CIRIACO GODDI

ANALYSIS TOOLS

After mapping all channels in the data set, we have a spectral line 3D data *cube* (RA, Dec, Velocity).

How do we visualize and extract the information from these cubes?

Analysis of Line Cubes

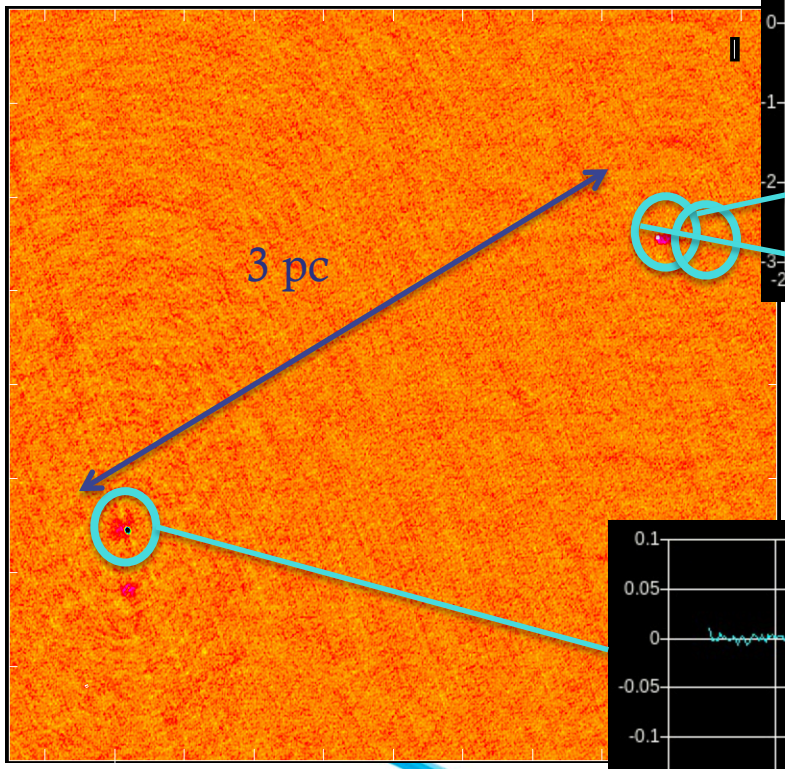
To visualize the information we usually make 1-D or 2-D projections providing different visualisation/analysis methods:

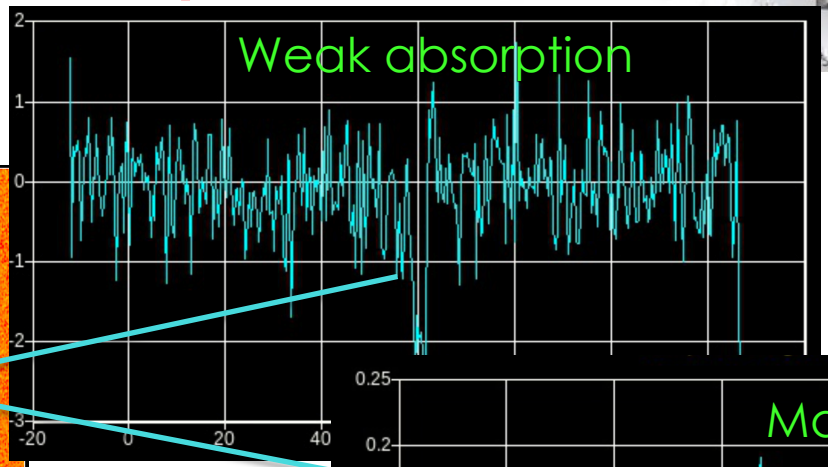
1. **Line profiles** (1-D slices along velocity axis)
2. **Channel maps** (2-D slices along velocity axis)
3. **Movies** (2-D slices along velocity axis)
4. **Moment maps** (integration along the vel. axis)
5. **Position-vel. plots** (slices along spatial dimension)

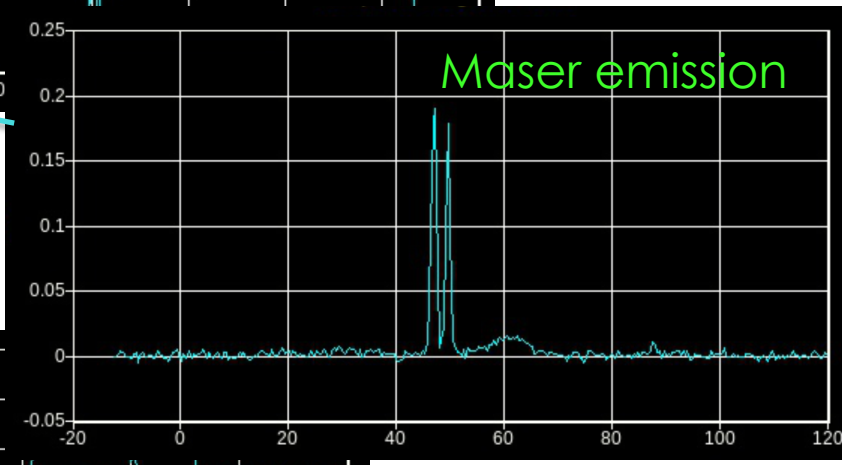
1. Line profiles

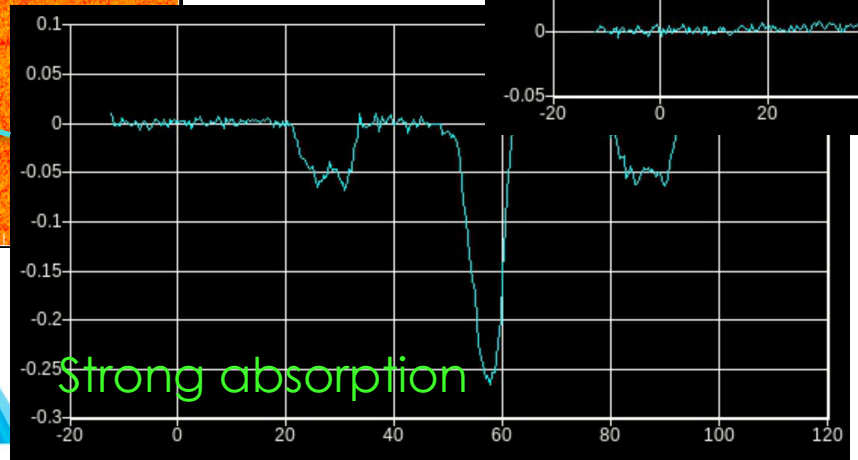
Line profiles may show changes in line shape, width and depth in different portions of your source.

W51 Star forming complex







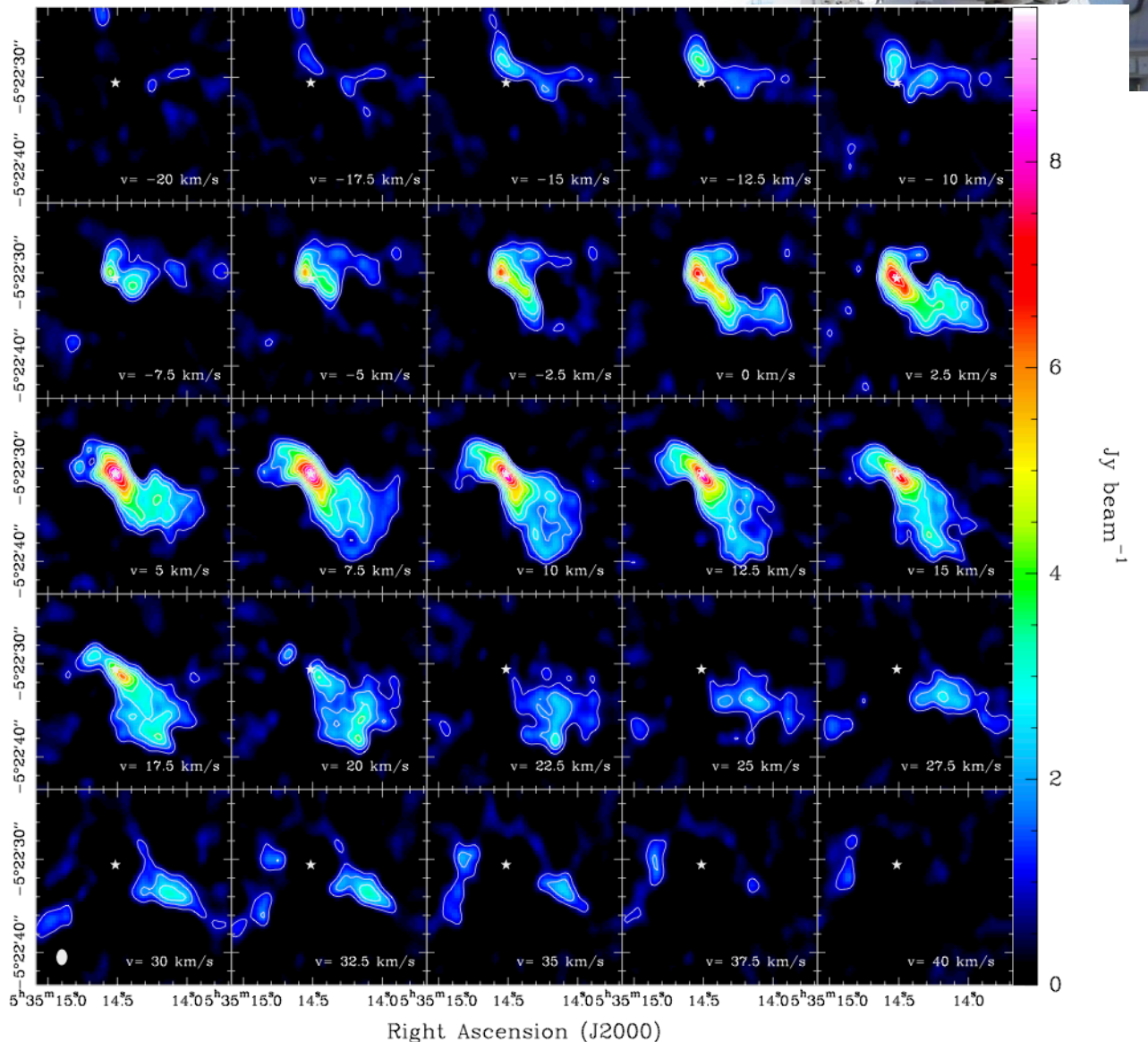


NH_3 lines (~26 GHz)
[JVLA]

2. Channel maps

Channel maps show how the spatial distribution of the line emission changes with frequency/ velocity

This cube shows SiO (J=5-4) line (217 GHz) emission imaged with ALMA in a massive protostellar outflow in Orion.



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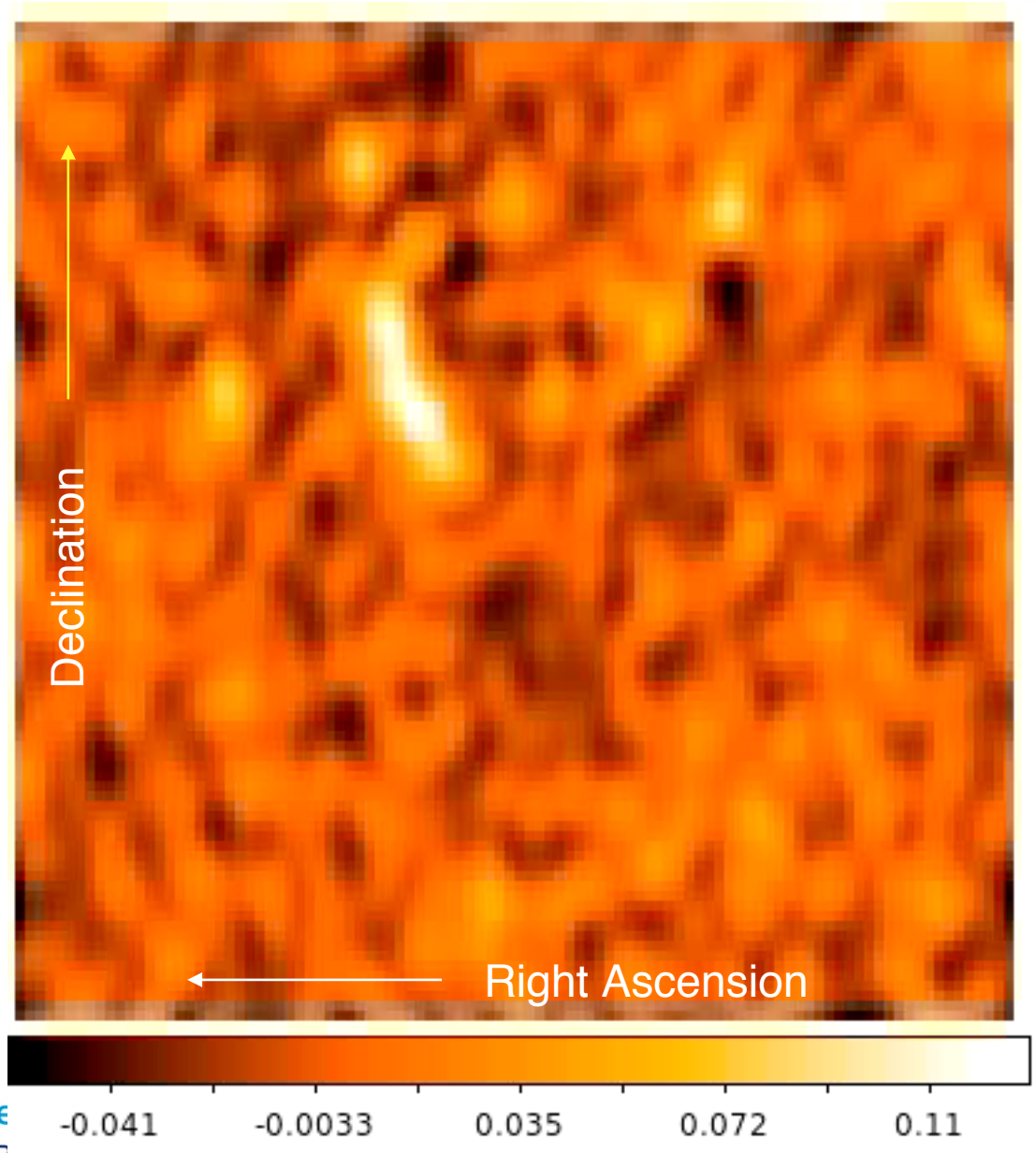
3. Movies



Movie showing a consecutive series of channel images from the same data cube as previous slide (168 channels, 0.7 km/s velocity resolution).

4. Moment analysis

Powerful tools to derive essential information like the spatial distribution of total intensity, the velocity field and the velocity dispersion of the molecular gas (as a function of position).

This is done by using the *moments* of the line profile:

$$I_{\rm tot}(\alpha,\delta) = \Delta v \sum_{i=1}^{N_{\rm chan}} S_\nu(\alpha,\delta,\nu_i)$$

Total intensity (**Moment 0**)

$$\overline{v}(\alpha,\delta) = \frac{\sum_{i=1}^{N_{\rm chan}} v_i\, S_\nu(\alpha,\delta,\nu_i)}{\sum_{i=1}^{N_{\rm chan}} S_\nu(\alpha,\delta,\nu_i)}$$

Intensity-weighted velocity (**Moment 1**)

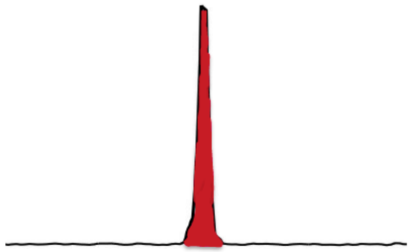
$$\sigma_v(\alpha,\delta) \equiv \sqrt{\langle (v_i - \overline{v}(\alpha,\delta))^2 \rangle} = \sqrt{\frac{\sum_{i=1}^{N_{\rm chan}} (v_i - \overline{v}(\alpha,\delta))^2\, S_\nu(\alpha,\delta,\nu_i)}{\sum_{i=1}^{N_{\rm chan}} S_\nu(\alpha,\delta,\nu_i)}}$$

Intensity-weighted velocity dispersion (**Moment 2**)

4. Moment analysis

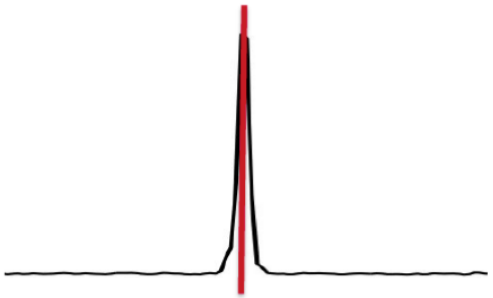
Integrated Intensity

$$\text{Moment } 0 = \int S_v dv$$



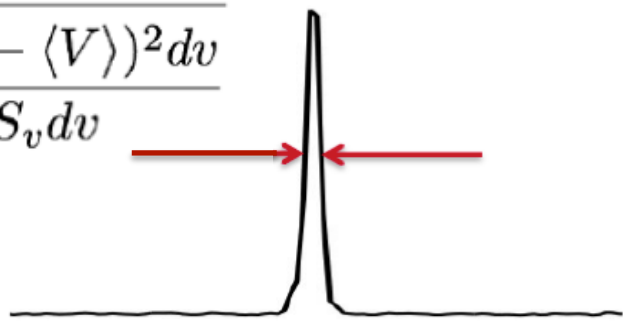
Intensity-weighted Velocity

$$\text{Moment } 1 = \langle V \rangle = \frac{\int S_v v dv}{\int S_v dv}$$

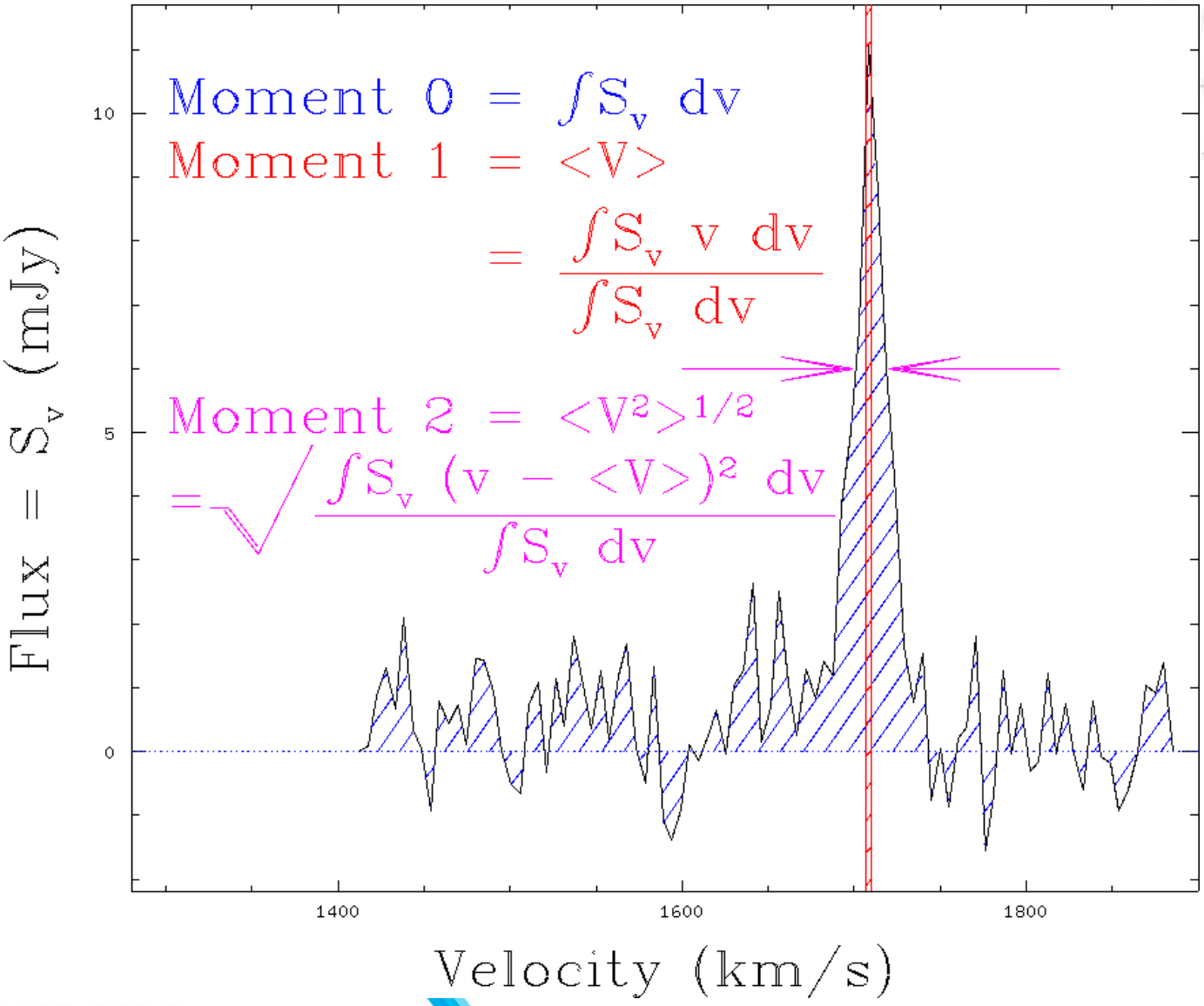


Intensity-weighted Velocity Dispersion

$$\text{Moment } 2 = \langle V^2 \rangle^{1/2} = \sqrt{\frac{\int S_v (v - \langle V \rangle)^2 dv}{\int S_v dv}}$$

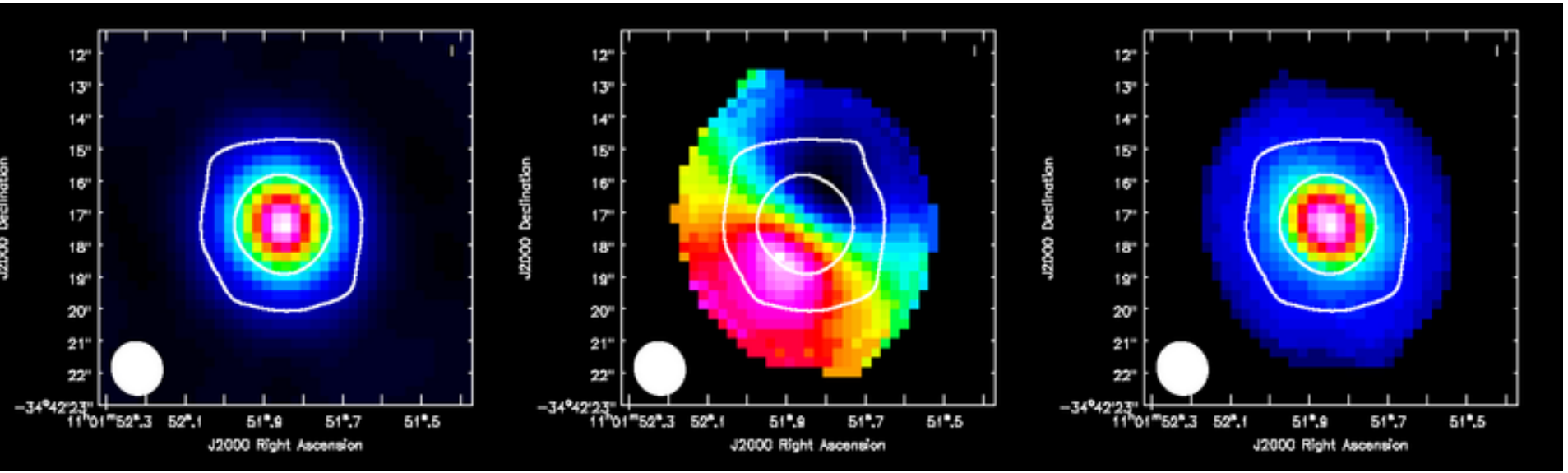


4. Moment analysis



4. Moment analysis

Moments Maps



Zeroth Moment
Integrated Flux

First Moment
Mean Velocity

Second Moment
Velocity Dispersion

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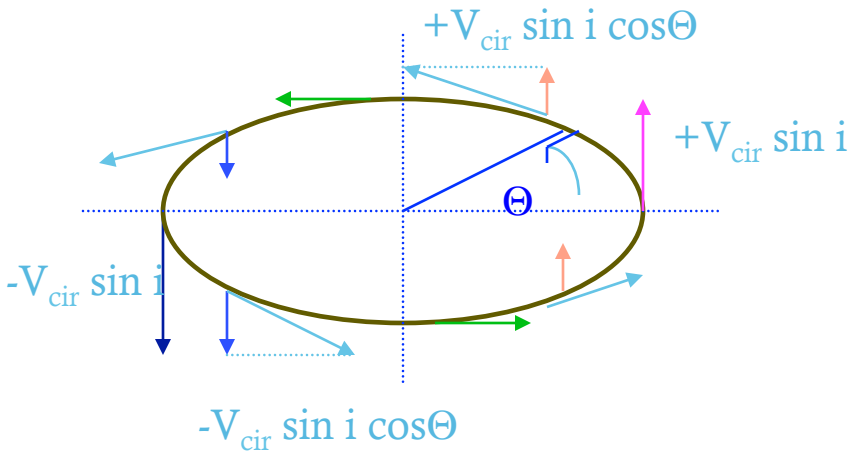
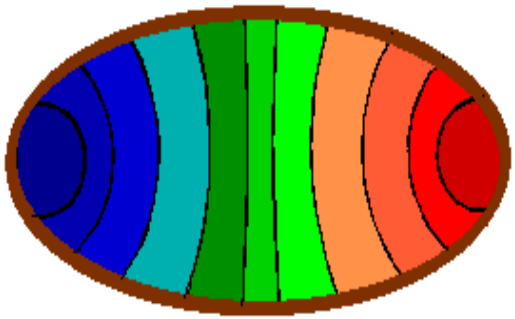
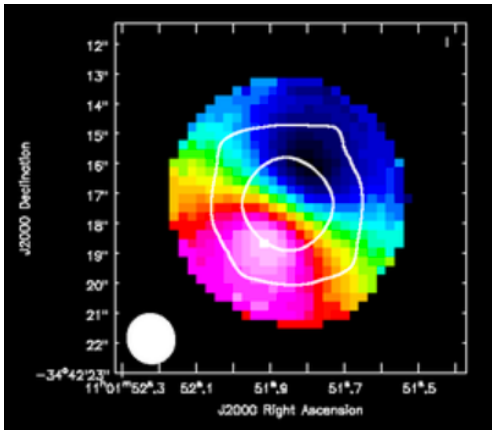
ALMA Cycle 0 CSV CO(3-2) moment maps
(with white continuum contours)

Example 2-D model: rotating disk

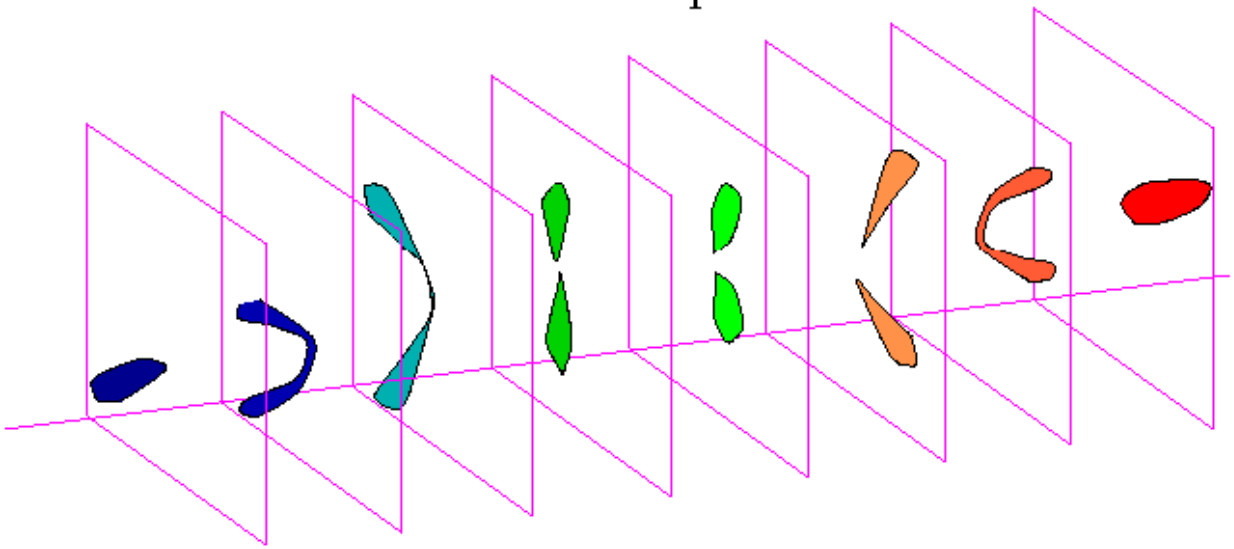




Mean Velocity Field

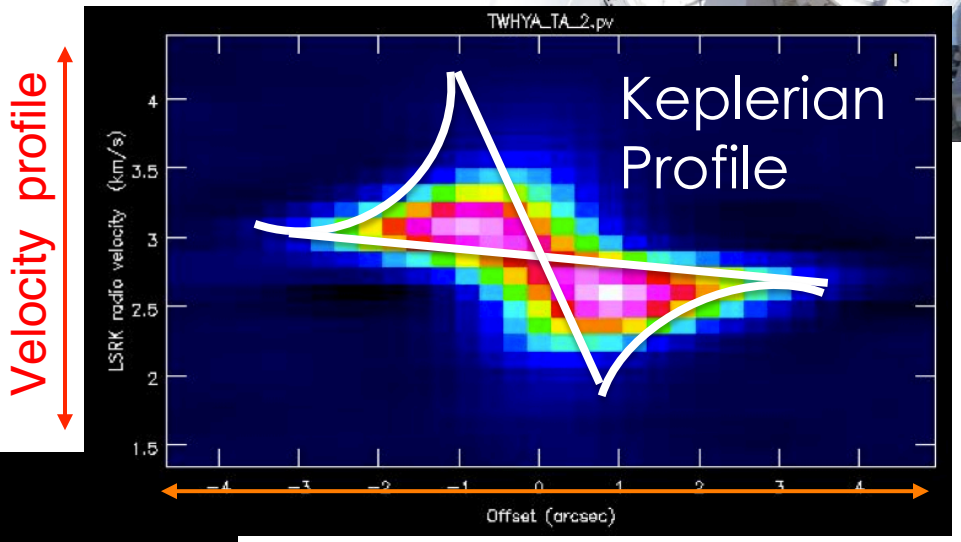


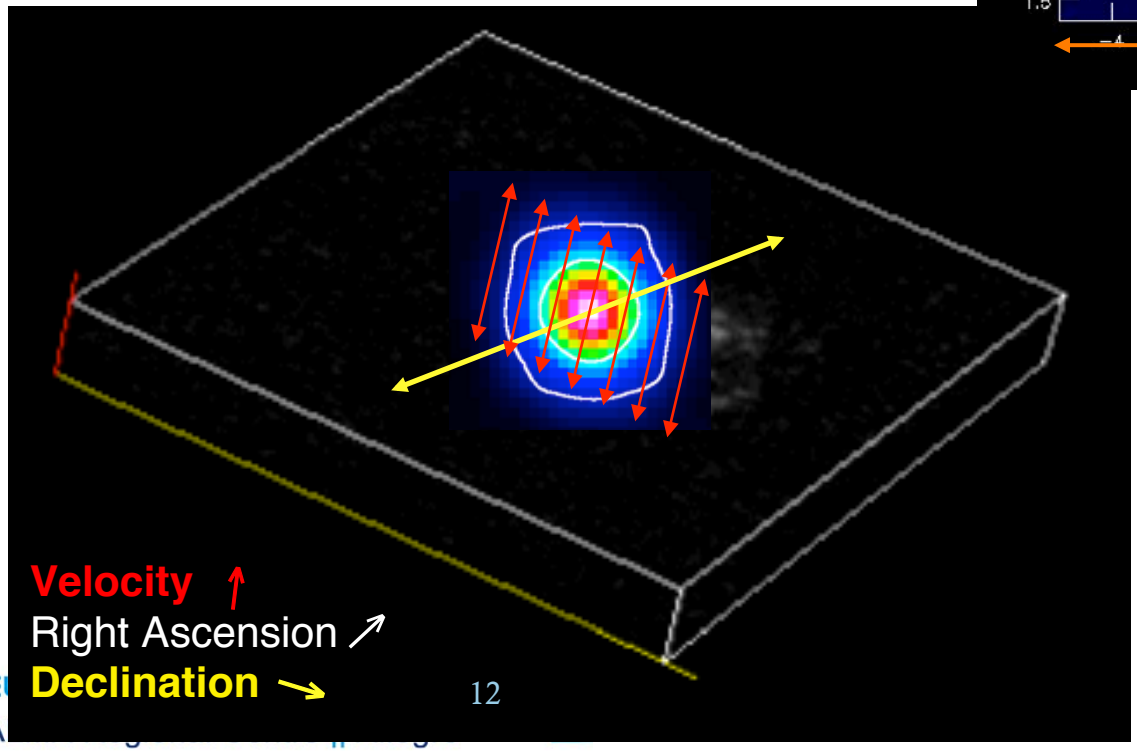
Channel Maps



5. Position-velocity Diagrams

PV-diagrams shows, for example, the line emission velocity as a function of radius. Here along a line through the disk major





Colors convey intensity of the emission.

Hands-on Session!

Image Analysis of TWHydra

- Using the CASA guides: https://casaguides.nrao.edu/index.php/First_Look_at_Image_Analysis

Image Analysis of TWHydra

- Using the CASA guides: https://casaguides.nrao.edu/index.php/TWHydraBand7_Imaging_4.5#Image_Analysis

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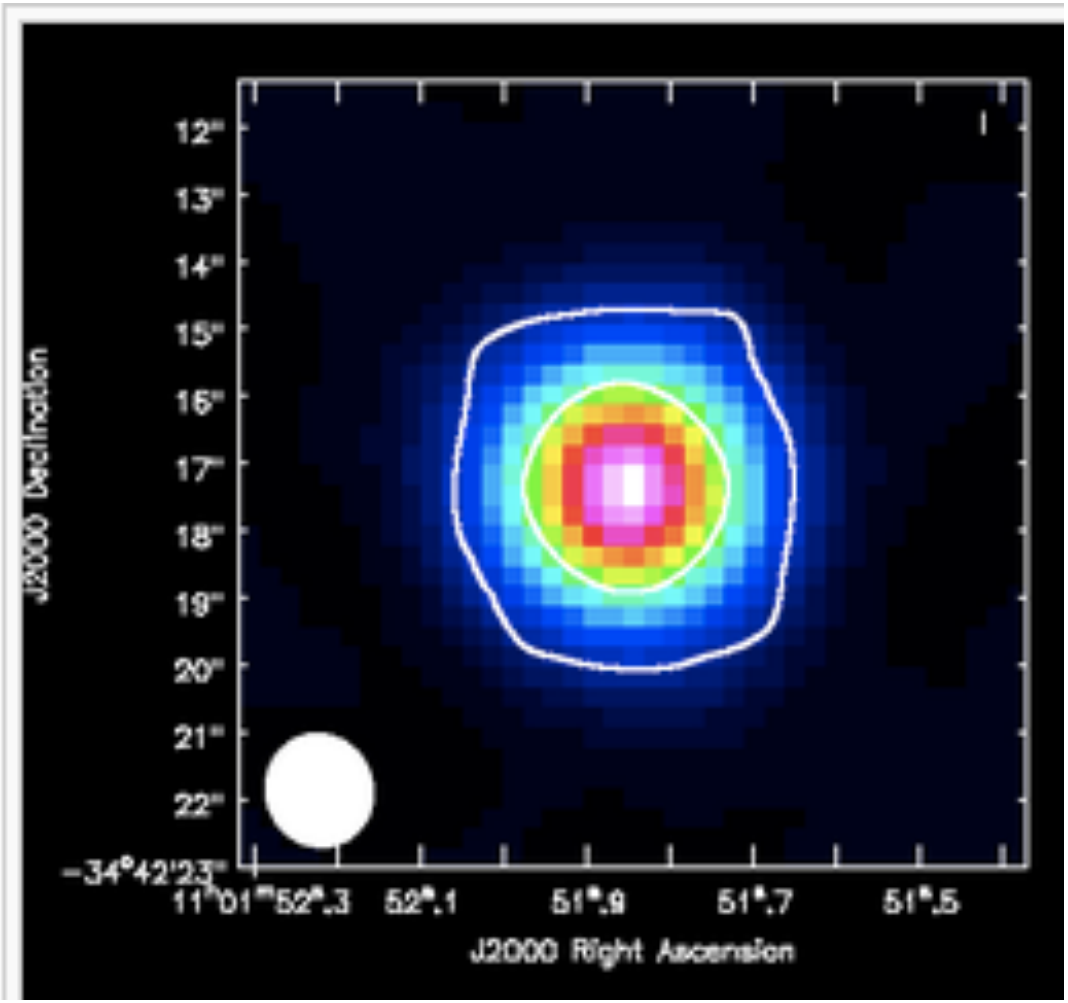
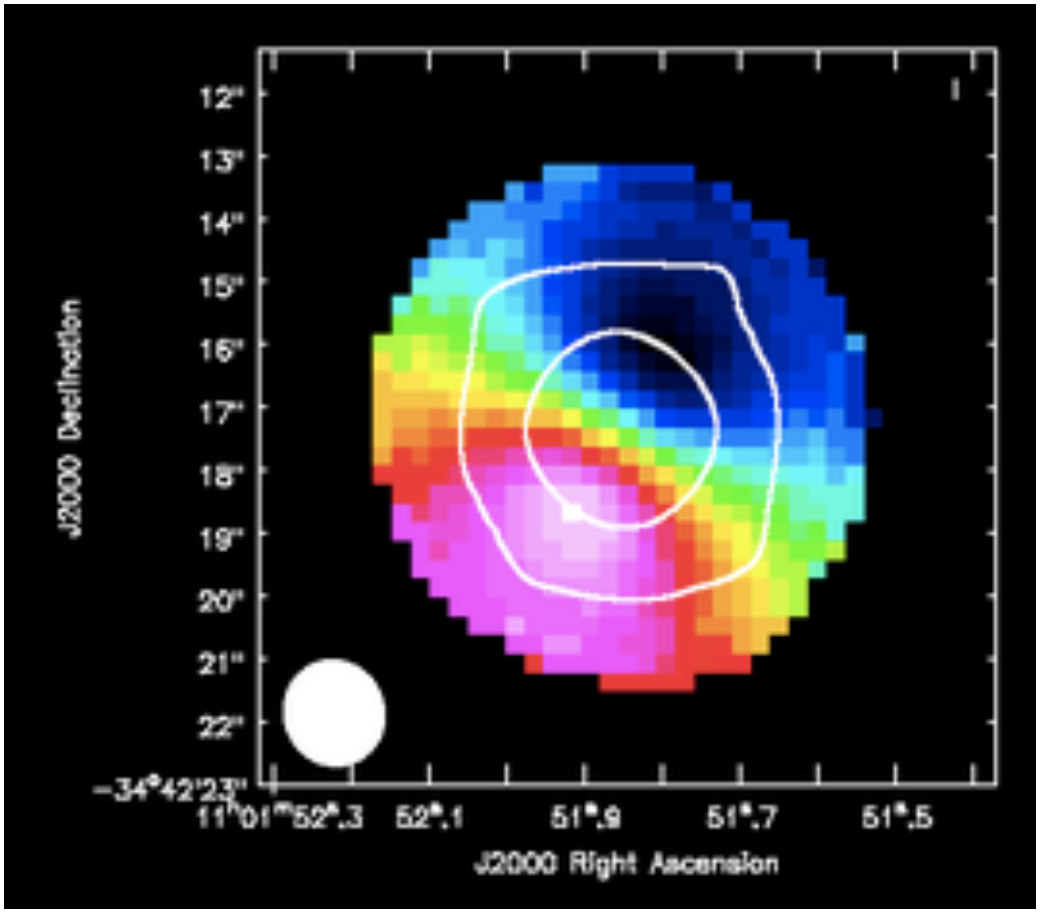
Moment 0

```
os.system("rm -rf sis14_twhya_n2hp.mom0")
immoments("sis14_twhya_n2hp.image",
outfile="sis14_twhya_n2hp.mom0",
includepix=[20e-3,100],
chans="4~12", moments=0)
```



Moment 1

```
os.system("rm -rf sis14_twhya_n2hp.mom1")
immoments("sis14_twhya_n2hp.image",
outfile="sis14_twhya_n2hp.mom1",
includepix=[40e-3,100],
chans="4~12", moments=1)
```



Moment 2

```
os.system("rm -rf sis14_twhya_n2hp.mom1")
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outfile="sis14_twhya_n2hp.mom1",
includepix=[40e-3,100],
chans="4~12", moments=2)
```

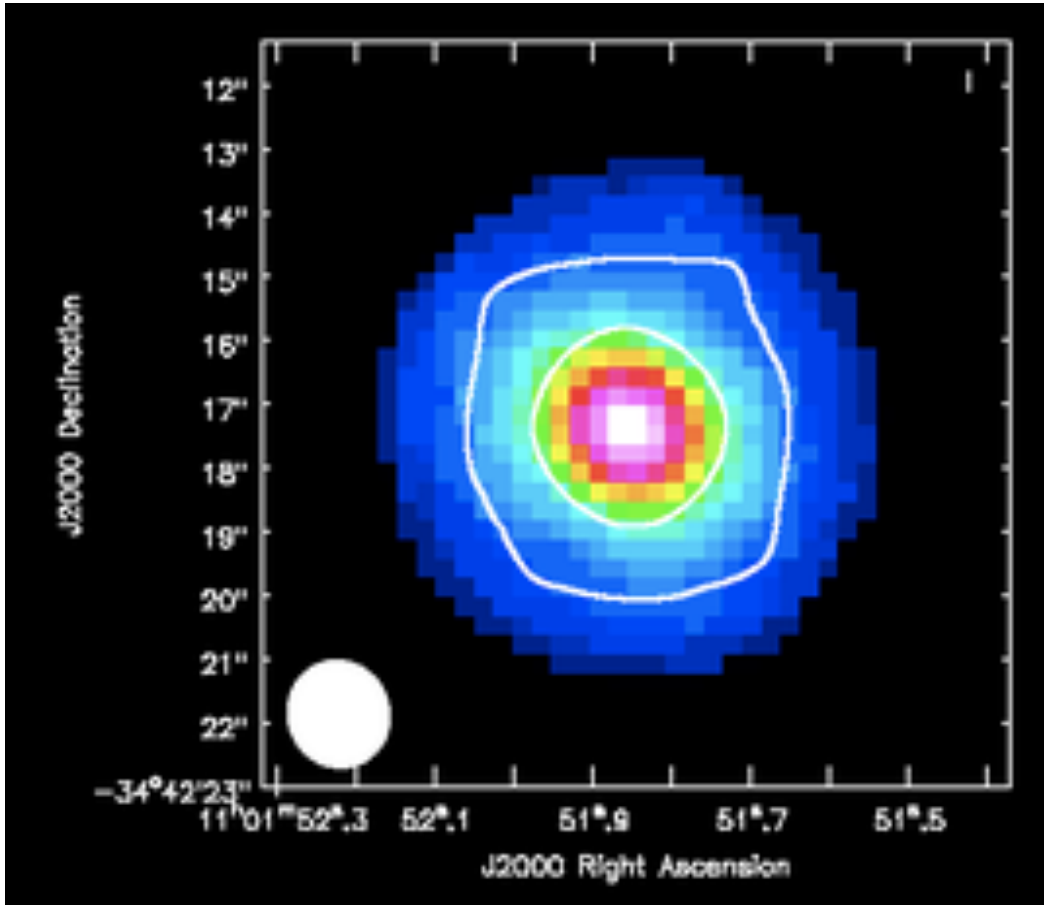

Links

https://casa.nrao.edu/docs/cookbook/

Image analysis chapter:
https://casa.nrao.edu/docs/cookbook/casa_cookbook007.html

CASA toolkit:
https://casa.nrao.edu/docs/CasaRef/image.moments.html