

# Spectral line observational and data reduction considerations

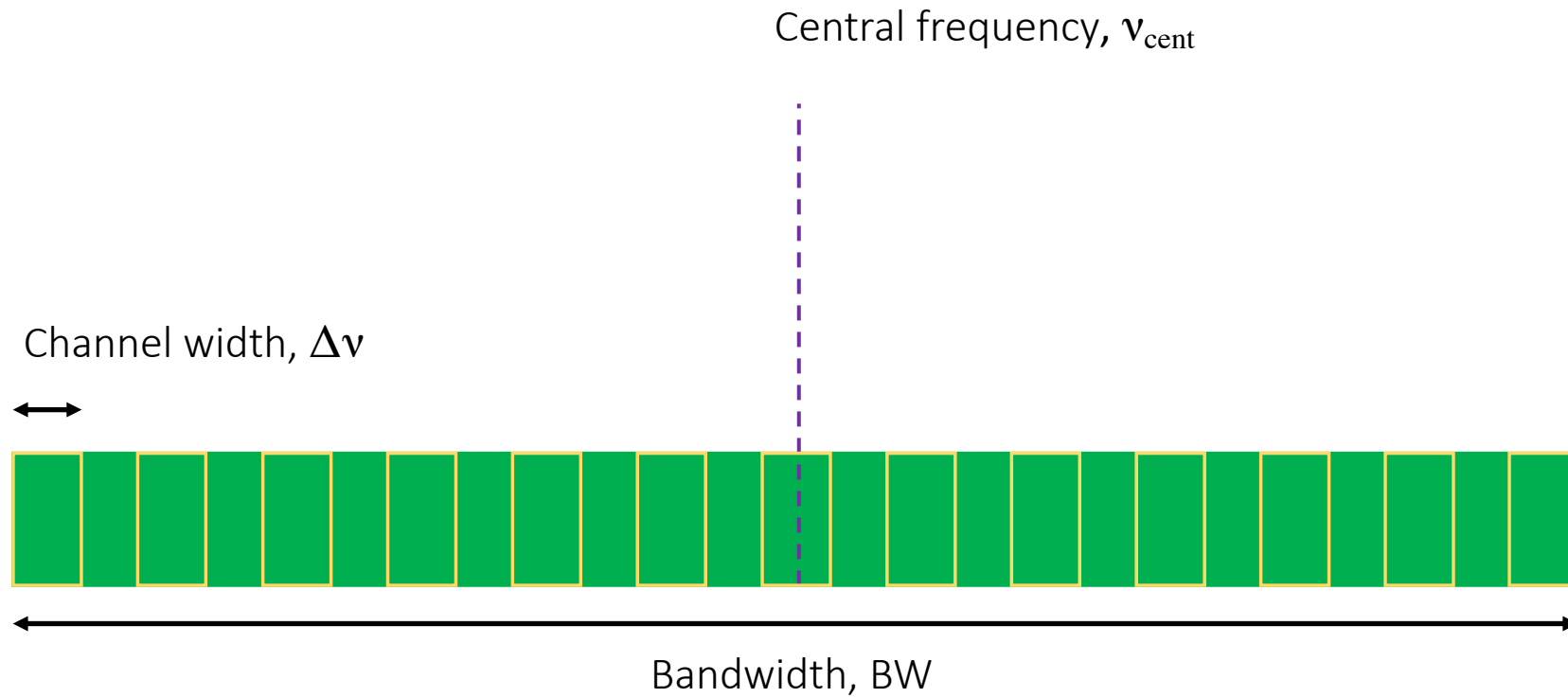
Adam Avison

Considerations for spectral line observations

# A generalized way to think about observational spectral set ups

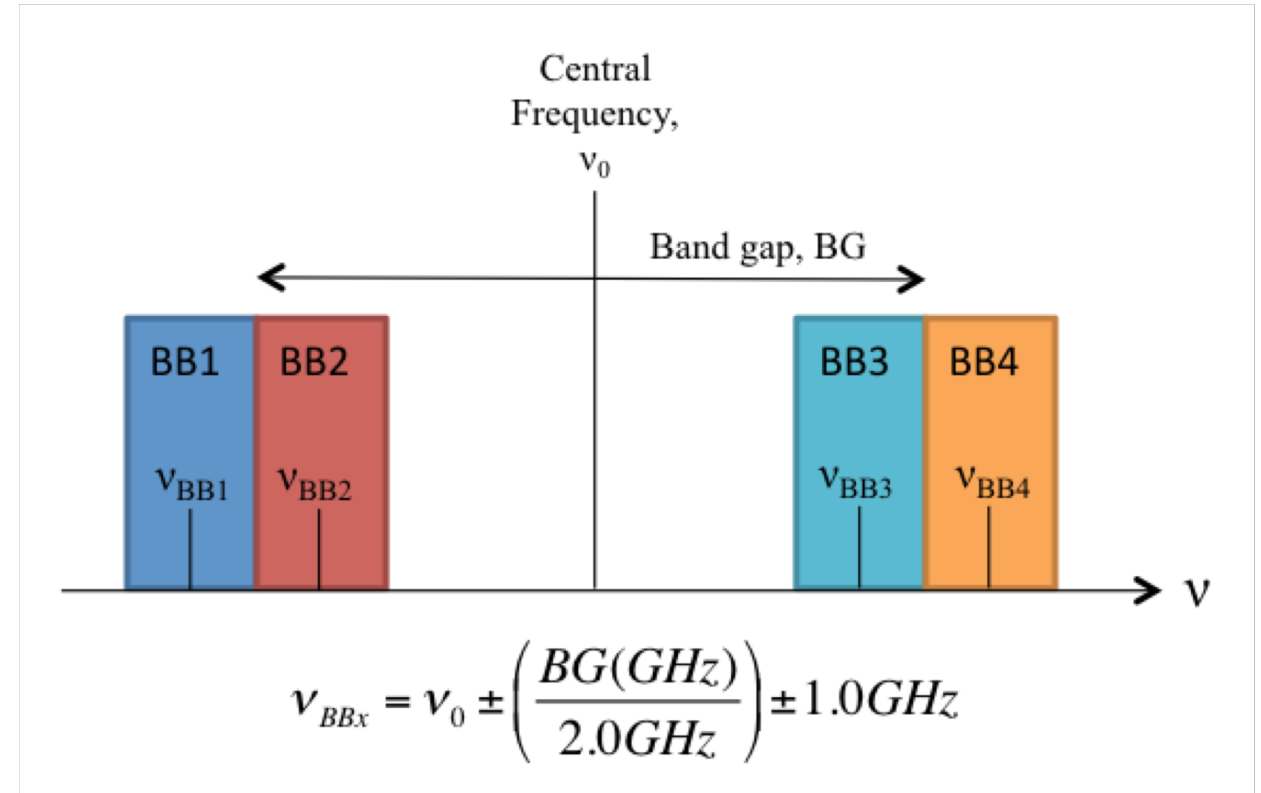
- Typically, telescopes will allow you to observe a given frequency range (bandwidth, BW) which is divided into a number,  $N$ , frequency intervals (channels) around a given central frequency.
- Your spectral resolution (channel width) is your  $BW/N$ .
- Normally, for data rate/hardware reasons  $N$  is limited to some maximum value (e.g 4096). This means the finer channel widths are limited to observations using smaller BWs.

# The last slide as a diagram



# ALMA specifics

- ALMA allows users to place spectral windows (SPWs) anywhere within four 2.0GHz basebands (BB) located in the upper and lower sidebands based on the LO frequency,  $\nu_0$ .
- SPWs in a given baseband must all have the same velocity resolution ( $\Delta v$ ). In practice that means that all SPWs in a BB must have the same BW.
- ALMA has a couple of modes TDM (time division mode) and FDM (frequency division mode). The former is used for SPWs which will primarily be used for continuum observations (few, coarse chans) the latter is the tunable spectral line observing mode.



BG differs based on ALMA bands

# Velocity – Frequency relation

- Radio convention

$$\frac{V_{radio}}{c} = \frac{\nu_0 - \nu}{\nu_0}$$

- Optical convention

$$\frac{V_{optical}}{c} = \frac{\nu_0 - \nu}{\nu} = z$$

- Thus  $V_{optical} \neq V_{radio}$  so be careful when working from  $z$  to frequency. You can change your Doppler convention in the Observing Tool.

# Velocity rest frames

- **Topocentric:** In this case no correction for the source or Earth motion is made. The Centre Frequency (both Rest and Sky) will be identical.
- **LSRK:** Velocity with respect to the Kinematic local standard of rest, at 20.0 km/s<sup>1</sup> in the direction 18h, +30° [B1900.0]. Based on the mean velocity of the stars in the Solar neighbourhood. *[Use for Galactic targets]*
- **Barycentric:** This is with respect to the center of mass of the Earth-Sun system, and is very close to the heliocentric frame. *[Use for Extra-galactic high-z targets]*

# Velocity rest frames, ALMA note

- If anything other than TOPO are selected in the OT at the proposal stage then:
  - ‘Velocity of the science target in the chosen reference frame *and* the velocity of the observatory relative to the chosen reference frame are used to set the centre frequencies of the science SPWs.’- **ALMA technical handbook**
- The ALMA observatory doesn’t apply Doppler tracking during observation. Corrections are set at the start of the observation and changes required to compensate for the Earth’s motion during the observation are made offline in CASA reduction.



# Know your source velocity

You need to be sure of

1. The source velocity and ...
2. The rest frame it will be measured in ...

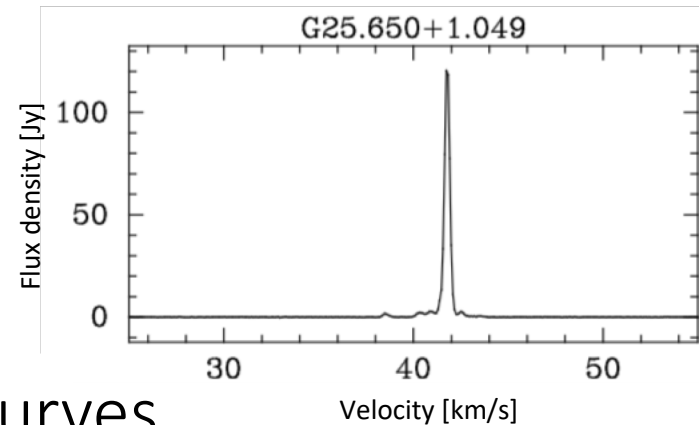
... so that your target line doesn't fall out of your SPW

If you're unsure go for a large BW!

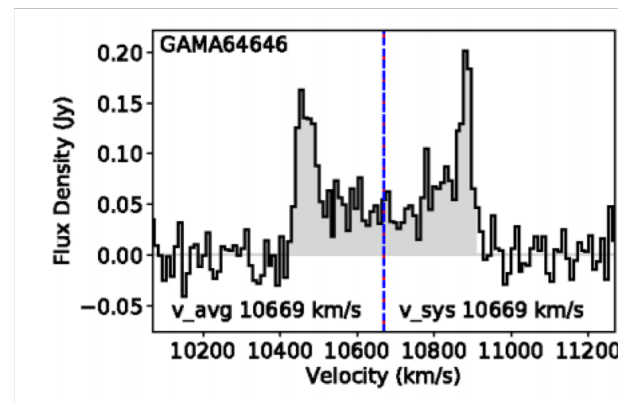
With ALMA the OT should allow to easily visualise this effect.

# Know your velocity width

- Depending on the astrophysical emission mechanism and kinematic properties of your source spectral line widths can vary from:
- Tenths to a couple of km/s  
e.g. Galactic Maser emission
- 100s of km/s e.g. galactic rotation curves



Breen et al. 2015



Sansom et al. 2018

# Know your velocity width

This has two fold implications

1. You should make sure you have sufficient velocity resolution to resolve your line (i.e not all emission in  $<1$  channel (preferably  $>3$ )).
2. Your BW needs to be large enough to accommodate all your emission.

# Signal-to-noise requirements

- When considering a spectral line observation an estimate on the expected peak emission will be required.
- In the ALMA specific case (i.e. sensitivity *(not time)* driven proposals) you should consider which of the following scenarios your project falls into:

## CASE 1: Spectral line 'only'

Continuum is unlikely to be detected in the source.

Base sensitivity goal on SNR required to achieve science with spectral lines.

## CASE 2: Line and Continuum

Source likely to contain both line and continuum emission, upon which I want to do science.

Base sensitivity goal on SNR required to do science with continuum. *Ensure SNR 'on line will also allow science.* Make sure your BW-line regions given sufficient sensitivity for continuum

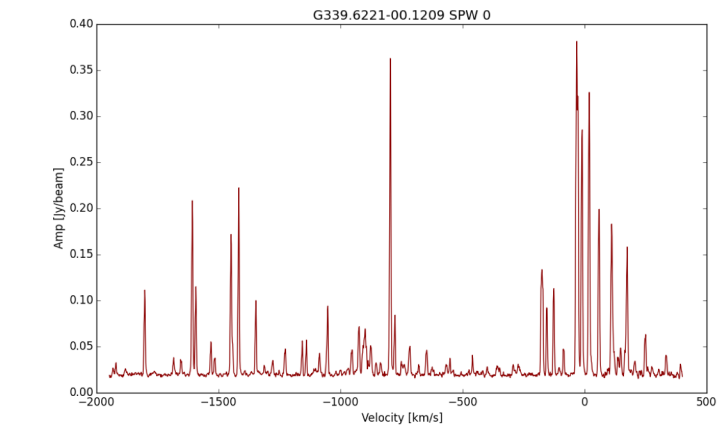
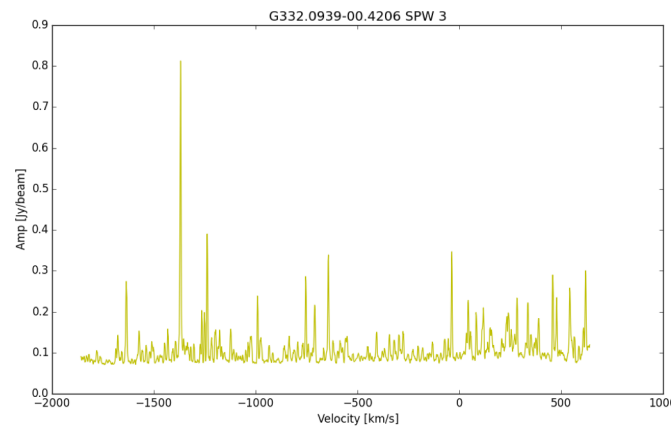
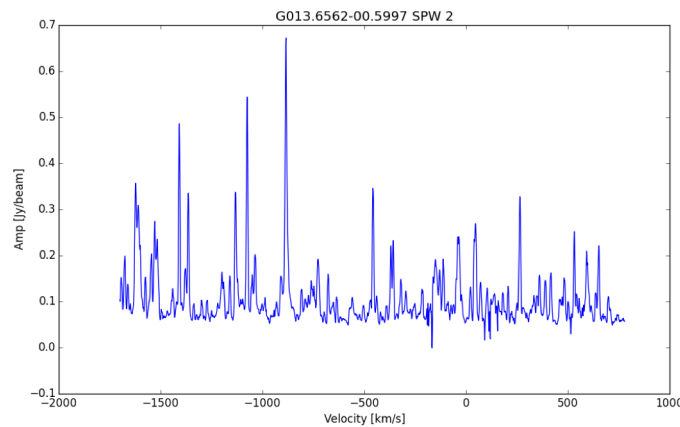
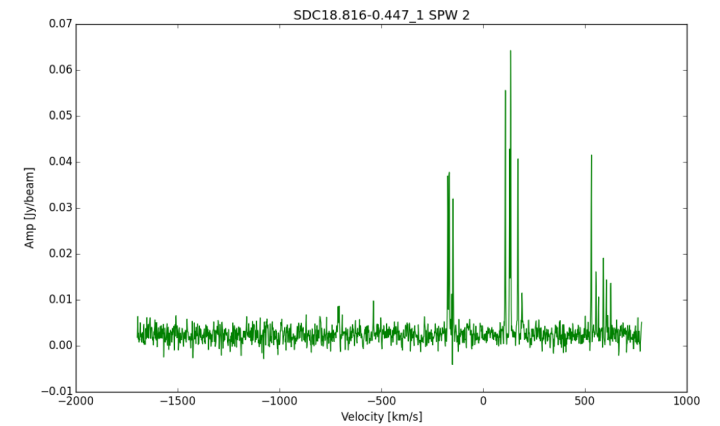
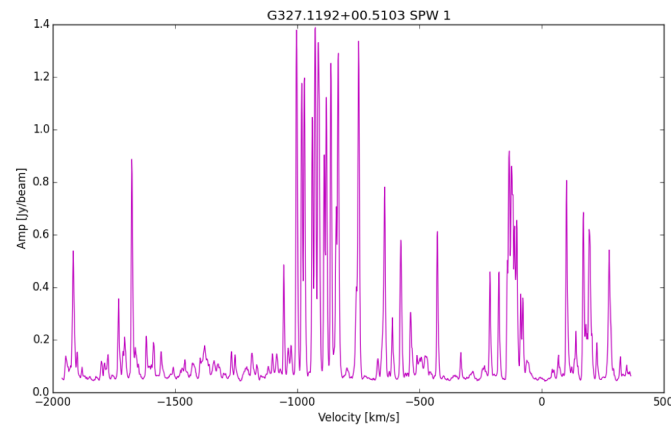
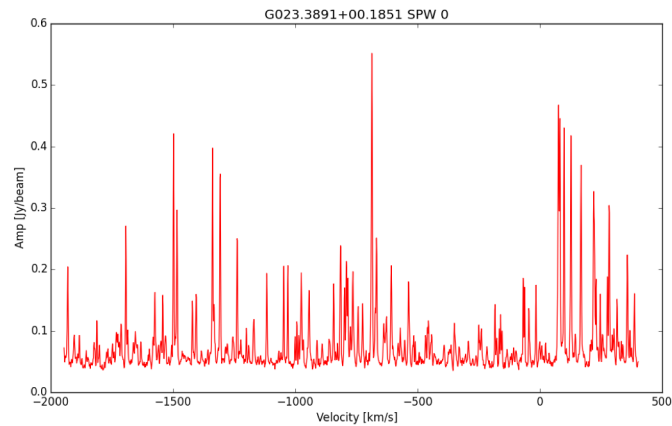
## CASE 3: Continuum only

I don't really care about any lines. They are a nuisance.

Base sensitivity goal on SNR required to do science with continuum. Estimate potential line contamination to ensure BW sufficient to achieve goals, make sure this is mentioned in your proposal.

# Case 4: Line forests

A chemists dream... An astronomers 'nightmare'



Differences in data reduction

# For calibration:

- Thankfully, there aren't many!
- **Bandpass:** It is often useful to do a bit of smoothing in terms of channels (you'll have a lot). This tends to give a better solution to the BP shape.
- Remember everything will be a bit slower as you're dealing with a greater number of channels, thus a greater parameter space to calibrate across.

# For imaging:

- **tclean:** You need to switch from specmode='mfs' to 'cube', which opens up options to set the dimensions of the velocity axis.

These are:

- Number of channels
  - Start 'channel' \*
  - Width of channel, here you can apply a bit of averaging \*
- 
- You'll also need to define a clean threshold in terms of the sensitivity 'per channel'.

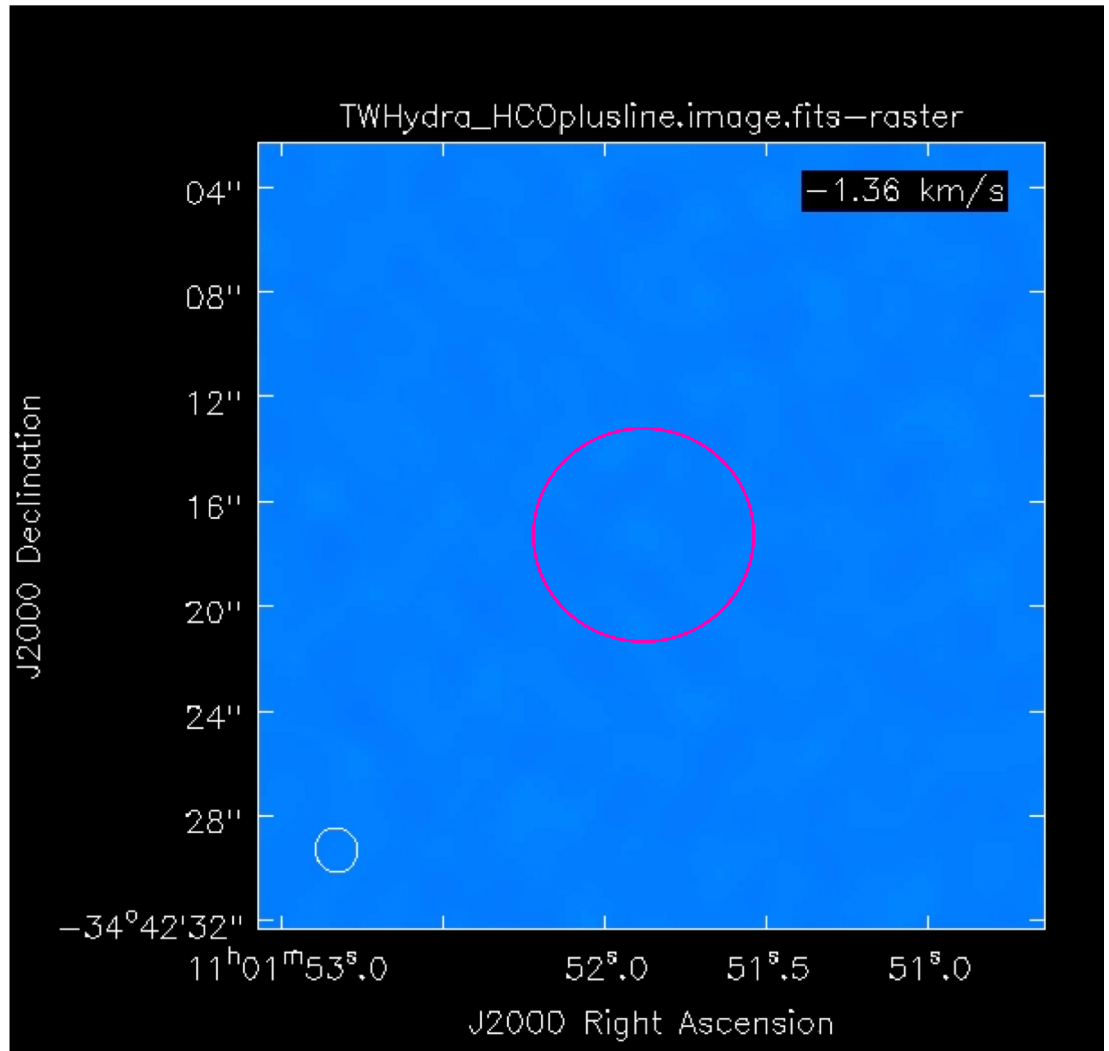
\* Both of these can be defined as a freq, vel or channel number



Working with cubes in CASA

# Spectral line fit


- We can inspect a spectral line seen in this example data using the spectrum viewer.
- Highlight the area of emission with a circular region.
- Then click the spectrum viewer button

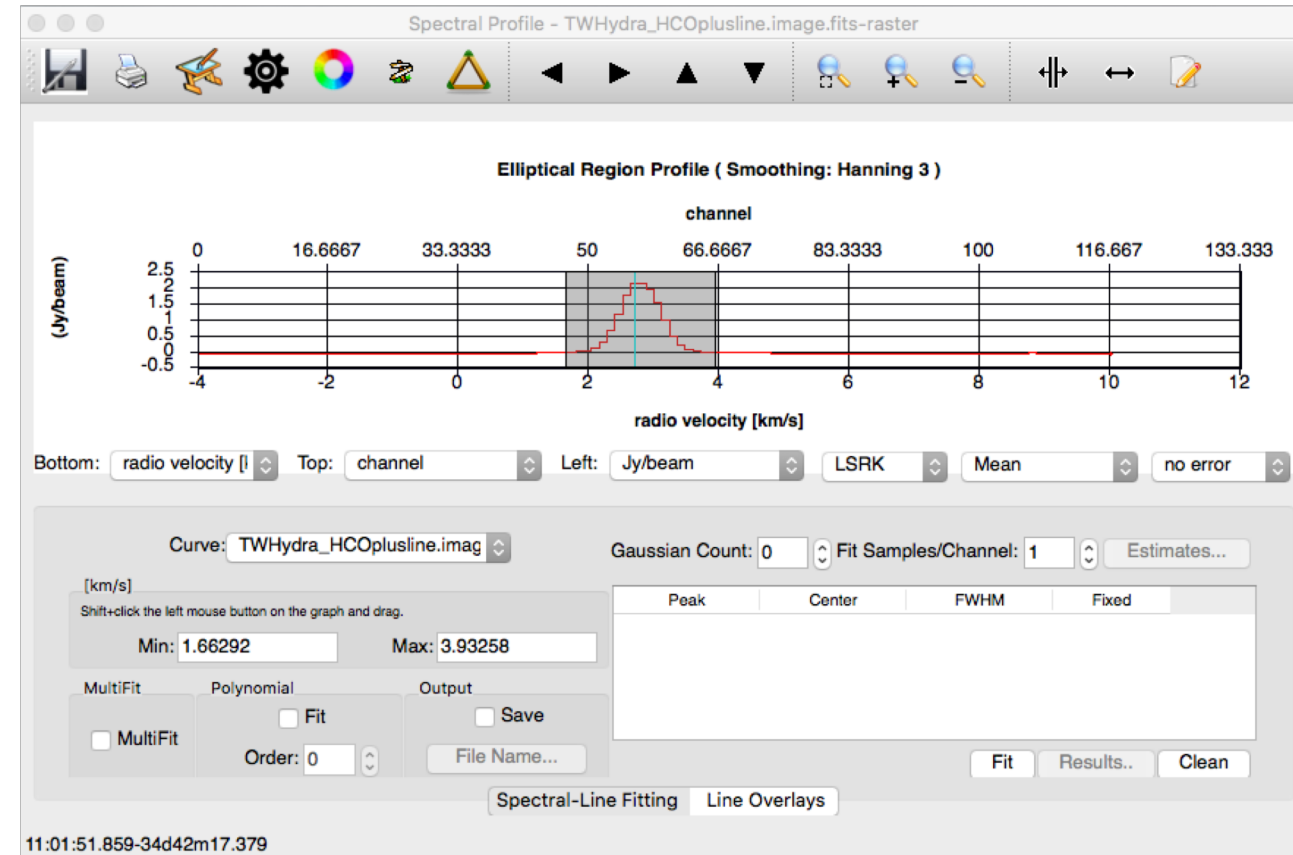


Here I am showing a CASA example dataset from TW-Hydra  
Observed in HCO+ in ALMA Band 7

Data available from: <https://casaguides.nrao.edu/index.php/TWHydraBand7>

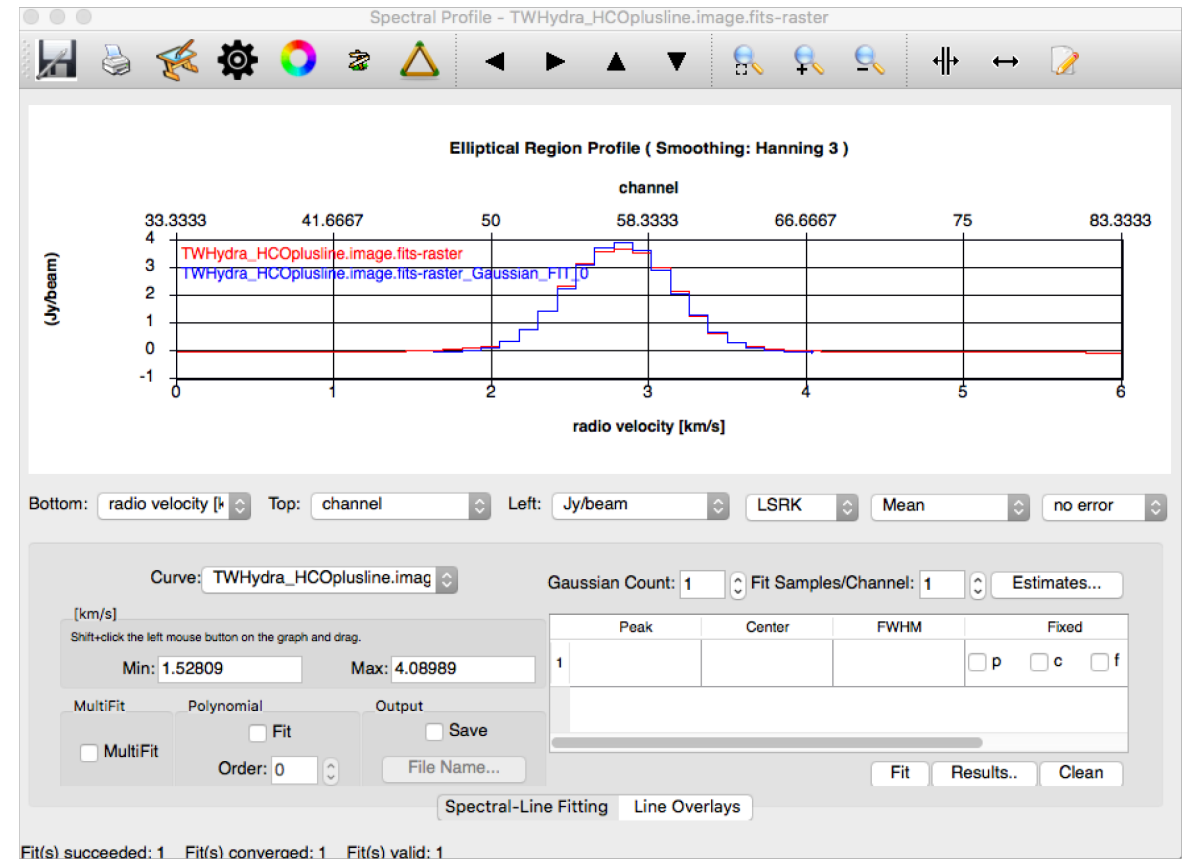
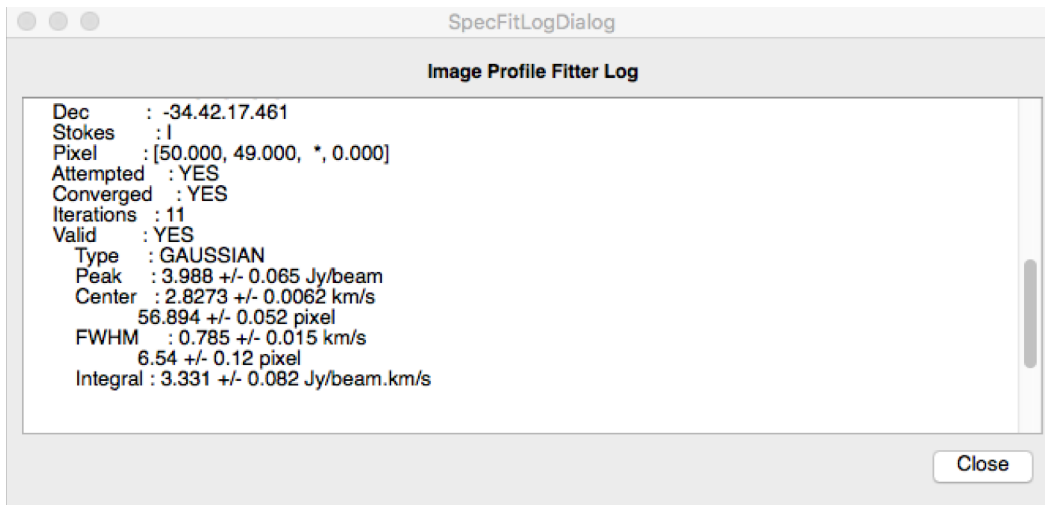
# Spectral line fitting

- We can highlight the line with the  button.
- Set Gaussian Count to 1
- Then hit the Fit button




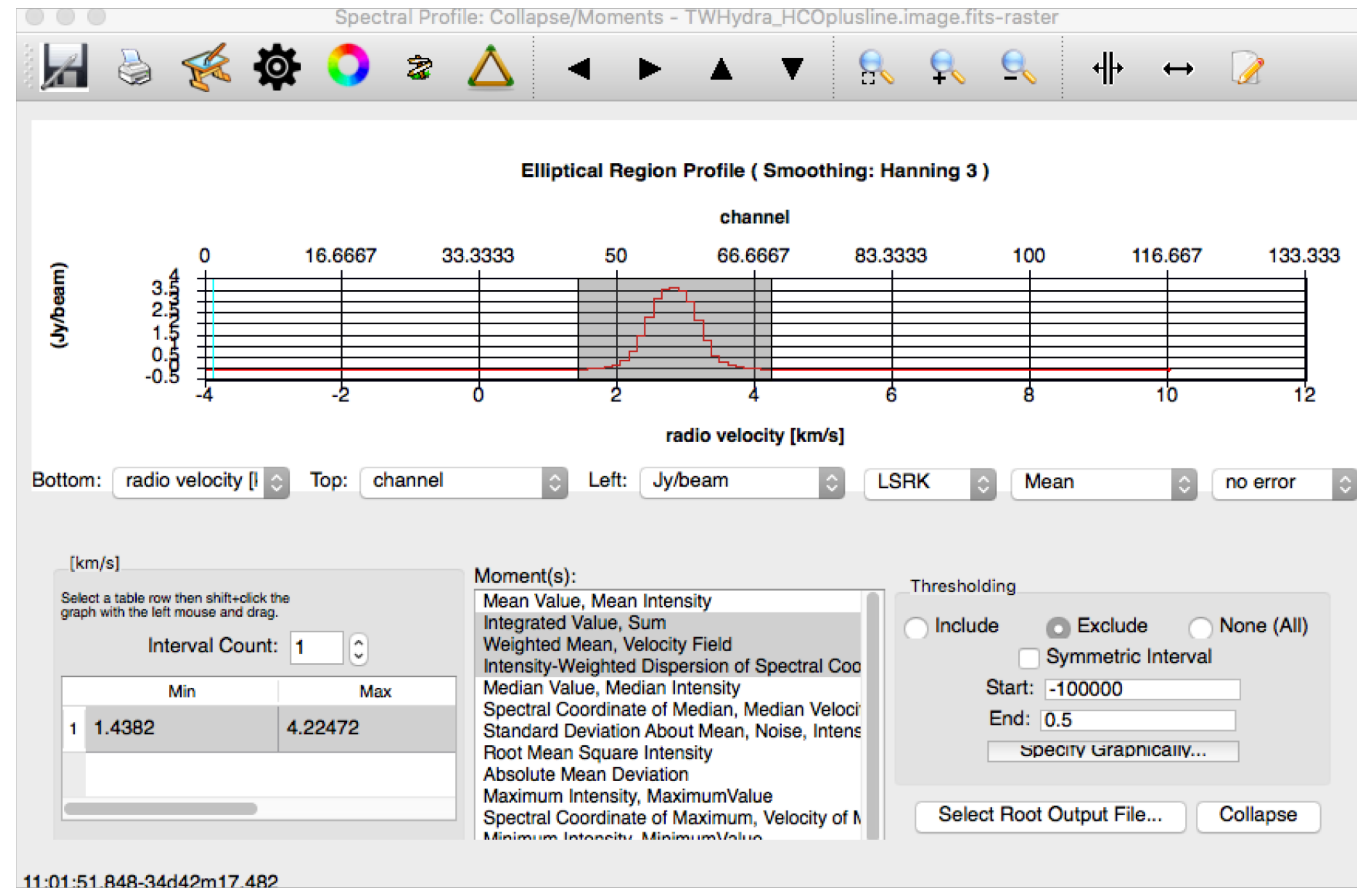
# Spectral line fitting

- This will plot the fitted line over the data and pop-up a Spectral Fit dialogue box with the fit parameters in it.



# Collapse (image moments)

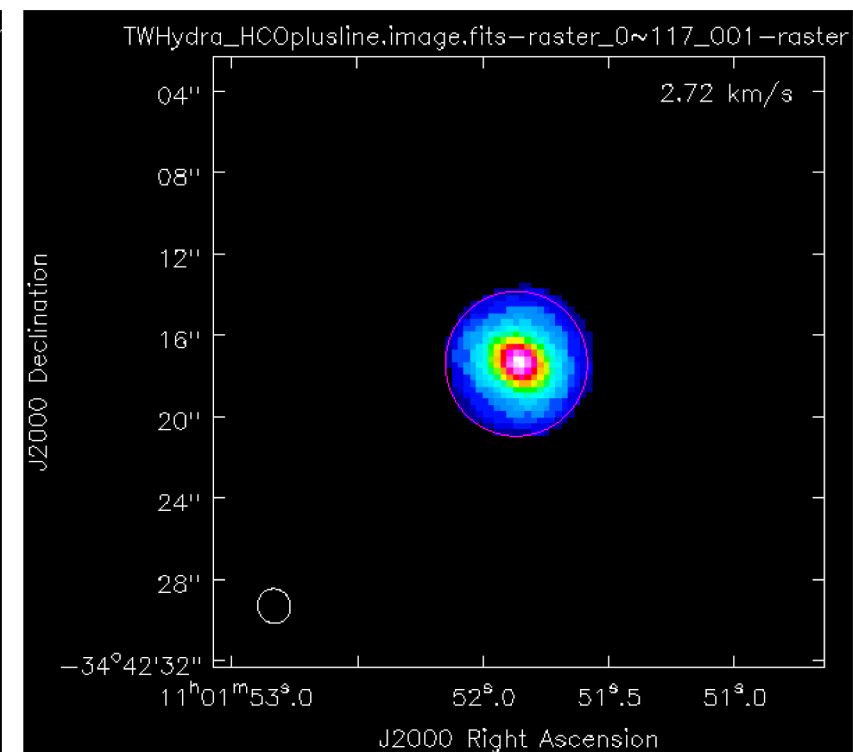
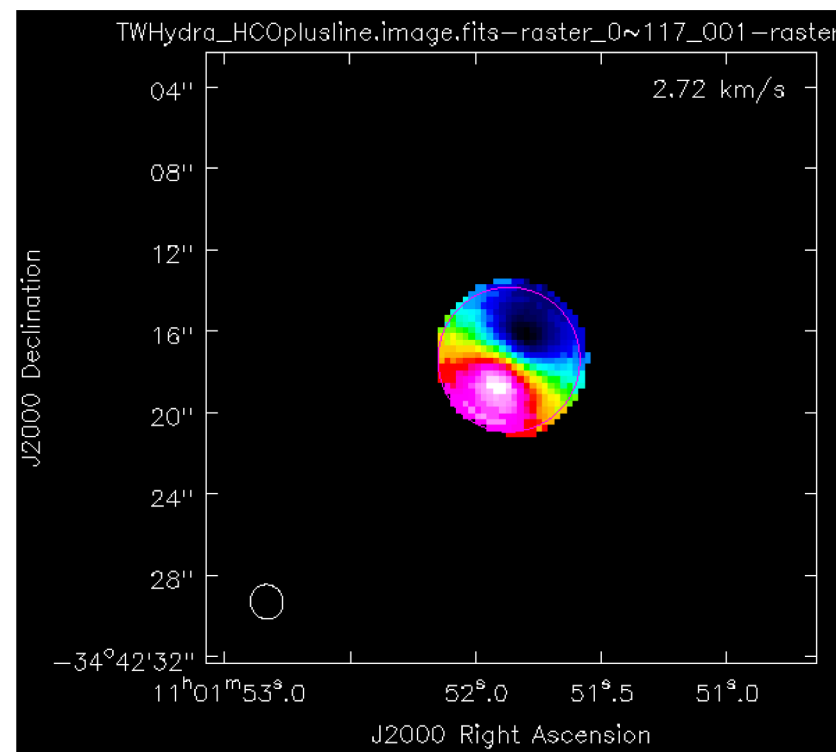
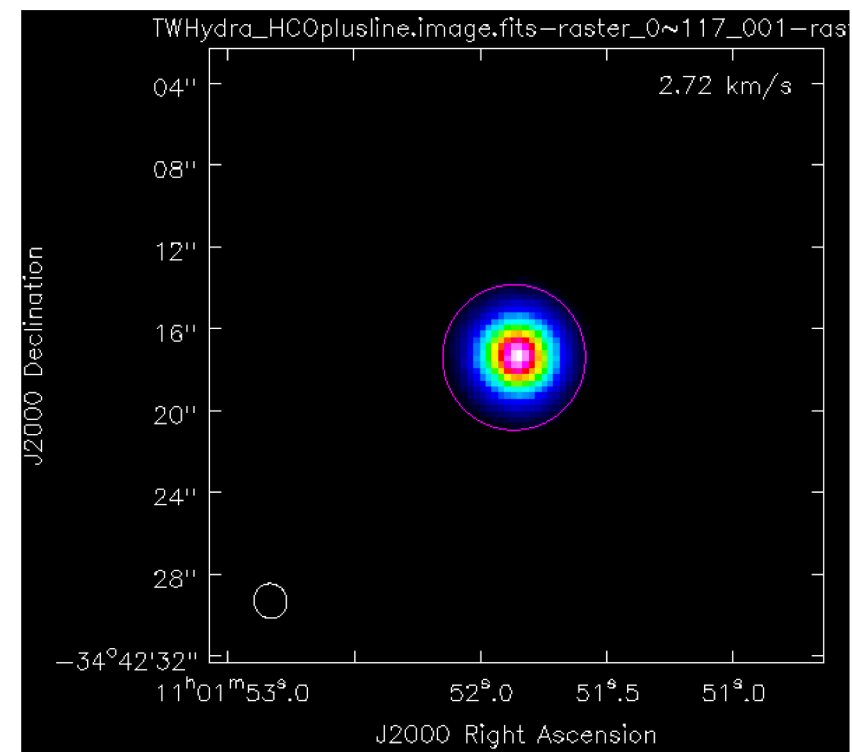
- GUI version of the CASA immoments() task used in the tutorial.
- Again highlight region of emission but we can access the collapse functionality with the  button.
- Highlight desired moments
- Set include/excludepix values and hit Collapse.




Integrated intensity,  
 $\text{mom} = 0$

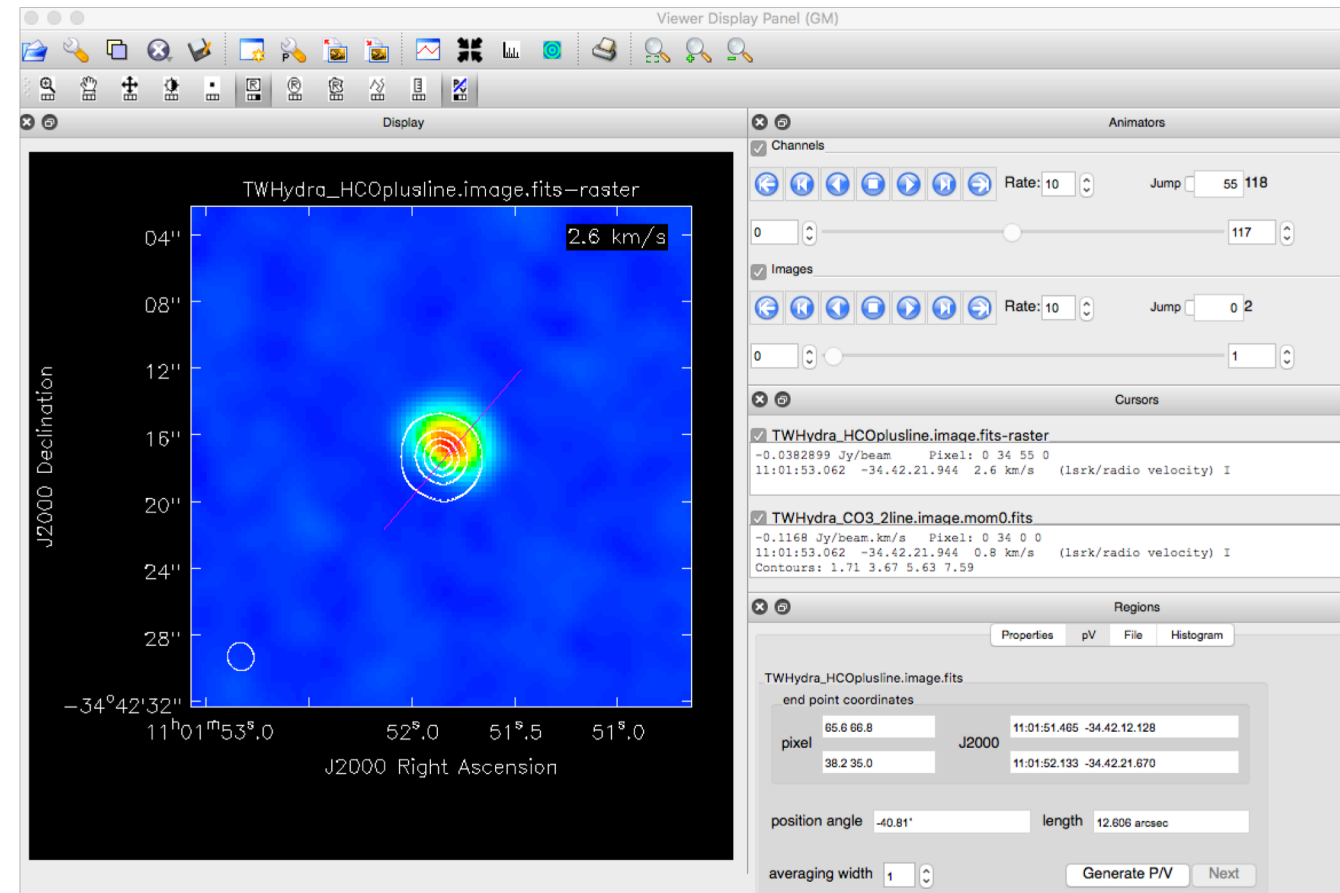
Velocity field,  
 $\text{mom} = 1$

Velocity dispersion,  
 $\text{mom} = 2$

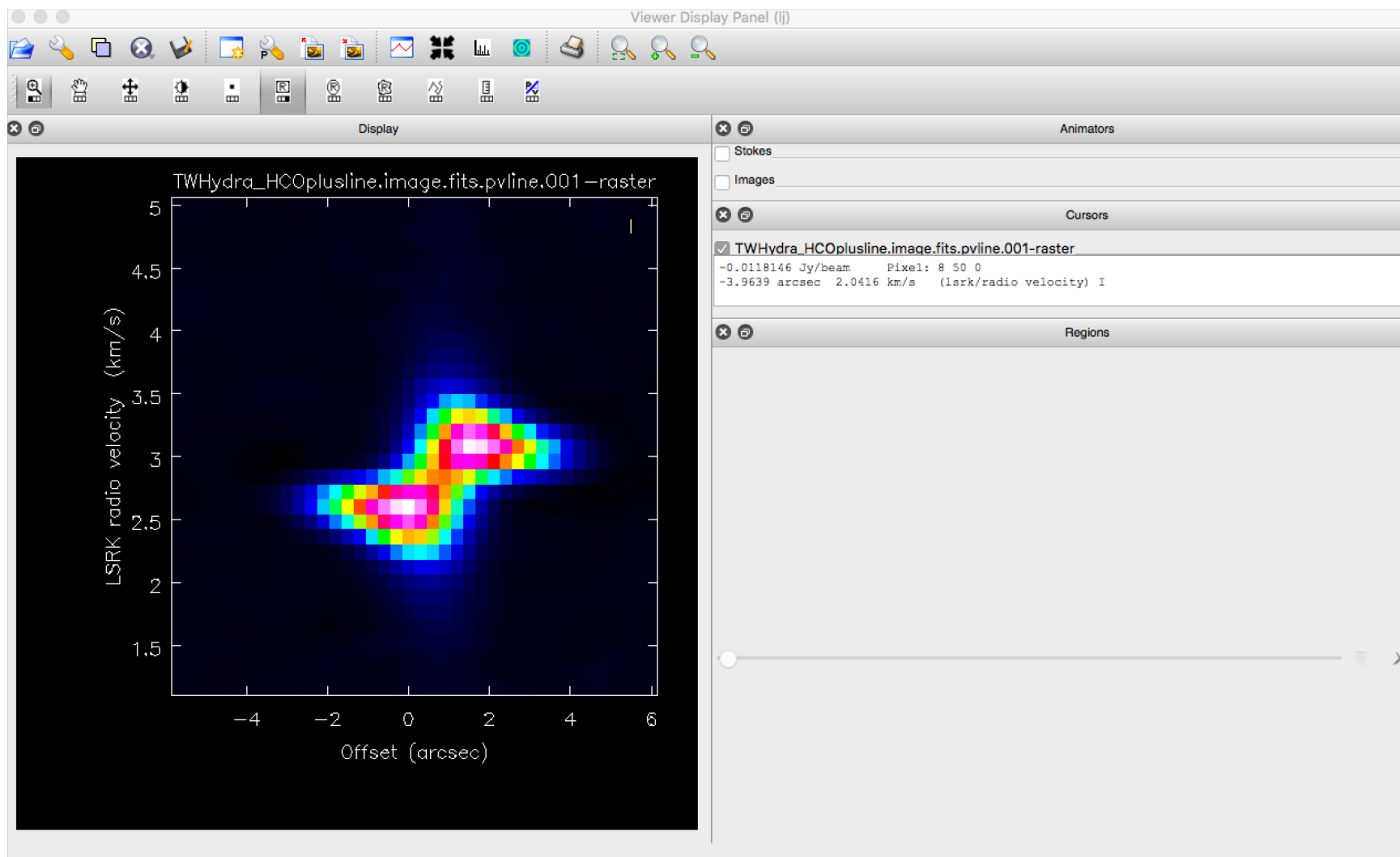


# Position/Velocity analysis

- To investigate velocity structure we can use the PV analysis too.
- Select this using the  button and draw a line along the direction you wish to inspect.
- Then press 'Generate P/V'.



# Position/Velocity analysis





OK ... Now to the hands on!