ALMA data reduction

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Contents

- ALMA
- Basic interferometry
- Imaging
- ALMA dataset
- Splatalogue
- Practice (please install CASA!)

**Today only the very basics covered:
for full understanding,
check online material ALMA/NRAO**

ALMA

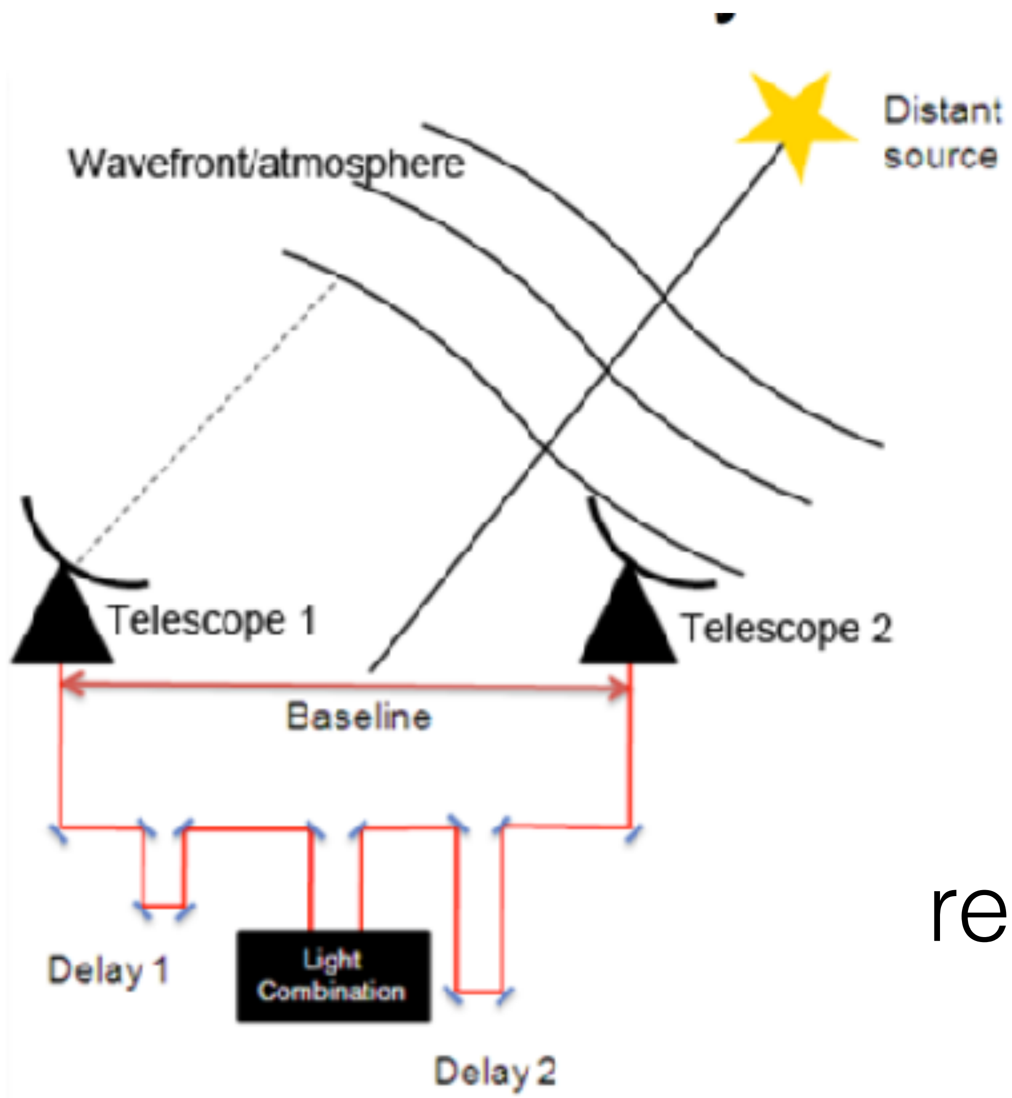
Much more in workshop on April 4th

- Interferometry array of 66 antennas in Atacama desert
- Global collaboration between NRAO, ESO, NAOJ & Chile => open access to all astronomers
- Observing 0.3-3 mm (80-900 GHz) at subarcsecond resolution:
  => rotational lines
- Sensitivity >100x better than previous interferometers
- Data sets are pre-reduced and accessible through searchable data archive (proprietary time 1 year only)
- Large bandwidth in each dataset:
  many options to detect lines serendipitously!

} Ideal for astrochemistry!

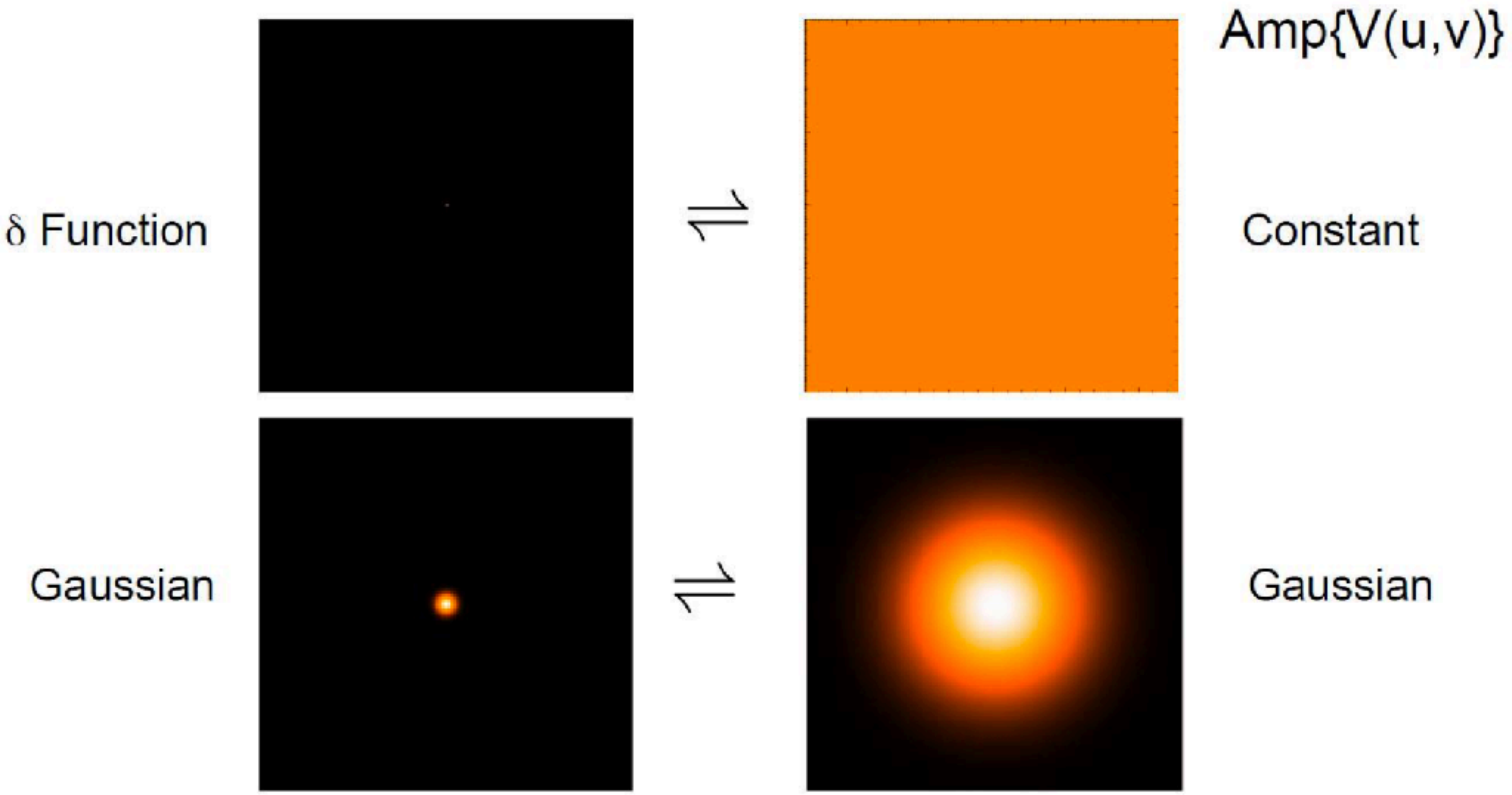
Basic interferometry

- Basic idea: combining the signal of multiple telescopes through interferometry for higher spatial resolution => Fourier transform the signal

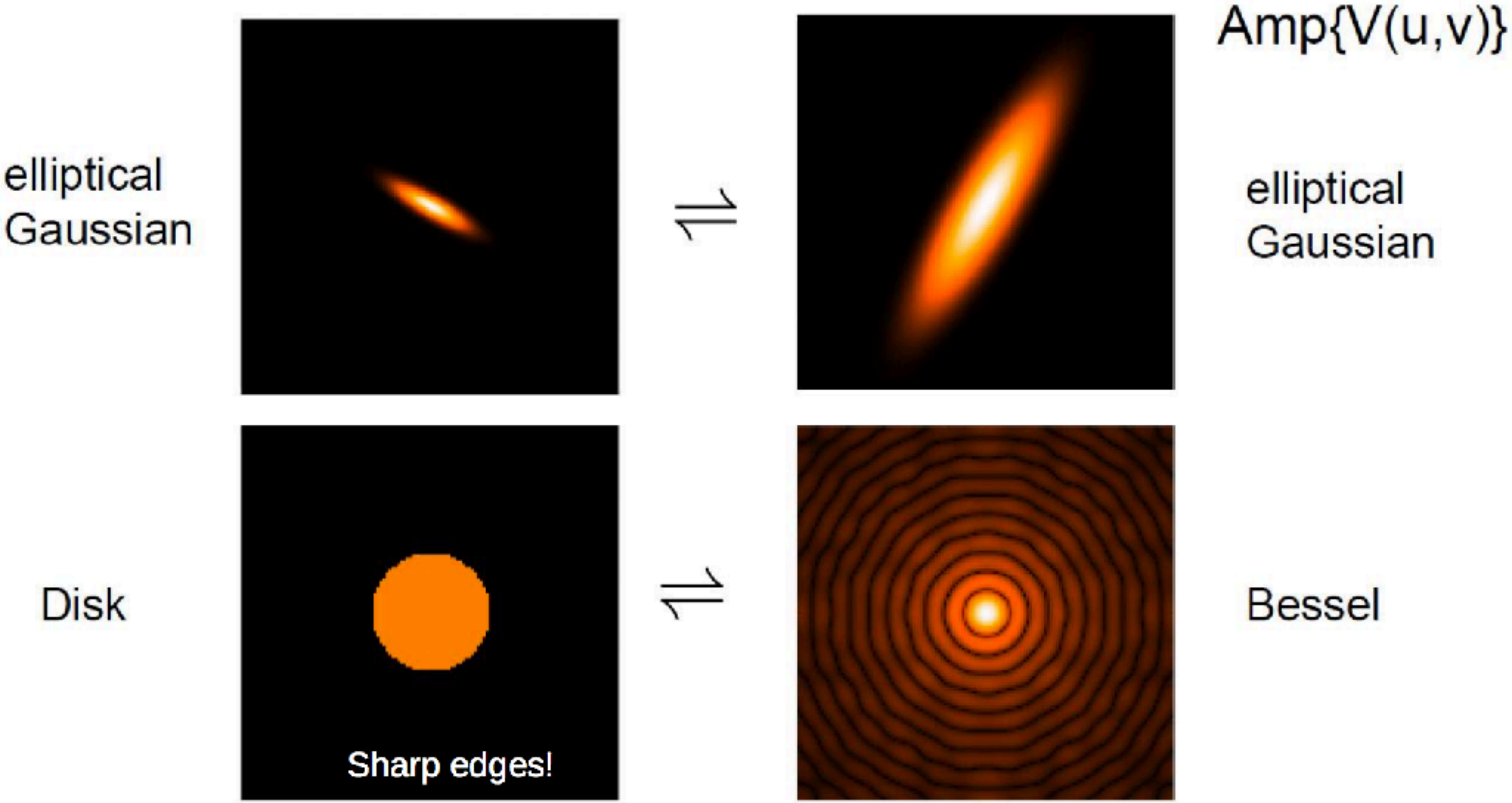


resolution ~ λ/baseline

Basic interferometry



Basic interferometry

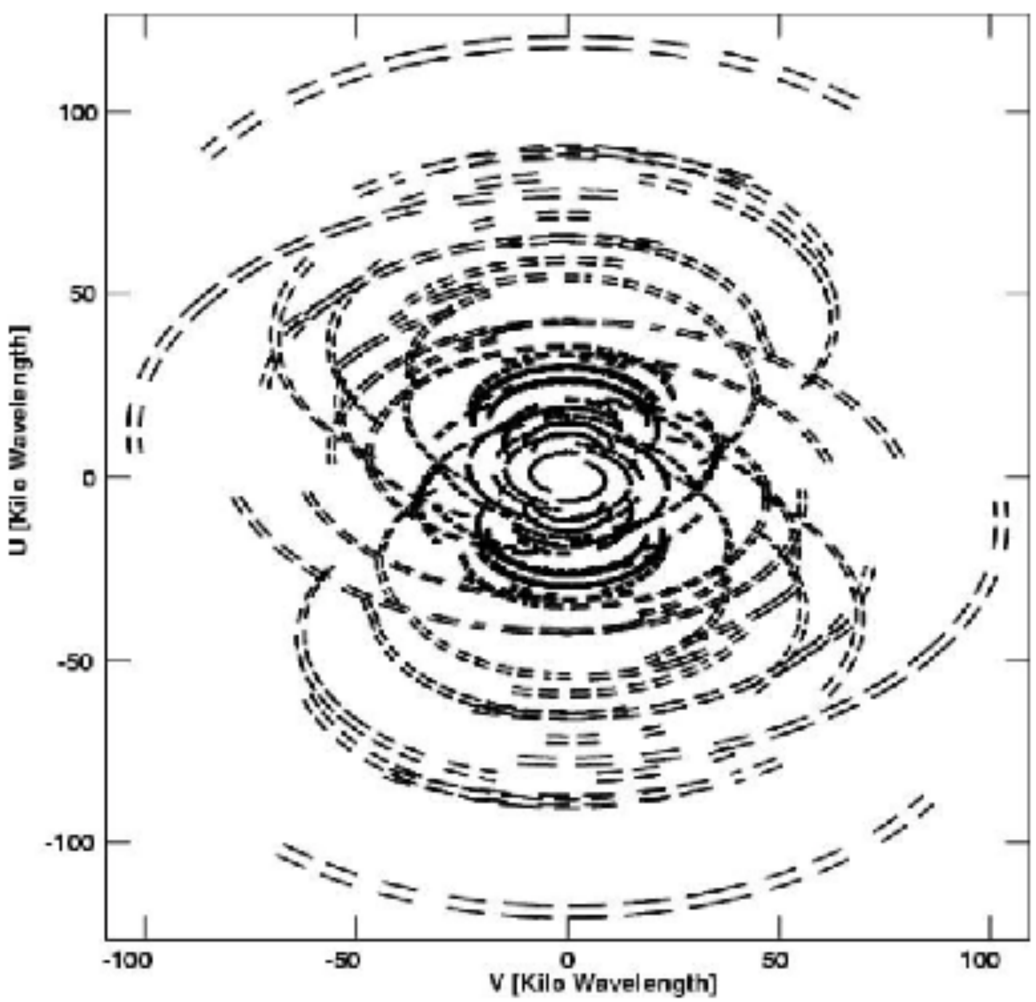


Basic interferometry

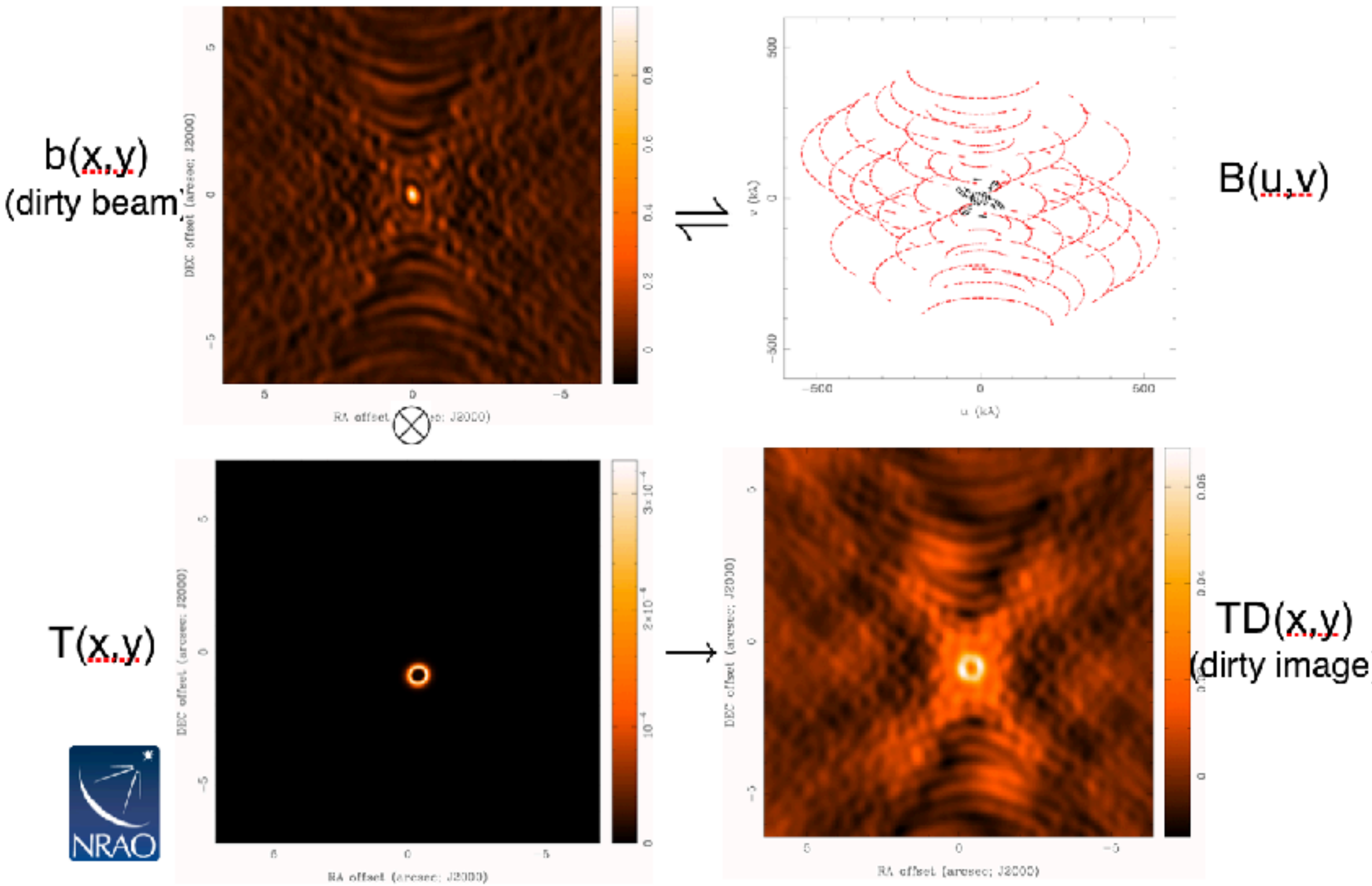
- Measuring signal in the "*uv*"-plane = Fourier transform of *xy*-plane

- *uv* coordinates are set by projected baselines (antenna configuration & Earth rotation)

- FT of *uv* coverage is beam => incomplete sampling: *dirty beam with sidelobes*



Basic interferometry



Imaging

- Cleaning = Imaging =
  Fourier transform ("deconvolving") while trying to remove sidelobes

- Basic idea

  - Deconvolve to create *dirty image*

  - Select a mask region containing *clean components ('model image')*

  - Clean task will convolve the *clean components* with the *dirty beam*, and subtract from the data

  - Repeat this step on the residuals until side lobes < noise level

  - Final output: *clean image = clean components+final residuals*

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user interaction

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user interaction

CASA

- Reducing interferometry data: CASA (python-based)
- Inspection basic properties of a measurement set:
  - listobs
  - plotms
- Using CASA:
  - *inp(task)*, set parameters one-by-one, and *go*
  - *task(parameter1=A, parameter2=B, etc.)*
- Use CASA viewer for checking your final images/cubes
- Important note:
  => for running the ALMA calibration (pipeline) script, always use the proper version of CASA: check README file
  => for imaging the version does not matter (as far as I've seen)

Imaging

- In CASA: task clean()
- Distinguish continuum and line cleaning:
  - continuum
    - mode='mfs'
    - use only line-free channels
  - line
    - mode='velocity' (or 'frequency/channel')
    - restfreq='XGHz'
    - do a continuum subtraction first

Imaging

- In CASA: task clean()
- Distinguish continuum and line cleaning:
  - continuum
    - mode='mfs'
    - use only line-free channels

Prepared datasets of this class

=> Use IRS48_cont.ms

  - line
    - mode='velocity' (or 'frequency/channel')
    - restfreq='XGHz'
    - do a continuum subtraction first

=> Use IRS48_line.ms.contsub

```
#  clean :: Invert and deconvolve image
vis                 =  'measurement.ms'
imagename           =  'myimage.clean'
outlierfile         =         ''
field               =         ''
spw                 =         ''
selectdata          =       True
     timerange      =         ''
     uvrange        =         ''
     antenna        =         ''
     scan           =         ''
     observation    =         ''
     intent         =         ''

mode                =  'velocity'
     nchan          =         -1
     start          =         ''
     width          =         ''
     interpolation  =   'linear'
     resmooth       =      False
     chaniter       =      False
     outframe       =         ''
     veltype        =    'radio'

gridmode            =         ''
niter               =        500
gain                =        0.1
threshold           =   '0.0mJy'
psfmode             =    'clark'
imagermode          =  'csclean'
     cyclefactor    =        1.5
     cyclespeedup   =         -1

multiscale          =         []
interactive         =      False
mask                =         []
imsize              =  [256, 256]
cell                =  ['1.0arcsec']
phasecenter         =         ''
restfreq            =         ''
stokes              =        'I'
weighting           =  'natural'
uvtaper             =      False
modelimage          =         ''
restoringbeam       =      ['']
pbcor               =      False
minpb               =        0.2
usescratch          =      False
allowchunk          =      False
async               =      False
```

Imaging

Image parameters:

- Input/output file names
- imsize = FOV in pixels [400]

=> cover your science target

=> QA2 FOV is large enough for PB, but in disk studies this can be set much smaller, unless other targets nearby

- cell = pixel size ['0.025arcsec']

=> ~5-10 pixels per beam dimension

- weighting = 'natural'/'uniform'/'briggs'/etc.

=> compromise sensitivity and beam size: for now 'natural'

- restoringbeam = fixed beam size ['0.3','0.2','40deg']

=> Only if you want to compare with other data and only with realistic beam size

- pbcor = primary beam correction [True]

Imaging

- Weighting parameter: beam size vs sensitivity

(Super-uniform)

- Extreme uniform
- Careful with image quality

Uniform

- Based on uv-coverage
- Smaller beam
- Lower PS sensitivity
- Problems sampling
- Suitable for high S/N

Briggs Robust = +0.5 (-2 … +2)

- Compromise between resolution and sensitivity
- 'Default'

Natural

- Based on noise-level
- Larger beam
- Higher PS sensitivity
- Suitable for low S/N (weak lines!)

(Tapering)

- Less weight to long baselines: extended structures
- Less relevant in disk studies until <0.1" data

Imaging

Recommended for weak lines

(Super-uniform)

- Extreme uniform
- Careful with image quality

Uniform

- Based on uv-coverage
- Smaller beam
- Lower PS sensitivity
- Problems sampling
- Suitable for high S/N

Briggs Robust = +0.5 (-2 … +2)

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imagename           =  'myimage.clean'
outlierfile         =          ''
field               =          ''
spw                 =          ''
selectdata          =        True
     timerange      =          ''
     uvrange        =          ''
     antenna        =          ''
     scan           =          ''
     observation    =          ''
     intent         =          ''

mode                =  'velocity'
     nchan          =          -1
     start          =          ''
     width          =          ''
     interpolation  =    'linear'
     resmooth       =       False
     chaniter       =       False
     outframe       =          ''
     veltype        =     'radio'

gridmode            =          ''
niter               =         500
gain                =         0.1
threshold           =    '0.0mJy'
psfmode             =     'clark'
imagermode          =   'csclean'
     cyclefactor    =         1.5
     cyclespeedup   =          -1

multiscale          =          []
interactive         =       False
mask                =          []
imsize              =  [256, 256]
cell                = ['1.0arcsec']
phasecenter         =          ''
restfreq            =          ''
stokes              =         'I'
weighting           =   'natural'
uvtaper             =       False
modelimage          =          ''
restoringbeam       =        ['']
pbcor               =       False
minpb               =         0.2
usescratch          =       False
allowchunk          =       False
async               =       False
```

Imaging

Cleaning parameters:

- niter = # iterations of cleaning [10000]

=> set to large number, but interactive

- threshold = level where cleaning should stop

=> typically 2-3 sigma, but interactive

- interactive = cleaning mode [True]

=> unless mask and threshold well- defined, always clean interactively

- mask = mask used for cleaning

=> can be taken from previous cleaning, using the filename myimage.clean.mask, otherwise created in the beginning

```
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outlierfile         =          ''
field               =          ''
spw                 =          ''
selectdata          =        True
     timerange      =          ''
     uvrange        =          ''
     antenna        =          ''
     scan           =          ''
     observation    =          ''
     intent         =          ''

mode                =  'velocity'
     nchan          =          -1
     start          =          ''
     width          =          ''
     interpolation  =    'linear'
     resmooth       =       False
     chaniter       =       False
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     veltype        =     'radio'

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cell                =  ['1.0arcsec']
phasecenter         =          ''
restfreq            =          ''
stokes              =         'I'
weighting           =   'natural'
uvtaper             =       False
modelimage          =          ''
restoringbeam       =      ['']
pbcor               =       False
minpb               =         0.2
usescratch          =       False
allowchunk          =       False
async               =       False
```

Imaging

Line cleaning parameters:

- mode = 'velocity'/'frequency'/'channel'

=> for continuum, mode='mfs'

- nchan = # channels [50]

=> line width!

- start = start-velocity ['-5 km/s'] - width = velocity bin ['0.5 km/s']

=> S/N!

- outframe = velocity frame ['LSRK']

=> important, especially with multiple spws!

- restfreq = frequency molecule ['345.79600GHz']

=> accurate! Check databases

- stokes = Stokes parameter ['I']

=> sometimes accidentally set blank

Imaging

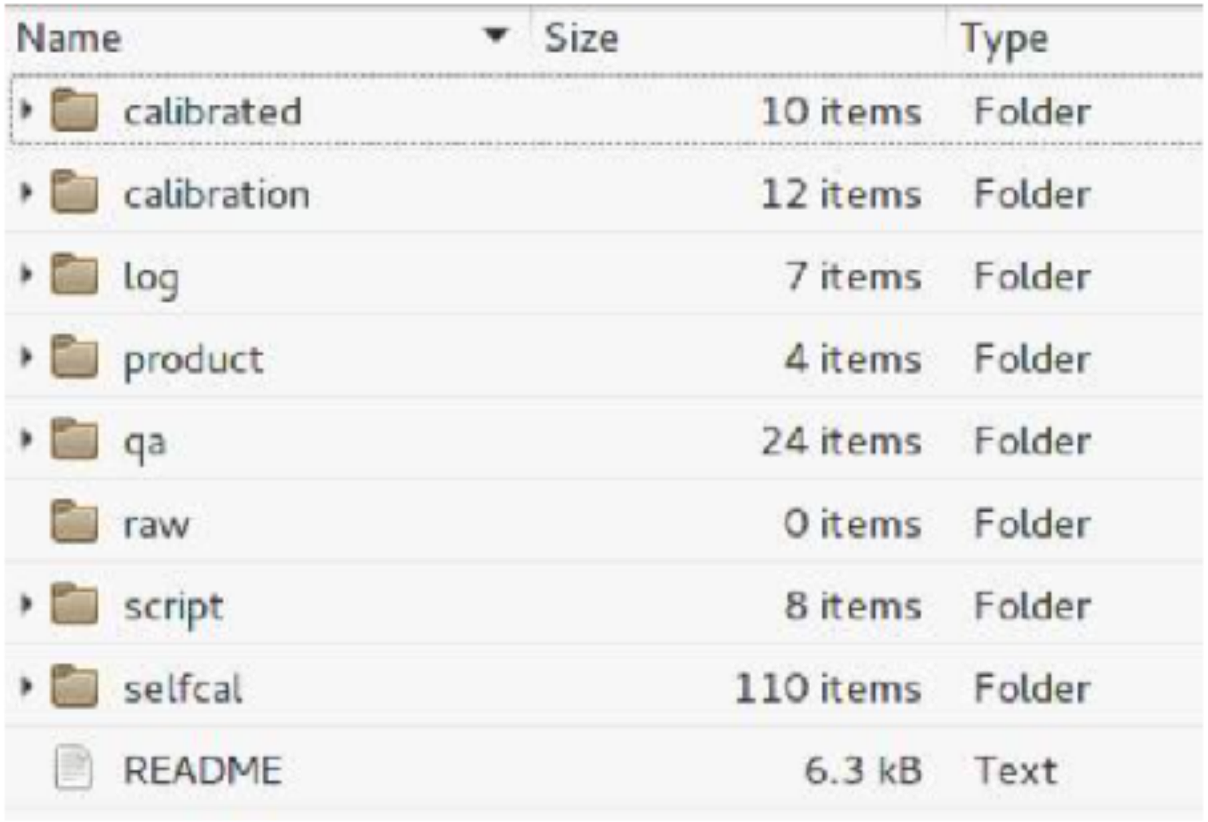
- Demonstration clean of ^{13}CO 6-5 line on screen

ALMA dataset

- All data public after 1 year in ALMA science archive: http://almascience.nrao.edu/aq/

ALMA dataset

- Data from archive are being calibrated and reduced (script or pipeline instructions provided)
- <u>*Measurement set*</u> contains all raw (calibrated) data before imaging
- A downloaded dataset tarball:
    - product fits files (images of lines that were selected by PI in proposal)
    - full dataset
        - *raw* data: run script to get <u>measurement set</u> for imaging in *calibrated*
        - *script*: contains scripts used by ALMA
        - *qa*: quality check of calibration
        - *product:* fits files
        - *README*: comments of reducer



Name	Size	Type
calibrated	10 items	Folder
calibration	12 items	Folder
log	7 items	Folder
product	4 items	Folder
qa	24 items	Folder
raw	0 items	Folder
script	8 items	Folder
selfcal	110 items	Folder
README	6.3 kB	Text

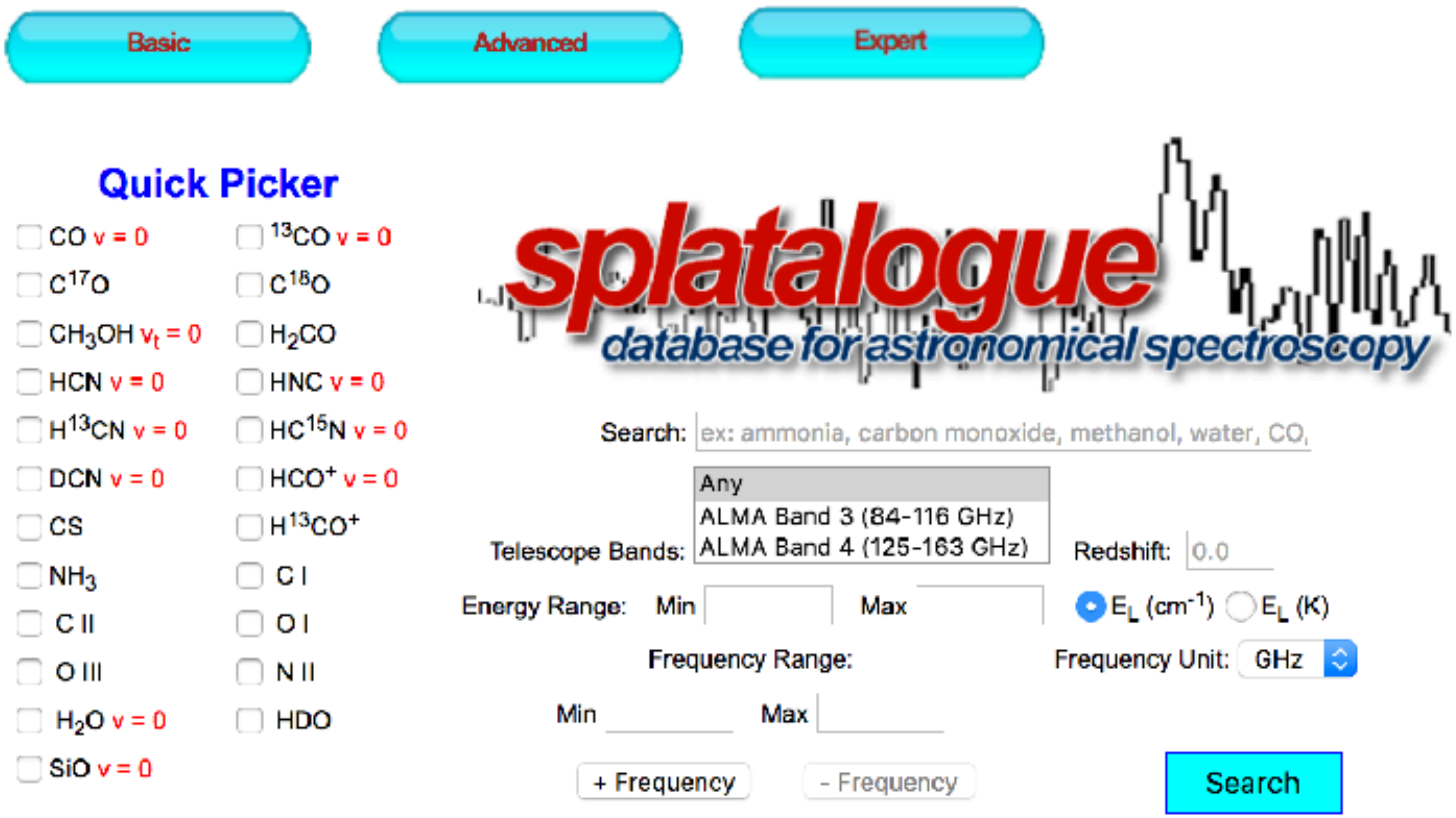
Recommended to practice with one of the online ALMA CASA reduction tutorials

Splatalogue

- ALMA has large spectral windows: potential to find many lines (many more than intent of the PI!)
- Problem with ALMA data: lines not easily visible in the interferometry data => cleaning required
- First find out which lines are present in a frequency range => splatalogue

Splatalogue

- http://www.splatalogue.net
- Online easy-access catalog for molecular lines, using data from various databases (CDMS, JPL, SLAIM)



Splatalogue

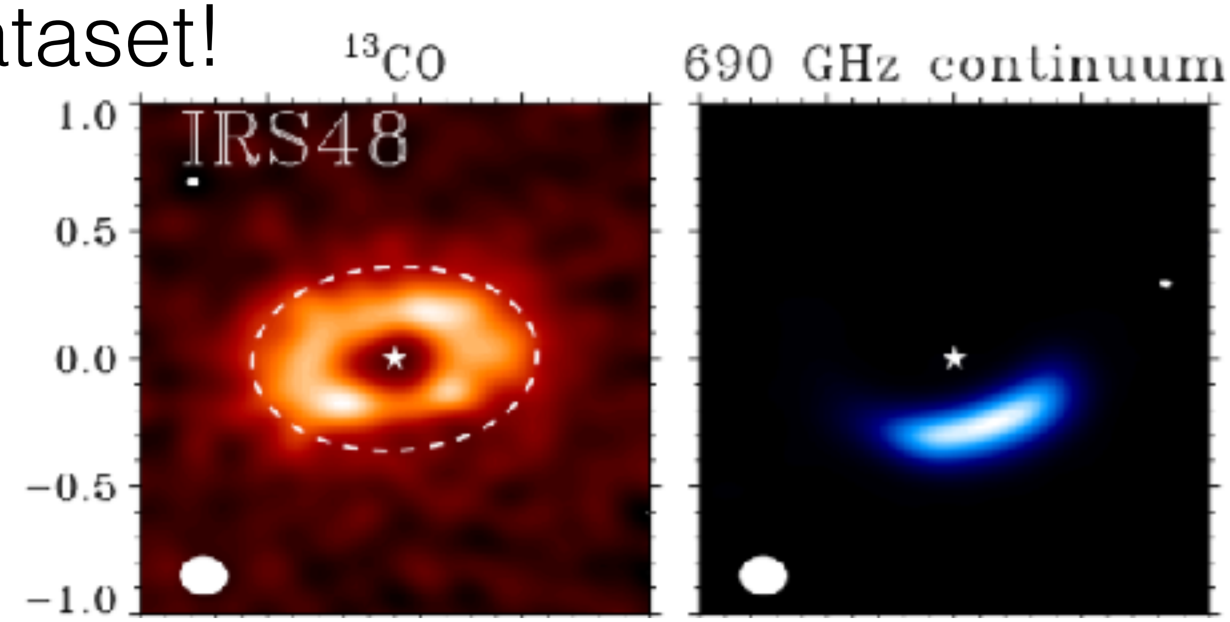
- Either search for properties specific molecule (transitions, rest frequencies, energy levels, Einstein A-coefficient, etc.)
- Or search **within a frequency range**
- Use *Advanced* rather than *Basic*
  - Set energy level < … K
  - Set minimum Einstein A coefficient

  } Why?

  - What molecules do you expect?
  - Careful with "observed transitions": be ready for surprises!

Practice!

- So let's get started with the dataset!



- IRS48:
  disk with asymmetric continuum and ^{13}CO 6-5 line
  => let's see what else is in there

- Continuum imaging as well for practice but try to focus on the lines

For more information and experience, check out online CASA ALMA tutorials:
https://casaguides.nrao.edu/index.php/ALMAguides

Next week(s)

- March 1st: Colloquium Ilse Cleeves
- March 2nd: Student presentations
- March 9th: Student presentations
- April 4th: ALMA preparation workshop (entire IfA)

Useful links interferometry

- NRAO CASA guides:
  https://casaguides.nrao.edu/

- ALMA Proposer's guide, Technical handbook, etc.:
  https://almascience.nrao.edu

- NRAO Synthesis imaging workshop:
  https://science.nrao.edu/science/meetings/2014/14th-synthesis-imaging-workshop/lectures

- CARMA Summer school:
  http://w.astro.berkeley.edu/~wright/school_2014.pdf

- IRAM Interferometry Summer school:
  http://www.iram-institute.org/EN/content-page-331-7-67-331-0-0.html