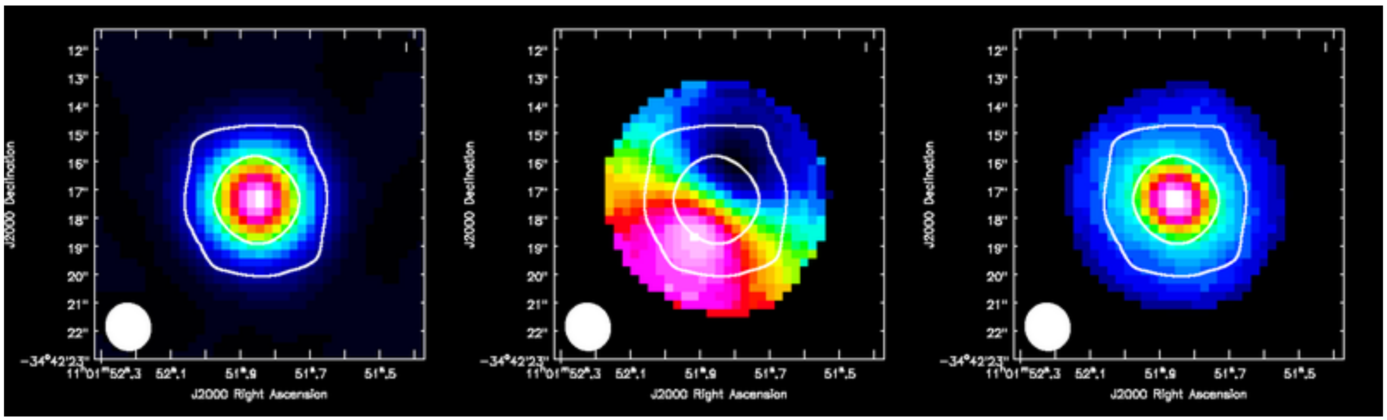
TW Hya CASA
Spectral Line Reduction Tutorial
Imaging and Analysis

Day 4, Wednesday September 9th 12:15



HCO+(4-3) moment maps of TW Hya

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CASA guides tutorial link

Will follow script given at link below, or on ERIS webpage, or available on data sticks:

www.mpia.de/~johnston/ERIS/TWHya_advanced_script.txt

Extended version of reduction can be found on the CASA guides website:
https://casaguides.nrao.edu

You can copy-paste these commands into CASA as we go along

Which data to use

- If you finished running the calibration script from T5 on Monday, you can use that.
- Or you can use the calibrated data tar file:

`TWHya_corrected.tgz`

You can untar/zip this using: `tar –xvzf FILENAME`

It should contain: `TWHydra_corrected.ms`

Average and split out the data for continuum imaging

This will speed up the clean task

```
os.system('rm -rf TWHydra_cont.ms*')
split(vis='TWHydra_corrected.ms',
      outputvis='TWHydra_cont.ms',
      spw='0~3:7~1273', width=30,
      datacolumn='data')
```

- When averaging your own data, remember not to over-average or you will get bandwidth smearing.
- Calculate the largest bandwidth you can safely average for your required field of view

Check which channels need flagged using plotms

```
plotms(vis='TWHydra_cont.ms', spw='0~3',
       xaxis='channel', yaxis='amp’,
       avgtime='1e8', avgscan=T,
       coloraxis='spw', iteraxis='spw',
       xselfscale=T)
```

Question: which channels need flagged?

Check which channels need flagged using plotms

```
plotms(vis='TWHydra_cont.ms', spw='0~3',
       xaxis='channel', yaxis='amp',
       avgtime='1e8', avgscan=T,
       coloraxis='spw', iteraxis='spw',
       xselfscale=T)
```

Question: which channels need flagged?

Answer:

spw 0:18, 2:23~24 and the end of spw 3

Flag these line/bad channels in continuum data

```
flagdata(vis='TWHydra_cont.ms', mode='manual',
         spw='0:18~18, 2:23~24, 3:33~42')
```

To do: check the flagging worked using plotms again

Estimating the noise for imaging

Run listobs on data:

```
listobs('TWHydra_corrected.ms',
        listfile='TWHydra_corrected.ms.listobs')
```

Can estimate total time on source using script here (or available on data sticks):

www.mpia.de/~johnston/ERIS/time_on_source.py

What is the time on source: ?

```
execfile('time_on_source.py')
```

Estimating the noise for imaging

Measure total time on source using script:

```
time_on_source.py
```

Time on source ~2.4 hr

Can then use the ALMA sensitivity calculator to determine the expected noise (if have internet):

https://almascience.nrao.edu/proposing/sensitivity-calculator

Need: Declination, Obs. frequency, bandwidth of continuum, number of antennas, time on source

Estimating the noise for imaging

Use the ALMA sensitivity calculator to determine the expected noise (if have internet connection):

https://almascience.nrao.edu/proposing/sensitivity-calculator

Need: Declination (-35deg), Obs. Frequency (~350GHz), bandwidth of continuum (3x0.46875GHz), number of antennas (8), time on source (2.4hr)

Expected sensitivity = 0.176 mJy/beam

To do:

Determine the sensitivity for the line observations for 0.32 km/s channels

(Answer: ~11 mJy/beam)

Continuum imaging

```
os.system('rm -rf TWHydra_contall.*')
clean(vis='TWHydra_cont.ms',
      imagename='TWHydra_contall',
      mode='mfs', imagermode='csclean',
      imsize=100, cell=['0.3arcsec'], spw='',
      weighting='briggs', robust=0.5,
      mask='', usescratch=False, interactive=T,
      threshold=‘0.6mJy', niter=10000)
```

Continuum imaging

```
os.system('rm -rf TWHydra_contall.*')
clean(vis='TWHydra_cont.ms',
      imagename='TWHydra_contall',
      mode='mfs', imagermode='csclean',
      imsize=100, cell=['0.3arcsec'], spw='',
      weighting='briggs', robust=0.5,
      mask='', usescratch=False, interactive=T,
      threshold='0.6mJy', niter=10000)
```

mode='mfs' – use multi-frequency synthesis algorithm for continuum imaging

imagermode='csclean' – Cotton-Schwab clean

cell=['0.3arcsec'] – the synthesised beam at 350GHz should be ~1.7”, want 4-5 pixels across the beam

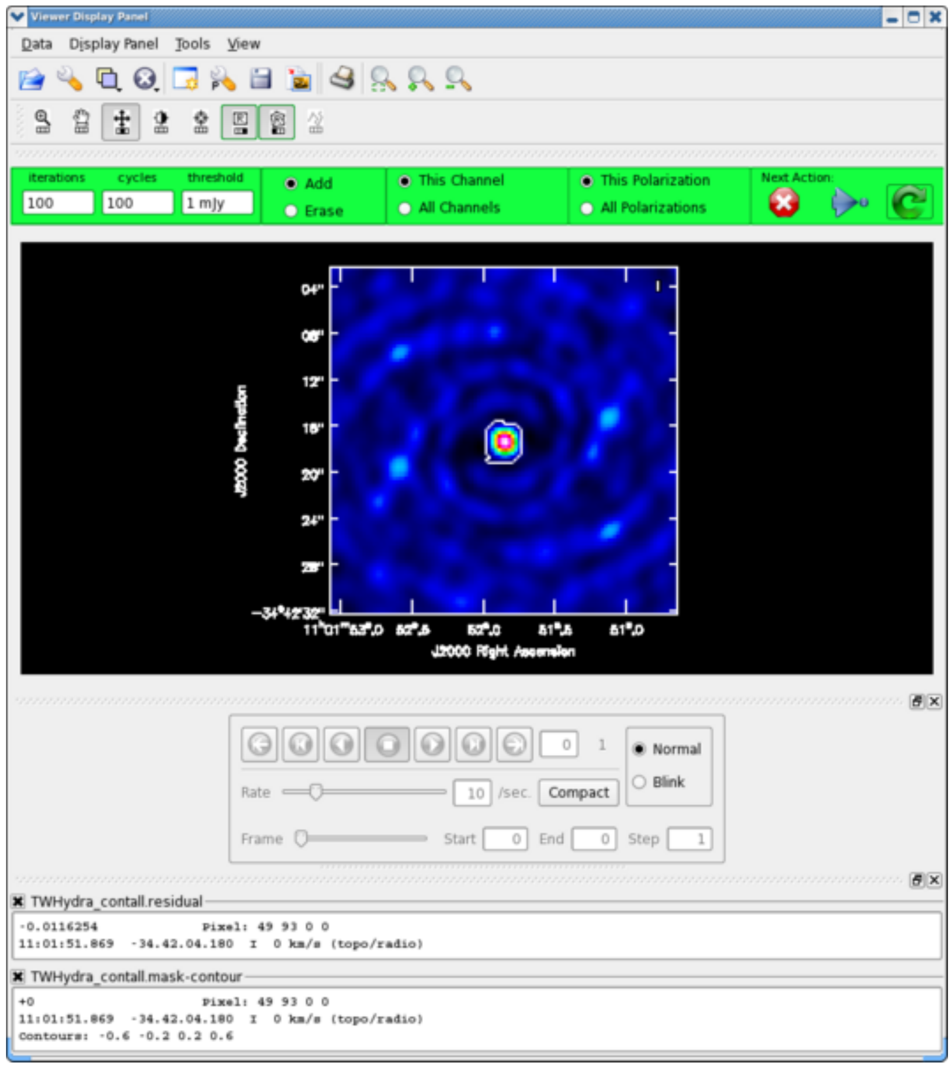
imagesize=100 – primary beam is ~18”, so 0.3”x100 = 30” will cover it

weighting='briggs', robust=0.5 – how you weight the data in uv-space (this is a good compromise)

threshold='0.6mJy' — a threshold for cleaning ~3 x noise

niter=10000 – enough iterations so you reach the threshold first

Continuum imaging



Split out the line data

For the $^{12}CO(3\text{-}2)$:

```
os.system('rm -rf TWHydra_CO3_2.ms*')
split(vis='TWHydra_corrected.ms’,
      outputvis='TWHydra_CO3_2.ms',
      datacolumn=‘data', spw='2')
```

For the HCO^+:

```
os.system('rm -rf TWHydra_HCOplus.ms*')
split(vis='TWHydra_corrected.ms',
      outputvis='TWHydra_HCOplus.ms',
      datacolumn=’data', spw='0')
```

Continuum subtraction

To do: Find the line free channels for both datasets using plotms, e.g. for $^{12}CO(3\text{-}2)$:

```
plotms(vis='TWHydra_CO3_2.ms',
       spw='0',xaxis='channel', yaxis='amp',
       avgtime='1e8', avgscan=T, coloraxis='spw',
       plotfile='CO3_2_channel.png')
```

Continuum subtraction

To do: Find the line free channels for both line datasets using task **plotms**, e.g. for $^{12}CO(3\text{-}2)$:

```
plotms(vis='TWHydra_CO3_2.ms',
       spw='0',xaxis='channel', yaxis='amp',
       avgtime='1e8', avgscan=T, coloraxis='spw',
       plotfile='CO3_2_channel.png')
```

Then subtract them using task **uvcontsub**, e.g.

```
uvcontsub(vis='TWHydra_CO3_2.ms',
          fitorder=1,
          fitspw='0:0:6~630,0:800~1265')
```

Can also use task **imcontsub** to subtract in image plane.

Continuum subtraction

To do:

Plot the continuum subtracted data (*.ms.contsub) as a function of velocity using task plotms.

Parameters you'll need to set:

avgtime and **avgscan** (average over all time and scans)

transform and **freqframe** (transform to LSR velocity frame)

restfreq CO(3-2): 345.79599GHz and HCO+(4-3) 356.7342GHz

Continuum subtraction

To do:

Plot the continuum subtracted data (*.ms.contsub) as a function of velocity using task plotms.

Which would look like this:

```
plotms(vis='TWHydra_CO3_2.ms.contsub',
        xaxis='velocity', yaxis='amp’, avgtime='1e8',
        avgscan=T, transform=T, freqframe='LSRK’,
        restfreq='345.79599GHz', plotrange=[-20,23,0,0],
        plotfile='CO3_2_vel.png')
```

Questions:

Which reference frame would the data be in if freqframe was not set?

Which velocities should we image between? (including line-free channels)

Continuum subtraction

To do:
Plot the continuum subtracted data (*.ms.contsub) as a function of velocity using task plotms.

Which would look like this:

```
plotms(vis='TWHydra_CO3_2.ms.contsub',
       xaxis='velocity', yaxis='amp', avgtime='1e8',
       avgscan=T, transform=T, freqframe='LSRK',
       restfreq='345.79599GHz', plotrange=[-20,23,0,0],
       plotfile='CO3_2_vel.png')
```

Questions:
Which reference frame would the data be in if freqframe was not set?
Which velocities should we image between? (including line-free channels)

Answers:
Velocity reference frame: TOPO; Velocity range: -4 to +8 km/s

$^{12}CO(3-2)$ imaging

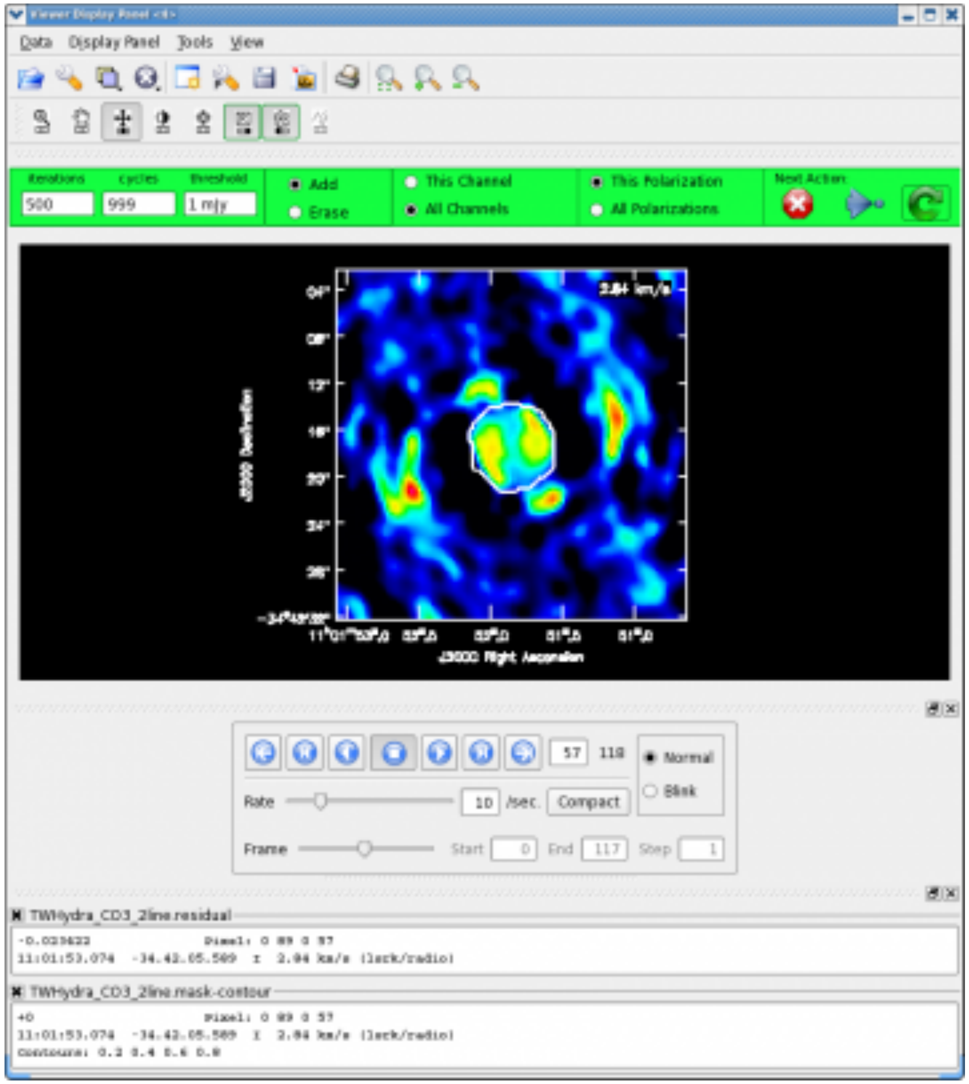
```
os.system('rm -rf TWHydra_CO3_2line.*')
clean(vis='TWHydra_CO3_2.ms.contsub',
      imagename='TWHydra_CO3_2line', imagermode='csclean',
      spw='', imsize=100, cell=['0.3arcsec'],
      mode='velocity', start='-4km/s', width='0.32km/s',
      nchan=40, restfreq='345.79599GHz', outframe='LSRK',
      weighting='briggs', robust=0.5,
      mask='', usescratch=False, interactive=T,
      threshold='33mJy', niter=100000)
```

The velocity resolution (3 x 122 kHz or 0.106km/s = 0.317 km/s)

Enough channels to get to +8.48 km/s

Approx. x3 expected noise

$^{12}CO(3\text{-}2)$ imaging



HCO^+(4-3) imaging

To do: (if you have time)

make an image of HCO^+(4-3)

Rest frequency of HCO+(4-3): 356.7342GHz

Image Analysis

To do: determine the restoring synthesised beam sizes for the two images using the task **imhead**, e.g.

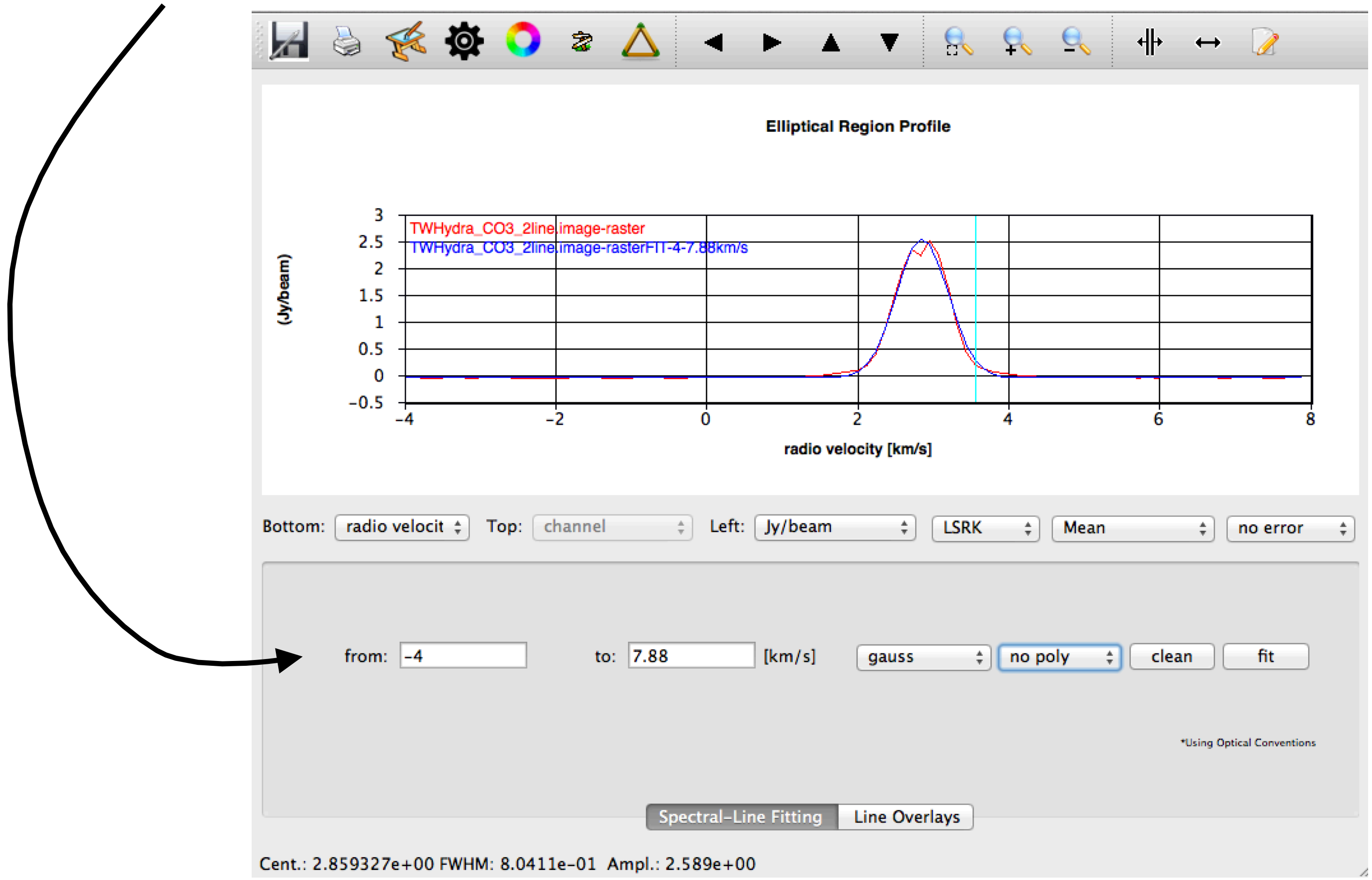
```
imhead("TWHydra_CO3_2line.image")
```

Save line spectra to file using spectral profile tool

- Open line images in viewer, e.g.
  `viewer("TWHydra_CO3_2line.image")`
- Use the Spectral Profile Tool (icon that looks like window with red line in it) to make a spectrum
- Save the spectrum to file (for creating a figure using your favourite software, e.g. python + matplotlib)
- Save elliptical region file using menu -> View -> Regions -> File tab

Line fitting in CASA

Can fit lines with Gaussians using “Spectral-Line fitting” tab in Spectral Profile Tool window



Line fitting in CASA

Can also do fit using command line, e.g.

```
specfit(imagename='TWHydra_CO3_2line.image',
        region='spectrum_region.crtf', poly=-1,
        logresults=True)
```

To do:

Check you get similar results to interactive fitting

Note: you'll need to save a region in the viewer first

Moment maps of line emission

Zero moment map = integrated flux map

First moment map = intensity-weighted velocity

Second moment map = intensity-weighted
velocity dispersion
about the mean

These are made using task **immoments**

RMS noise and spectral extent

First estimate the spectral extent of the $^{12}CO(3\text{-}2)$ emission using the viewer:

```
viewer("TWHydra_CO3_2line.image")
```

To do:

- Estimate the noise in the image by drawing a region in a line-free channel and double clicking in it (results appear in CASA terminal)
- Open the same image as a contour map in the same viewer
- Determine the range of channels which have flux > 5 sigma

RMS noise and spectral extent

RMS noise can also be determined using the task imstat for line-free channels, e.g.

```
results = imstat("TWHydra_CO3_2line.image",
                 chans=“7")
print results
print "  s.d. ", results['sigma']
print "  RMS ", results['rms']
```

Moment maps of line emission

To do:

Make zero moment maps for both lines using task immoments, e.g.

```
os.system('rm -rf TWHydra_CO3_2line.image.mom0')
immoments(imagename='TWHydra_CO3_2line.image',
          outfile='TWHydra_CO3_2line.image.mom0',
          moments=[0], chans='13~32')
```

Your range here

Viewing the moment maps using task imview

```
imview( raster= {'file':'TWHydra_CO3_2line.image.mom0',
                 'range':[-1.,10.]},
        contour={'file':'TWHydra_contall.image',
                 'base':0, 'unit':0.0025,
                 'levels':[3,100]} )
```

Making the first and second moment maps

First moment:

```
os.system('rm -rf TWHydra_CO3_2line.image.mom1')
immoments(imagename='TWHydra_CO3_2line.image',moments=[1],
          outfile='TWHydra_CO3_2line.image.mom1',
          chans='13~32',includepix=[0.5,100])
```

Second moment:

```
os.system('rm -rf TWHydra_CO3_2line.image.mom2')
immoments(imagename='TWHydra_CO3_2line.image',moments=[2],
          outfile='TWHydra_CO3_2line.image.mom2',
          chans='13~32',includepix=[0.5,100])
```

4 or 5 sigma from noise in channel with brightest emission

Viewing and exporting the moment maps

```
imview( raster=[ {'file':'TWHydra_CO3_2line.image.mom0'},
                 {'file':'TWHydra_CO3_2line.image.mom1'},
                 {'file':'TWHydra_CO3_2line.image.mom2'} ],
        contour={'file':'TWHydra_contall.image',
                 'base':0, 'unit':0.0025,
                 'levels':[3,100]} )
```

To do: Export your images using task exportfits, e.g.

```
os.system('rm -rf TWHydra_CO3_2line.image.fits')
exportfits(imagename='TWHydra_CO3_2line.image',
           fitsimage='TWHydra_CO3_2line.image.fits')
```

To do: Check what parameters **velocity=True** and **dropstokes=True** do

Primary beam corrections

- Without correction for the primary beam response (default), images should have roughly constant noise across them…
- …but the flux is incorrect everywhere except the field centre
- To measure fluxes in your images, make sure to correct for the primary beam response first!

Primary beam corrections

You can use the task impbcor:

```
impbcor(imagename='TWHydra_contall.image',
       pbimage='TWHydra_contall.flux’,
       mode=‘divide’,
       outfile='TWHydra_contall.pbcor')
```

Fitting a gaussian to the continuum using task imfit

Fit the continuum emission with a 2D gaussian:

```
imfit(imagename="TWHydra_contall.pbcor",
      box="40,40,60,60”, logfile = "contin_fit.log",
      residual="TWHydra_contall.fitresid")
```

To do:

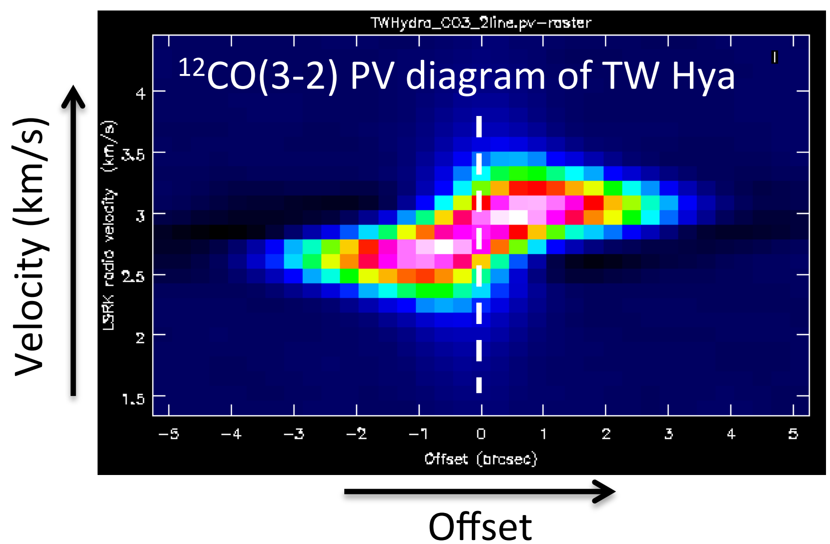
- Check the residual image to make sure the fit was good
- Look at the log file and determine the integrated flux and deconvolved size

Making position-velocity diagrams in viewer and using task impv

- Open one of the image cubes in the viewer
- Click on the P/V tool button 
- Draw a slice across the source (blue to red shifted)
- Go to menu => view => Regions => pV tab
- Click “Generate P/V”
- Change the averaging width and generate again
- Save the image
- (Note down the position angle!)

Making position-velocity diagrams in viewer and using task impv

If you had the full spectral resolution dataset, your pv plot would look like this:



Making position-velocity diagrams in viewer and using task impv

Can also generate pv diagrams using the task impv, e.g.

```
os.system('rm -rf TWHydra_CO3_2line.image.pv')
impv(imagename='TWHydra_CO3_2line.image',
               mode='length', center=[50,49],
               length='10arcsec', width='8arcsec',
               pa='-35deg', chans='12~30',
               outfile='TWHydra_CO3_2line.image.pv')
```

Peak pixel in mom0 map

Position angle determined above (could also fit mom0 emission)

Reprojecting an image using task imregrid

For example, to reproject to Galactic coordinates:

```
imregrid(imagename='TWHydra_CO3_2line.image',
         template='GALACTIC',
         output='TWHydra_CO3_2line.Galactic')
```

Or to reproject to another image header (only example!!):

```
regrid_dict = imregrid(imagename="target.image",
                       template="get")
imregrid(imagename="input.image",
         output="output.image",
         template=regrid_dict)
```

parameters in blue are not real images, just example entries

More analysis tasks…

Can be found by typing "tasklist" in CASA:

```
Analysis
------------------
imcollapse              imsmooth
imcontsub               imstat
imfit                   imsubimage
imhead                  imtrans
immath                  imval
immoments               listvis
impbcor                 rmfit
impv                    slsearch
imrebin                 specsmooth
imreframe               splattotable
imregrid
```

More analysis tasks…

The CASA **toolkit** (from which the CASA tasks are built) can also be used, but is more advanced:

http://casa.nrao.edu/docs/CasaRef/CasaRef.html