.915	2
2	3.575	7.65	3.575	2
2	3.915	3.575	2.915	2
1	2.01	3.05	2.01	1
2	3.05	8.1	4.05	2
2	2.01	4.05	2.01	2
2	2	3	2	2

- Gain = 0.1
- Threshold = 8.2
- niter = 5

- Dirty beam:

0.1	0.5	0.1
0.5	1.0	0.5
0.1	0.5	0.1

- Model → .model :

		0.85		
		1.9		

Peak (8.1) < Threshold (8.2). So, we stop.

Imaging with CASA – deconvolution

- Run **tclean** again but now with deconvolution.

Imaging with CASA – deconvolution

- Run **tclean** again but now with deconvolution.

```
default tclean
vis=['M101_final_1_obs_0.ms','M101_final_1_obs_3.ms']
imagename='test2'
imsize=1024
cell='10arcsec'
datacolumn='DATA'
niter=1000
gain=0.1
threshold=0.
inp
go
```

ASTRON

Imaging with CASA – deconvolution

- Run **tclean** again but now with deconvolution.

```
default tclean
vis=['M101_final_1_obs_0.ms','M101_final_1_obs_3.ms']
imagename='test2'
imsize=1024
cell='10arcsec'
datacolumn='DATA'
niter=1000
gain=0.1
threshold=0.
inp
go
```

- Don't forget to look at your log.

Imaging with CASA – deconvolution

- Run **tclean** again but now with deconvolution.

```
default tclean
vis=['M101_final_1_obs_0.ms','M101_final_1_obs_3.ms']
imagename='test2'
imsize=1024
cell='10arcsec'
datacolumn='DATA'
niter=1000
gain=0.1
threshold=0.
inp
go
```

- Don't forget to look at your log.
- What was the peak residual after 1000 iterations?

Imaging with CASA – deconvolution

- Open **test2.image** in **viewer()**
- Does the image look better than before?

Imaging with CASA – deconvolution

- Open **test2.image** in **viewer()**
- Does the image look better than before?
- Have a look at your **test2.model**.

Imaging with CASA – deconvolution

- Open **test2.image** in **viewer()**
- Does the image look better than before?
- Have a look at your **test2.model**.
- What does your **test2.residual** look like?
  - There is still a lot of undeconvolved emission in the image.

Imaging with CASA – deconvolution

- Open **test2.image** in **viewer()**
- Does the image look better than before?
- Have a look at your **test2.model**.
- What does your **test2.residual** look like?
  - There is still a lot of undeconvolved emission in the image.
  - niter=1000 is not sufficient.

Imaging with CASA – deconvolution

- Open **test2.image** in **viewer()**
- Does the image look better than before?
- Have a look at your **test2.model**.
- What does your **test2.residual** look like?
  - There is still a lot of undeconvolved emission in the image.
  - niter=1000 is not sufficient.
  - Careful deconvolution with niter + threshold + a clean mask is needed.

Visibility weighting

- **tclean** has a parameter called **weighting**

Visibility weighting

- **tclean** has a parameter called **weighting**
- Takes 3 values: natural, uniform, briggs.
- Make a new image 'test4' with same parameters as before + weighting='uniform'.

Visibility weighting

- **tclean** has a parameter called **weighting**
- Takes 3 values: natural, uniform, briggs.
- Make a new image 'test4' with same parameters as before + weighting='uniform'.
  - Compare **test4.image** and **test3.image**. Do they look identical?

Visibility weighting

- **tclean** has a parameter called **weighting**
- Takes 3 values: natural, uniform, briggs.
- Make a new image 'test4' with same parameters as before + weighting='uniform'.
  - Compare **test4.image** and **test3.image**. Do they look identical?
  - Do they have the same PSF?