



# CARTA: Cube Analysis and Rendering Tool for Astronomy

**Tutorials**

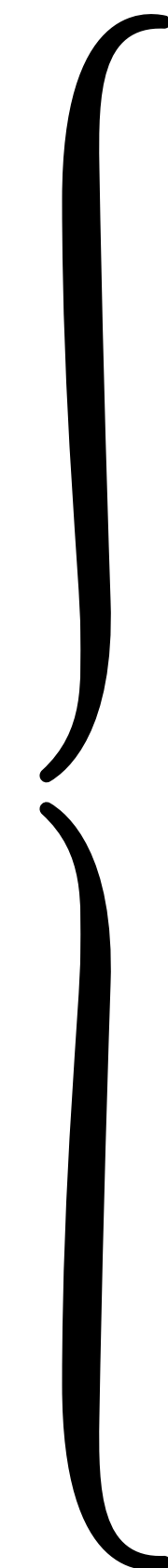
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ALMA Imaging Workshop 2025 @ ASIAA**



# Outline

## What we are going to talk about today

- CARTA basics
  - Tutorials
    - How to load images
    - How to render images
    - How to match images
    - Image analytics
    - Polarization cube visualization and analysis
    - Catalog visualization
    - GUI customization
  - Region of interest and statistics
  - Spatial profile
  - Spectral profile
  - Profile smoothing
  - Spectral profile fitting
  - Moment map generator
  - PV map generator
  - Spectral line ID
  - Rest frequency shifting
- 

# Test images

<http://bit.ly/3RQkPO1>



Unzipped size ~ 500 MB

- ▼ cosmos\_field
  - cosmos\_0\_simbad.xml
  - cosmos\_herschel250micron\_subimage.fits
  - cosmos\_spitzer3.6micron\_subimage.fits
  - vla\_20cm\_lg\_tan\_10\_subimage.fits
- ▼ G31.41p0.31\_bandscan
  - G31.41p0.31\_spw25.fits
  - G31.41p0.31\_spw27.fits
- ▼ Gaussian\_array
  - Gaussian\_SE.fits
  - Gaussian.fits
- ▼ HD163296
  - HD163296\_13CO\_2\_1.fits
  - HD163296\_C18O\_2\_1.fits
  - HD163296\_CO\_2\_1.fits
  - HD163296\_CO\_2\_1.mom0.fits
  - HD163296\_CO\_2\_1.mom1.fits
  - HD163296\_CO\_3\_2.fits
- ▼ HL\_Tau\_pol
  - HL\_tau\_band3\_Stokes\_I.fits
  - HL\_tau\_band3\_Stokes\_Q.fits
  - HL\_tau\_band3\_Stokes\_U.fits
  - HL\_Tau\_band6\_Stokes\_IQUV.fits
  - HL\_Tau\_band6.POLA.fits
  - HL\_Tau\_band6.POLI.fits
  - HLTau\_band7\_cont.fits
- ▼ IRCp10216\_line\_pol
  - IRCp10216.cube.IQUV.fits
- ▼ S255
  - S255\_CH3CN\_subcube.fits

# Tutorials

# How to load images

## Graphical user interface (GUI) v.s. commendline user interface (CLI)

- Supported format: FITS, CASA, HDF5-IDA, MIRIAD
- GUI
  - “File -> Open image” (close existing images first)
  - “File -> Append image” (without closing existing images)
  - Flexible file filtering modes
  - Multi-selection (macOS: CMD+click, Linux: CTRL+click) to load multiple images at once
  - Load a “computed” image via “lattice expression language” (LEL)

The screenshot displays a software interface with a central 'File Browser' window. The browser shows a list of files with columns for 'Filename', 'Type', 'Size', and 'Date'. A 'File Information' panel on the right provides detailed metadata for the selected file 'HD163296\_CO\_2\_1.fits'. The background features a dark image visualization with axes labeled 'Decline' and '22.0'. Other panels include a 'Render Configuration' window at the bottom left, a 'X Profile: Cursor' plot at the top right, and a 'Polarization' plot at the bottom right.

Filename	Type	Size	Date
HD163296_CO_3_2.fits	FITS	73.5 MB	6 Feb 2023
HD163296_C18O_2_1.fits	FITS	60.6 MB	6 Feb 2023
HD163296_13CO_2_1.fits	FITS	41.9 MB	6 Feb 2023
HD163296_CO_2_1.fits	FITS	56.8 MB	6 Feb 2023
HD163296_CO_2_1.mom1.fits	FITS	846.7 kB	23 Oct 2012
HD163296_CO_2_1.mom0.fits	FITS	846.7 kB	23 Oct 2012

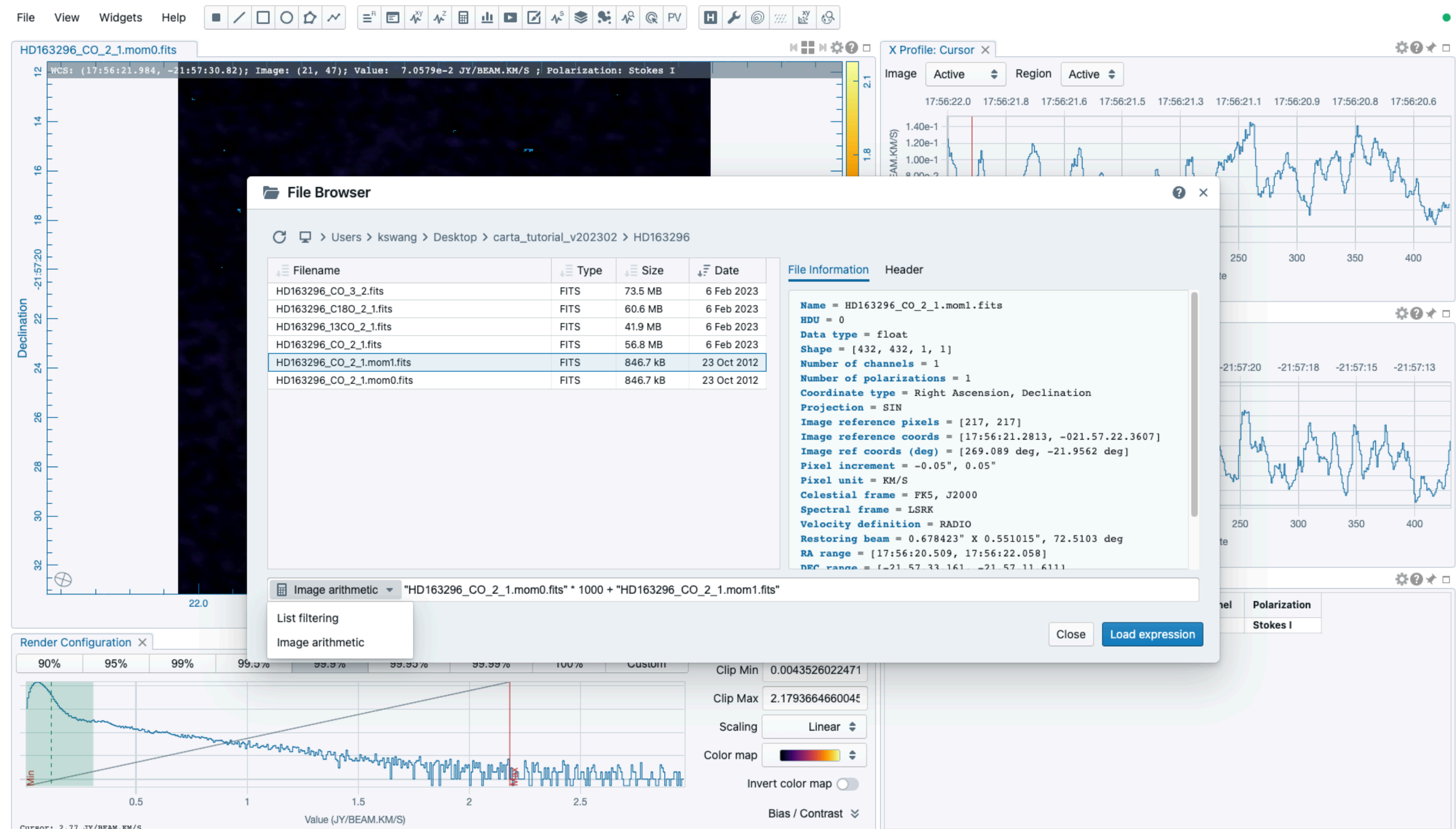
**File Information**

```
Name = HD163296_CO_2_1.fits
HDU = 0
Data type = float
Shape = [432, 432, 76, 1]
Number of channels = 76
Number of polarizations = 1
Coordinate type = Right Ascension, Declination
Projection = SIN
Image reference pixels = [217, 217]
Image reference coords = [17:56:21.2813, -021:57:22.3607]
Image ref coords (deg) = [269.089 deg, -21.9562 deg]
Pixel increment = -0.05", 0.05"
Pixel unit = Jy/beam
Celestial frame = FK5, J2000
Spectral frame = LSRK
Velocity definition = RADIO
Restoring beam = 0.678423" X 0.551015", 72.5103 deg
RA range = [17:56:20.509, 17:56:22.058]
DEC range = [-21:57:33.161, -21:57:11.611]
```

# How to load images

## Graphical user interface (GUI) v.s. commendline user interface (CLI)

- Supported format: FITS, CASA, HDF5-IDIA, MIRIAD
- GUI
  - “File -> Open image”  
(close existing images first)
  - “File -> Append image”  
(without closing existing images)
  - Flexible file filtering modes
  - Multi-selection (macOS: CMD+click, Linux: CTRL+click) to load multiple images at once
  - Load a “computed” image via “lattice expression language” (LEL)



# How to load images

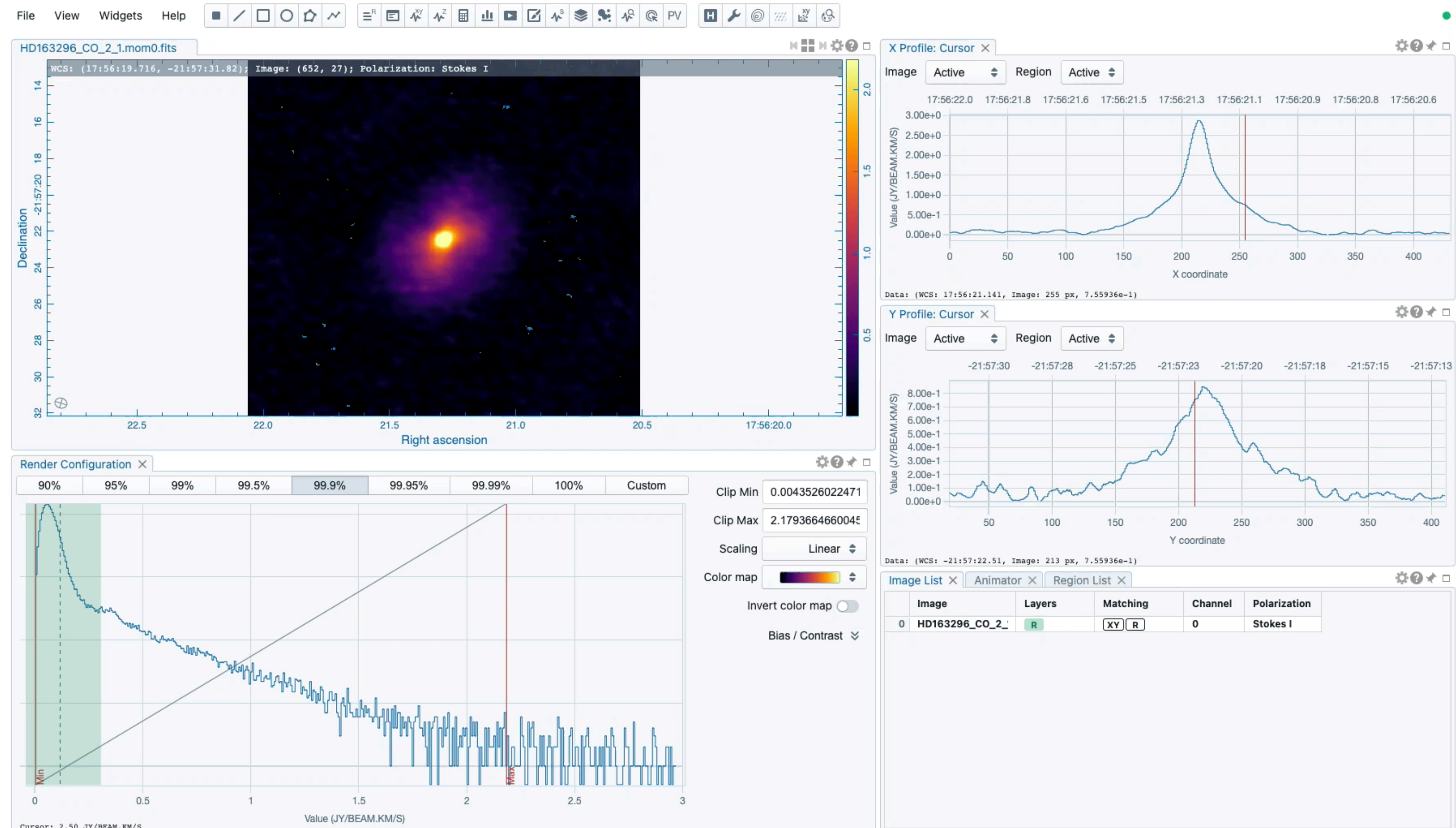
## Graphical user interface (GUI) v.s. commendline user interface (CLI)

- CLI
  - macOS electron app: in `.zshrc`, set up an alias as  
`alias carta='/Applications/CARTA.app/Contents/MacOS/CARTA'`  
Then in terminal  
`carta a.fits`
  - macOS homebrew installation:  
`carta a.fits`
  - Linux:  
`./carta.AppImage a.fits` (may also set up an alias too)  
`carta a.fits` (installation via a package manager like `apt` or `dnf`)
  - URL query parameter (useful for workflow integration)  
<http://localhost:3002/?file=a.fits>  
[http://localhost:3002/?files=\[a.fits,b.fits\]](http://localhost:3002/?files=[a.fits,b.fits])

# How to render images

## Raster image rendering

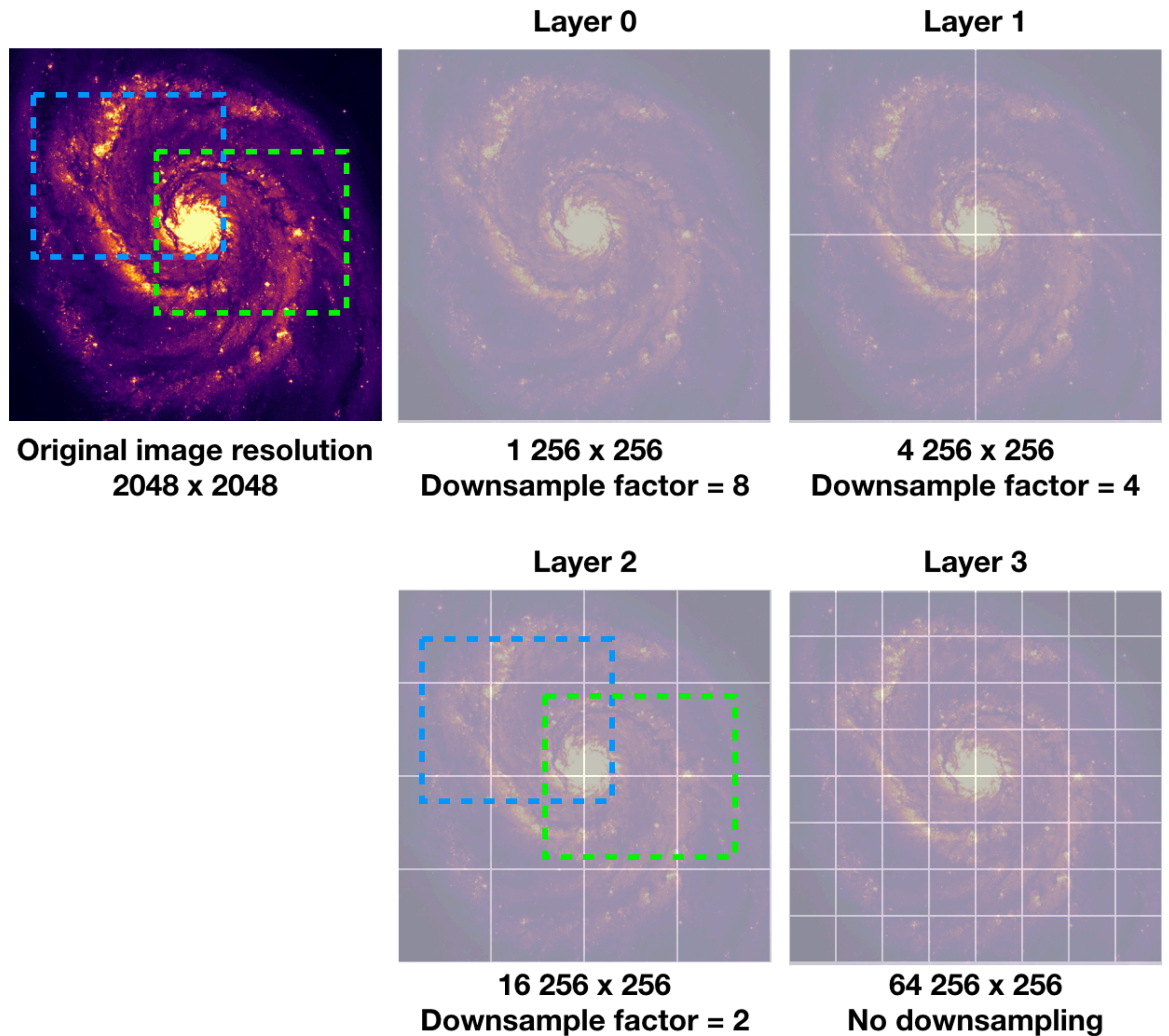
- By default, images are rendered as raster
- Per-channel clip range as default
- Use render configuration widget to modify raster rendering
- Raster rendering:
  - GPU-accelerated (WebGL2)
  - Tile-based, multi-resolution



# How to render images

## Raster image rendering

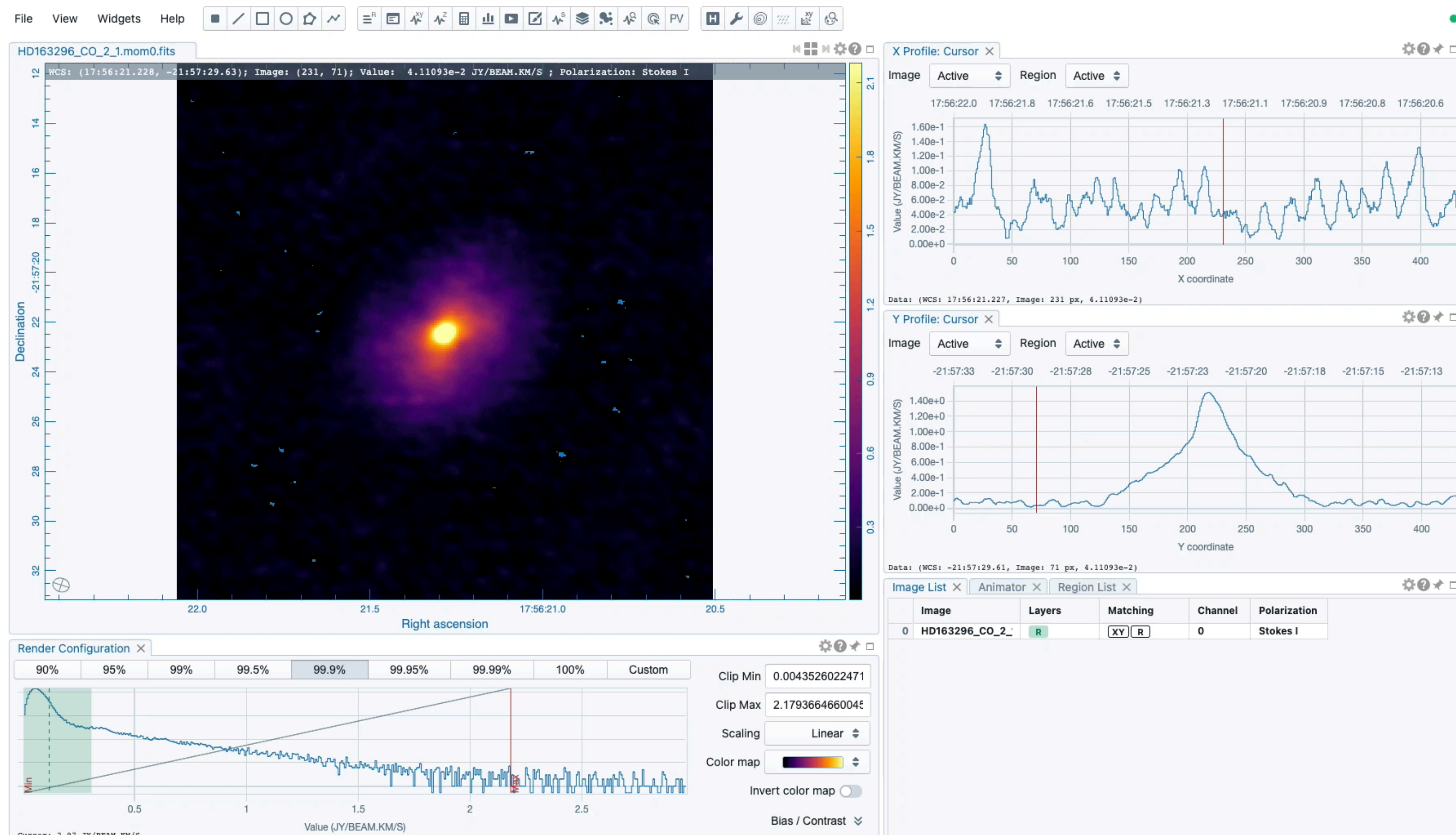
- By default, images are rendered as raster
- Per-channel clip range as default
- Use render configuration widget to modify raster rendering
- Raster rendering:
  - GPU-accelerated (WebGL2)
  - Tile-based, multi-resolution



# How to render images

## Contour image rendering

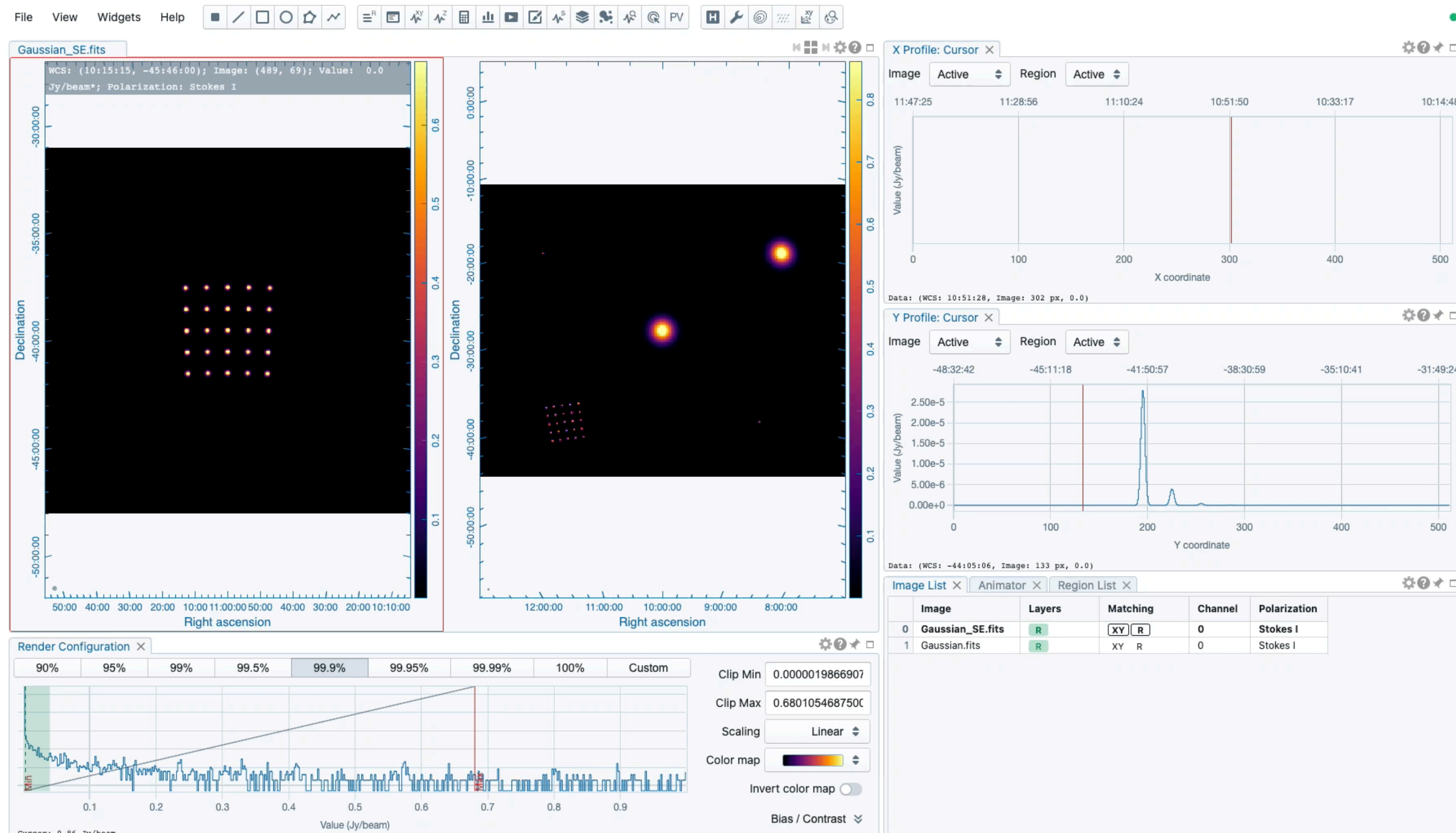
- Use contour configuration dialog for contour rendering
- Flexible
  - Level definition
  - Smoothing scheme
  - Styling
- Contour rendering:
  - GPU-accelerated (WebGL2)
  - Contour vertices are computed in parallel



# How to match images

## Spatial matching

- Multiple images can be matched spatially so image panning and zooming are synchronized.
- Use the image list widget to perform image matching
- Matched images share their
  - contour / vector field / catalog rendering
  - region set
- Reference image v.s. secondary images



# How to match images

## Spatial matching and spectral matching

- Multiple image cubes can be matched spatially and spectrally so image panning and zooming are synchronized and channel switching is also synchronized
- Use the image list widget to perform image matching
- Spectral matching adopts nearest interpolation
- Reference image v.s. secondary images
- Use the animator widget for channel navigation

The screenshot shows a software interface with a file browser window open over a main application window. The main application window has a menu bar (File, View, Widgets, Help) and a toolbar. The file browser window displays a list of files in a table format:

Filename	Type	Size	Date
HD163296_CO_3_2.fits	FITS	73.5 MB	6 Feb 2023
HD163296_C18O_2_1.fits	FITS	60.6 MB	6 Feb 2023
HD163296_13CO_2_1.fits	FITS	41.9 MB	6 Feb 2023
HD163296_CO_2_1.fits	FITS	56.8 MB	6 Feb 2023
HD163296_CO_2_1.mom1.fits	FITS	846.7 kB	23 Oct 2012
HD163296_CO_2_1.mom0.fits	FITS	846.7 kB	23 Oct 2012

Below the table is a search filter: "Filter by filename with fuzzy search". To the right of the table is a "File Information" panel showing metadata for the selected file:

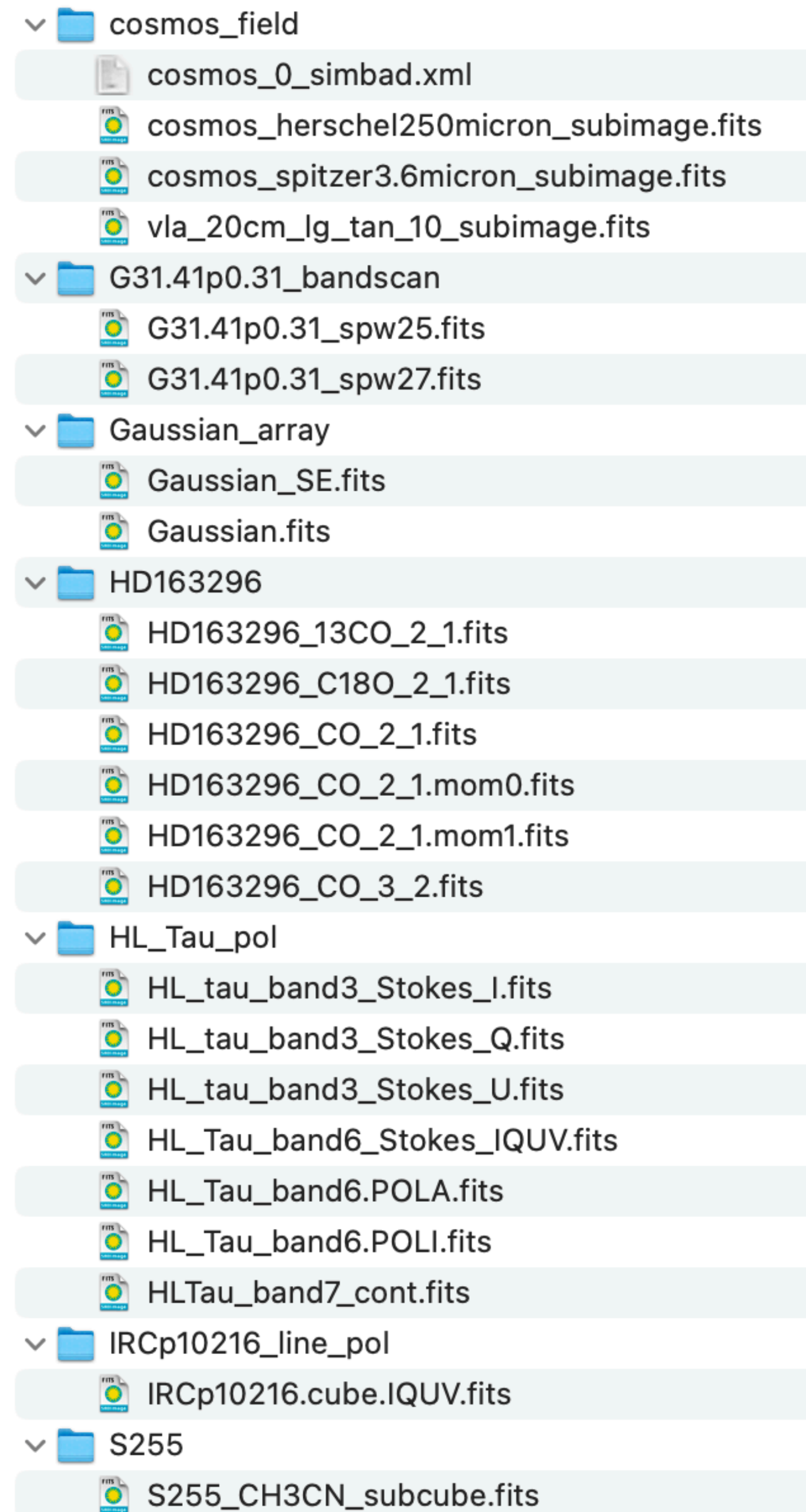
```
Name = HD163296_CO_2_1.fits
HDU = 0
Data type = float
Shape = [432, 432, 76, 1]
Number of channels = 76
Number of polarizations = 1
Coordinate type = Right Ascension, Declination
Projection = SIN
Image reference pixels = [217, 217]
Image reference coords = [17:56:21.2813, -21:57:22.3607]
Image ref coords (deg) = [269.089 deg, -21.9562 deg]
Pixel increment = -0.05", 0.05"
Pixel unit = Jy/beam
Celestial frame = FK5, J2000
Spectral frame = LSRK
Velocity definition = RADIO
Restoring beam = 0.678423" X 0.551015", 72.5103 deg
RA range = [17:56:20.509, 17:56:22.058]
DEC range = [-21:57:33.161, -21:57:11.611]
```

The file browser window has buttons for "Close", "Load selected", and "Load as hypercube". The main application window shows a "No image loaded" message and a "Render Configuration" widget.



# Exercise 1/4

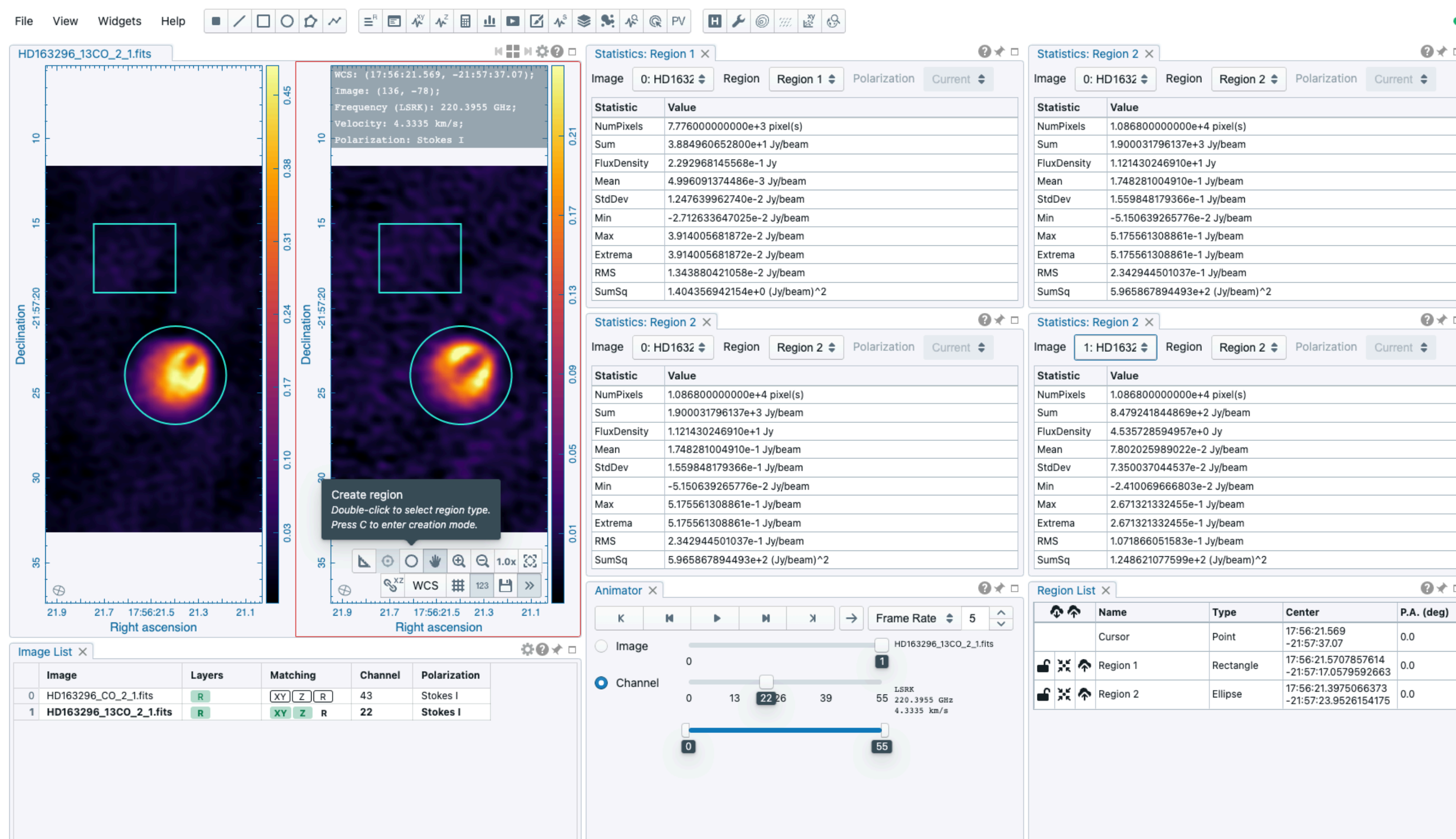
- **Try to load images in CARTA**
  - Use any of the test images
- **Try to change the appearance of your raster images**
  - Use any of the test images
- **Try to configure and render contours**
  - Use any of the test images
- **Try to match your raster and contour images**
  - Use images in Gaussian\_array
  - Use images in HD163296 folder



# Image analytics

## Region of interest and statistics

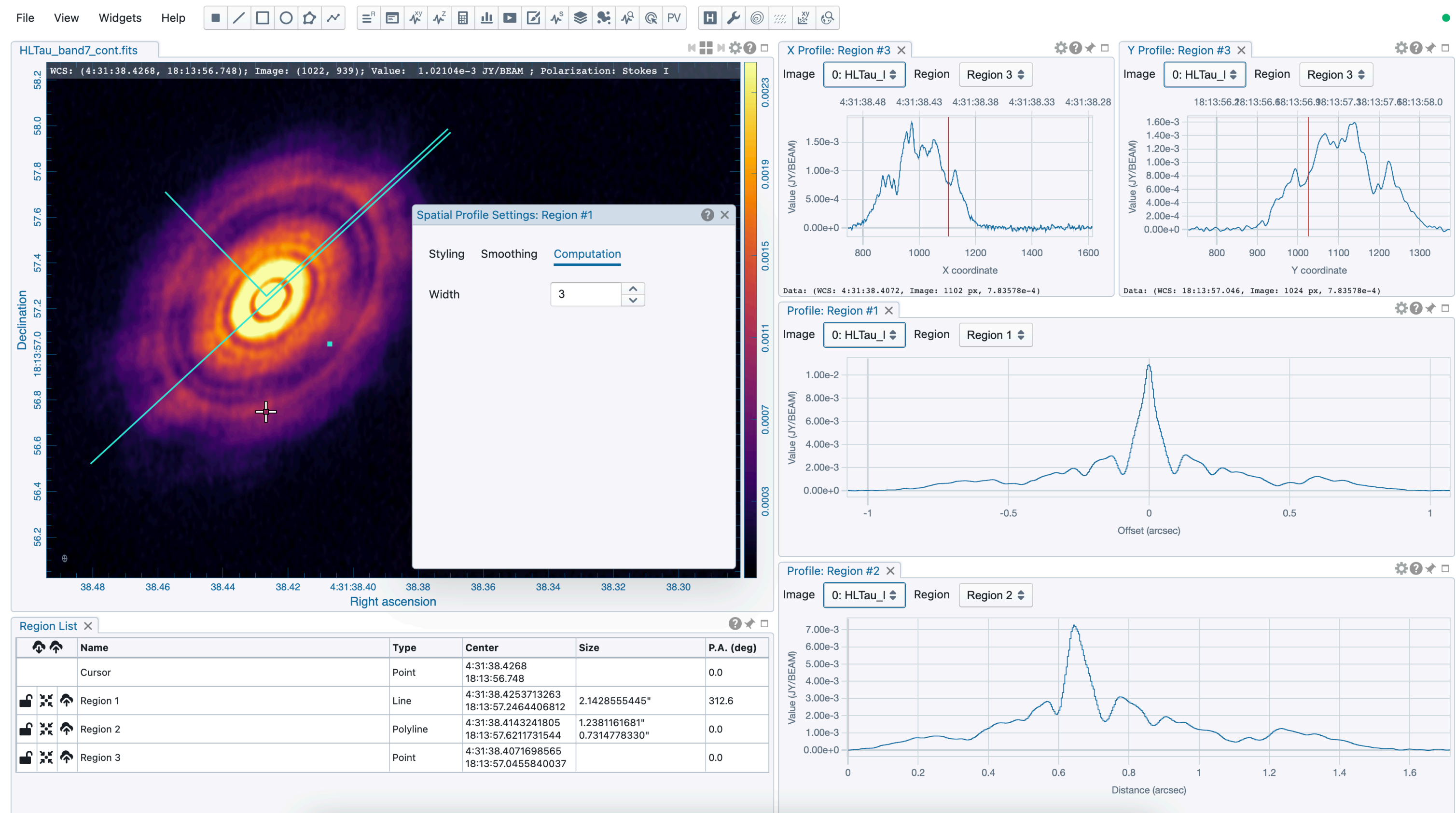
- Region of interest can be created via
  - the region bar at the top of the GUI
  - the tool bar in the image viewer
- Region of interest can be exported as a text file in CASA (`.crtf`) or ds9 (`.reg`) format
- The region list widget summarize all region properties
- The statistics widget reports region statistics
- “Active” image and “active” region
- Flexible image, region, and polarization configuration



# Image analytics

## Spatial profile

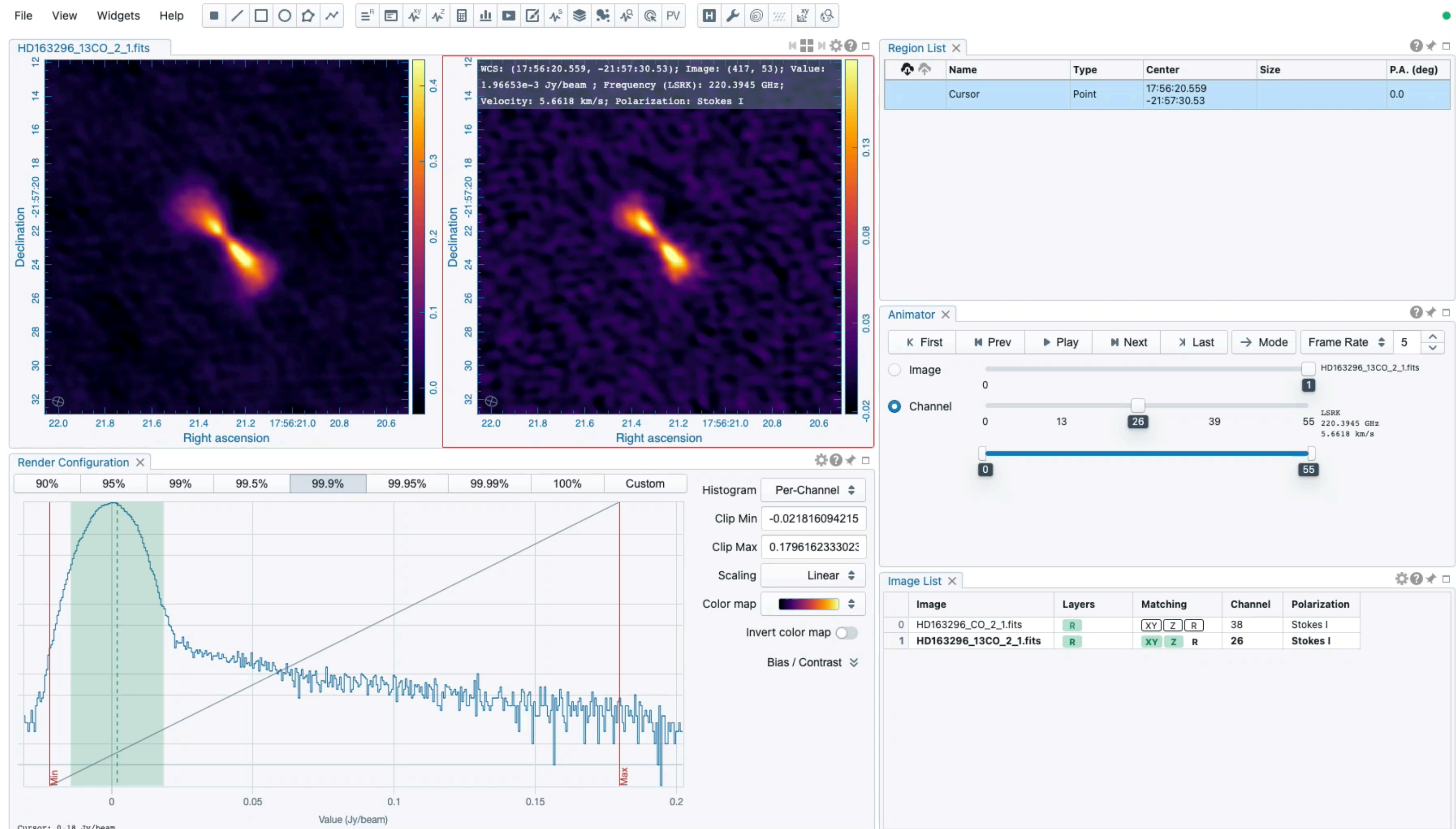
- The spatial profile widget displays a spatial profile from
  - Cursor and point region (treated as a horizontal or a vertical cut)
  - Line region
  - Polyline region
- The averaging width is configurable in the settings dialog
- Projection distortion is considered when the offset or distance is calculated



# Image analytics

## Spectral profile

- The spectral profiler widget displays spectral profiles
  - from different images
  - from different regions
  - with different statistics
  - from different polarization components
- Channel navigation can also be performed with the profiler plot



# Image analytics

## Spectral profile

- The spectral profiler widget displays spectral profiles
  - from different images
  - from different regions
  - with different statistics
  - from different polarization components
- Channel navigation can also be performed with the profiler plot

**Region List**

Name	Type	Center	Size	P.A. (deg)
Cursor	Point	17:56:20.843 -21:57:28.20		0.0
Region 1	Ellipse	17:56:21.3940402918 -21:57:20.8427941389	2.2178571429" 2.3142857143"	0.0
Region 2	Ellipse	17:56:21.1653073244 -21:57:24.2177939945	2.2660714286" 2.1696428571"	0.0
Region 3	Rectangle	17:56:21.2831398366 -21:57:22.6508322548	11.3785714286" 10.5107142857"	0.0

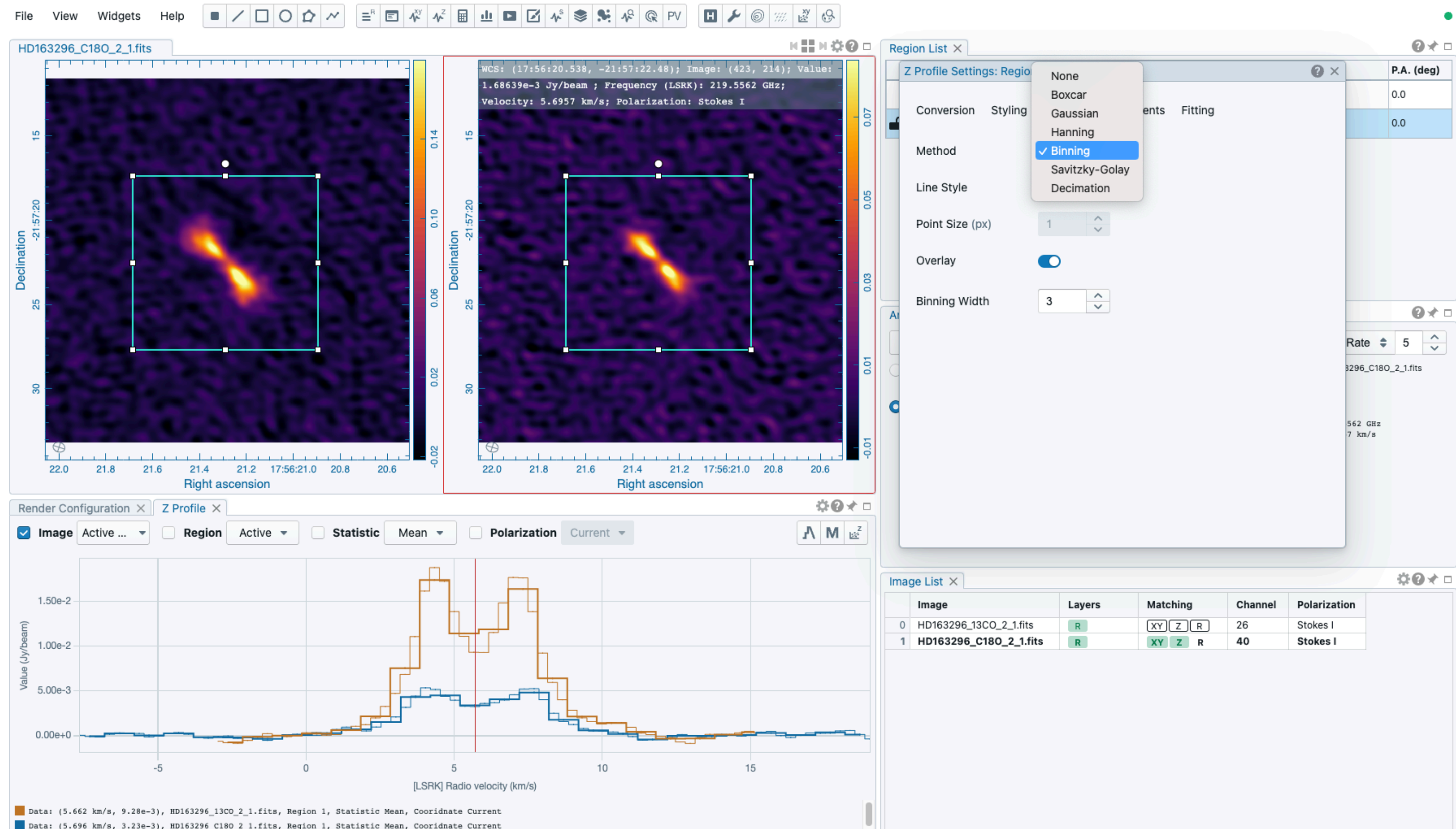
**Image List**

Image	Layers	Matching	Channel	Polarization
0 HD163296_CO_2_1.fits	R	XY Z R	38	Stokes I
1 HD163296_13CO_2_1.fits	R	XY Z R	26	Stokes I

# Image analytics

## Profile smoothing

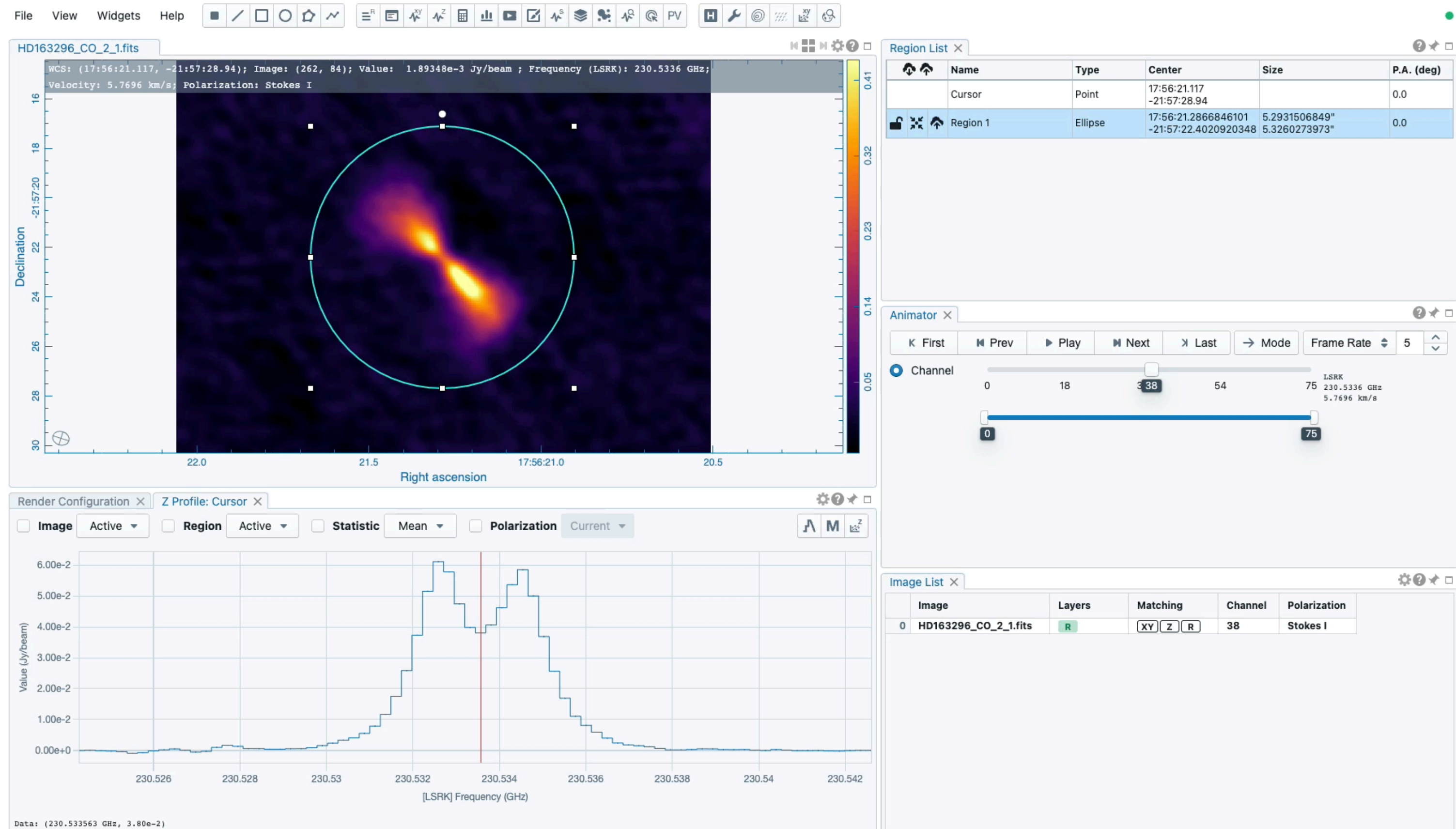
- Profile smoothing can be applied to spatial profiles or spectral profiles to enhance the S/N
- Various smoothing schemes are supported



# Image analytics

## Spectral profile fitting

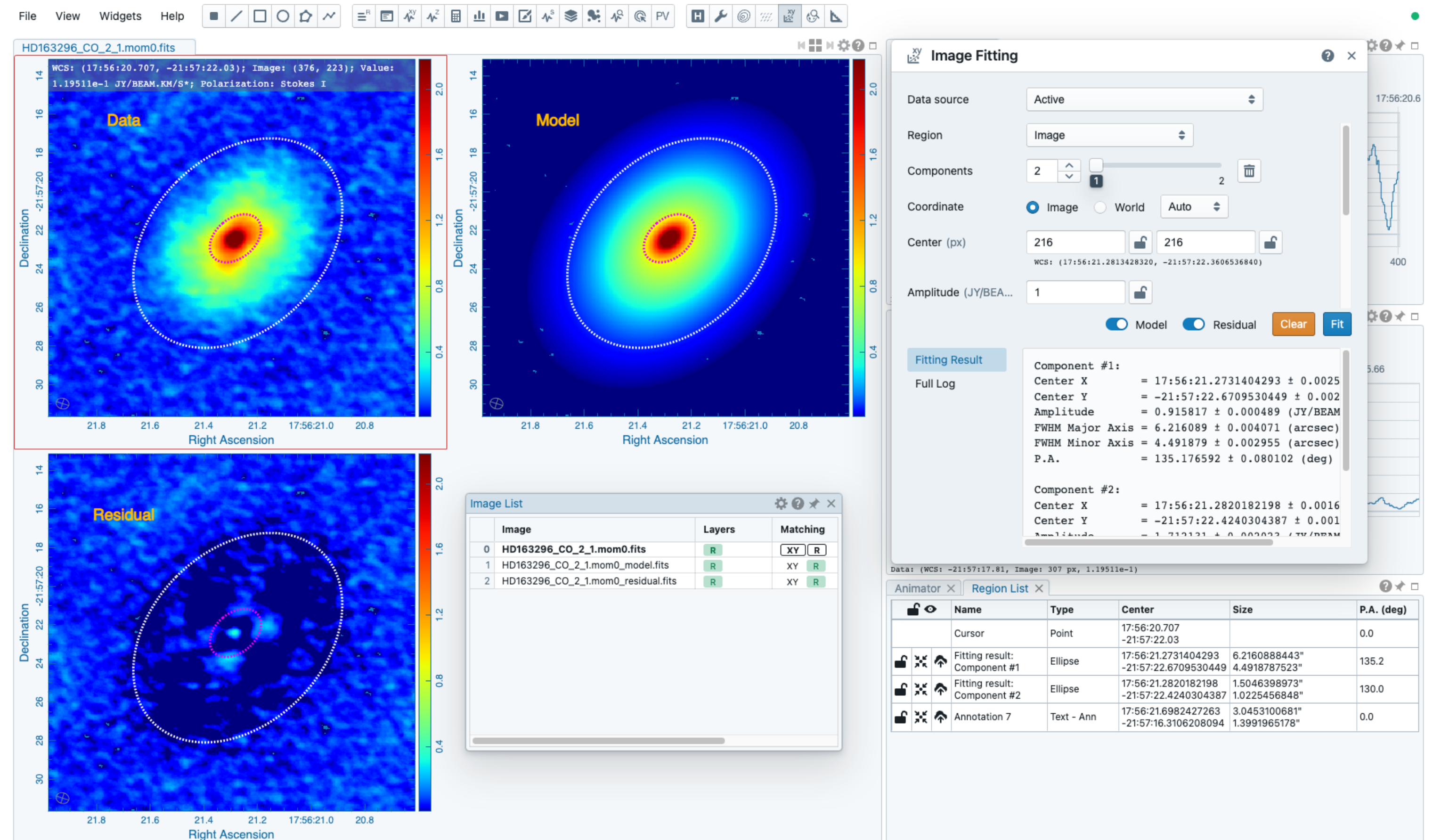
- Multiple Gaussian or Lorentzian profiles are supported with an optional 0th or 1st order continuum.
- Flexible initial guess configuration
- Smart guess!
- Profile data in the view are the input data for the smart guess and fitting
- If profile smoothing has been applied, smoothed profile is the input data for fitting



# Image analytics

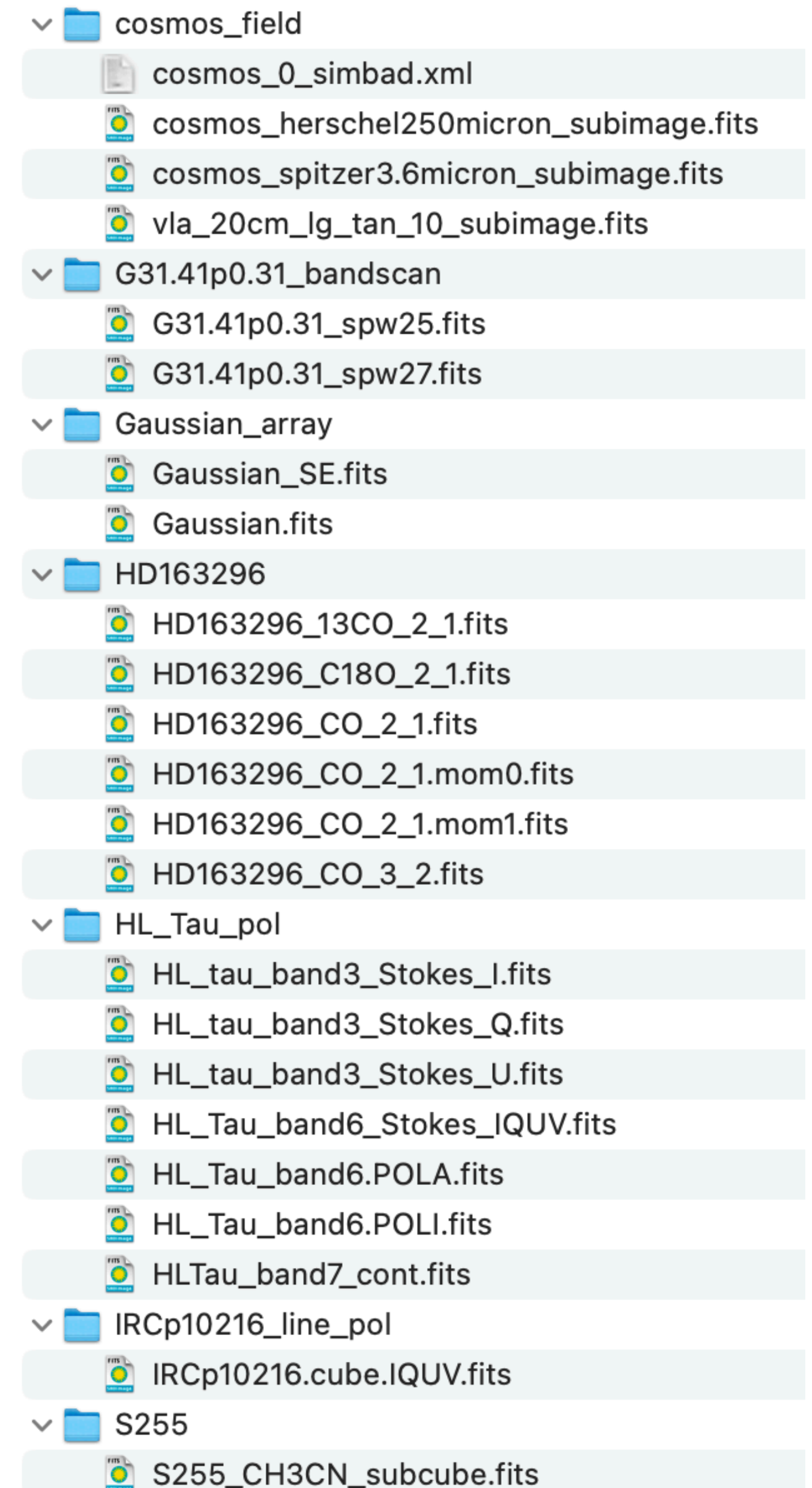
## Image fitting

- Multiple-Gaussian components can be fitted
- Optionally, fitting parameters can be locked
- Model and residual images are generated and appended after fitting
- Elliptical regions can be created based on the fitting results



# Exercise 2/4

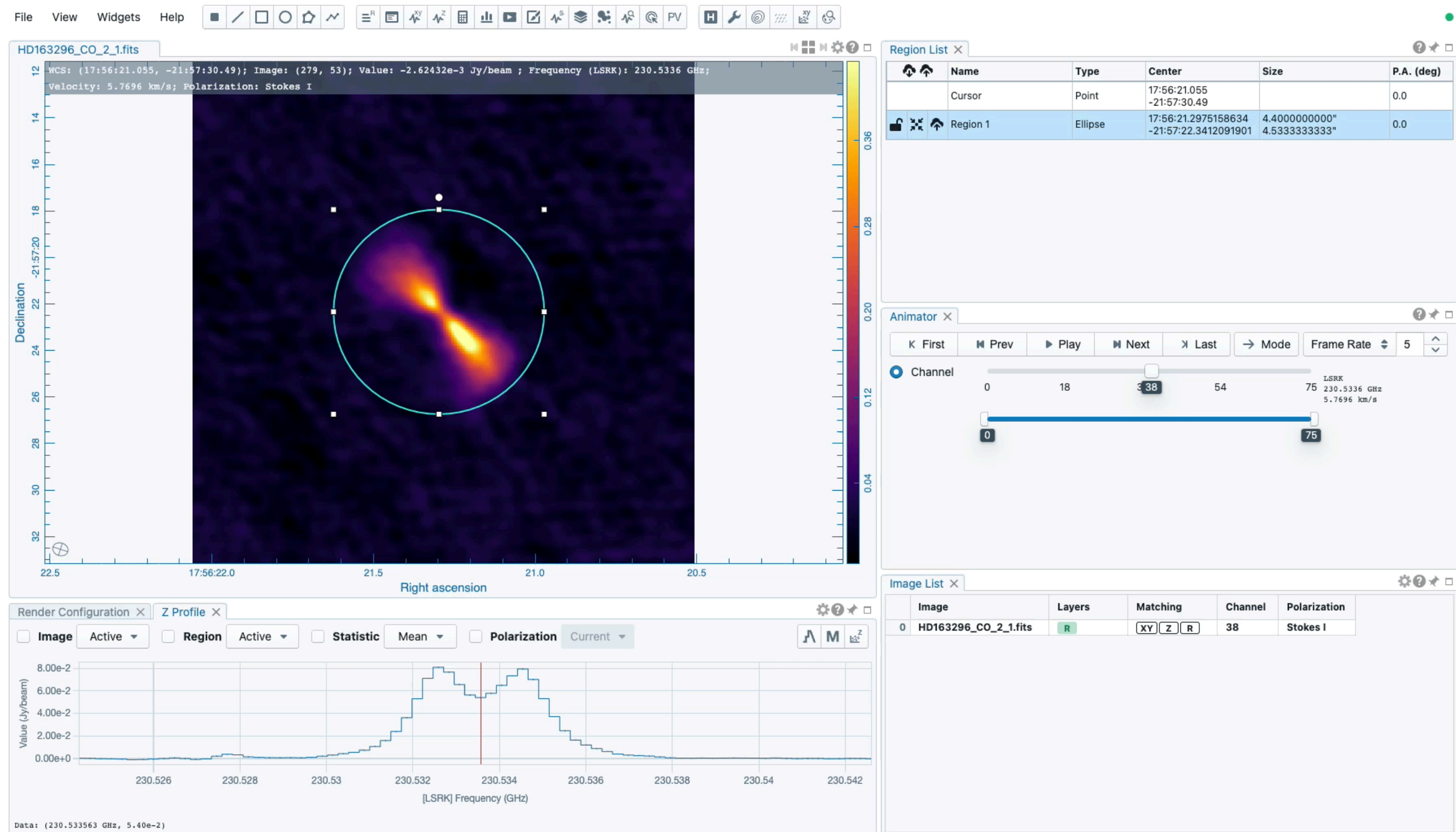
- **Try to visualize a spatial profile from a line or a polyline region**
  - Use any of the test images
- **Try to visualize spectral profiles from multiple matched images**
  - Use images in HD163296 folder
- **Try to visualize spectral profiles from different regions of an image**
  - Use images in HD163296 folder or S255 folder
- **Try to smooth a spatial or a spectral profile**
  - Use images in HD163296 folder or S255 folder
- **Try to fit Gaussians to a spectral profile**
  - Use images in HD163296 folder or S255 folder



# Image analytics

## Moment map generator

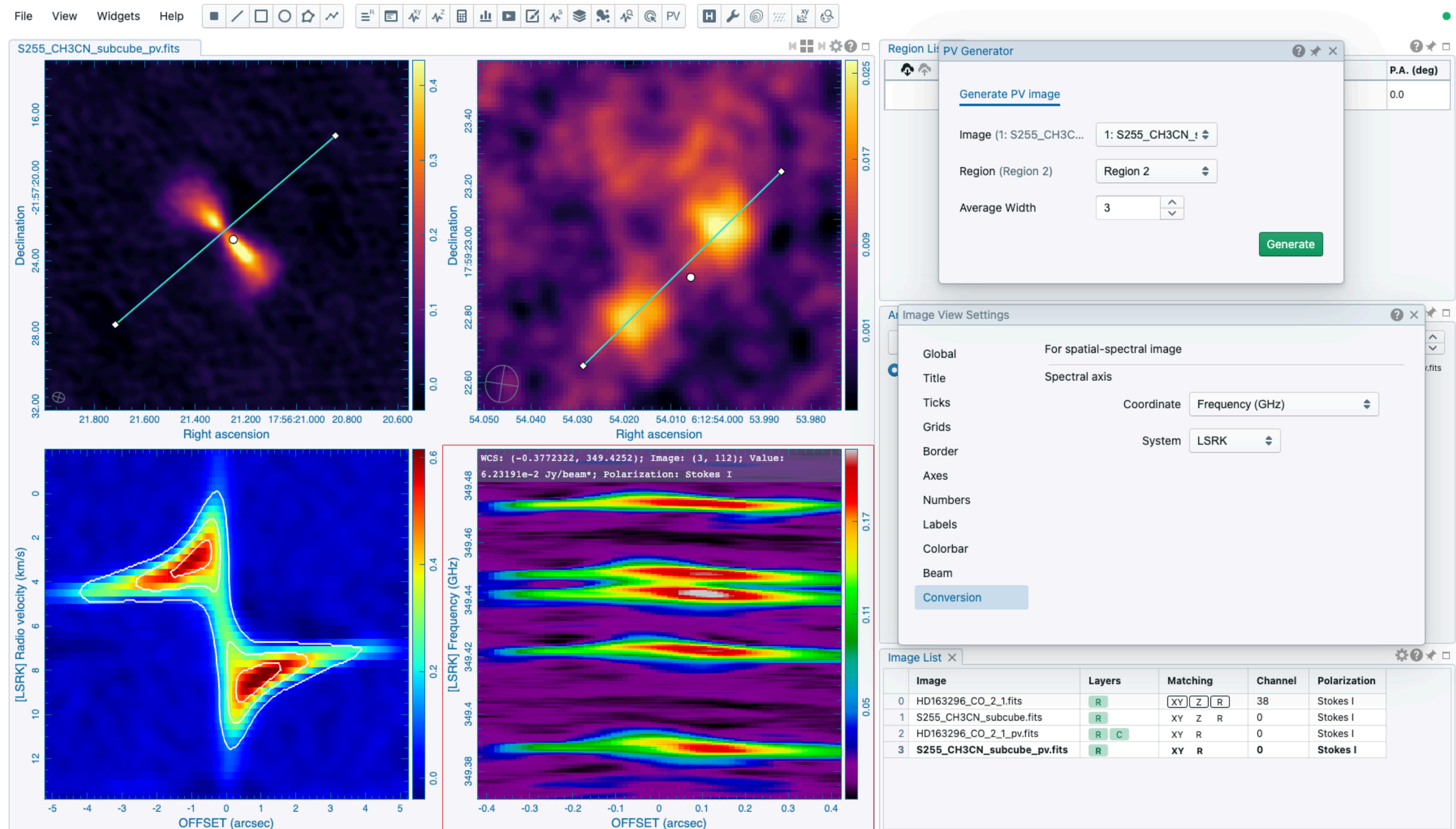
- The moment generator can produce a set of “moment” images as defined in CASA
- Generated moment images are automatically appended.
- Moment images may serve as a guide map for spectral profile exploration
- May save a generated moment image via “File -> Save image”



# Image analytics

## PV map generator

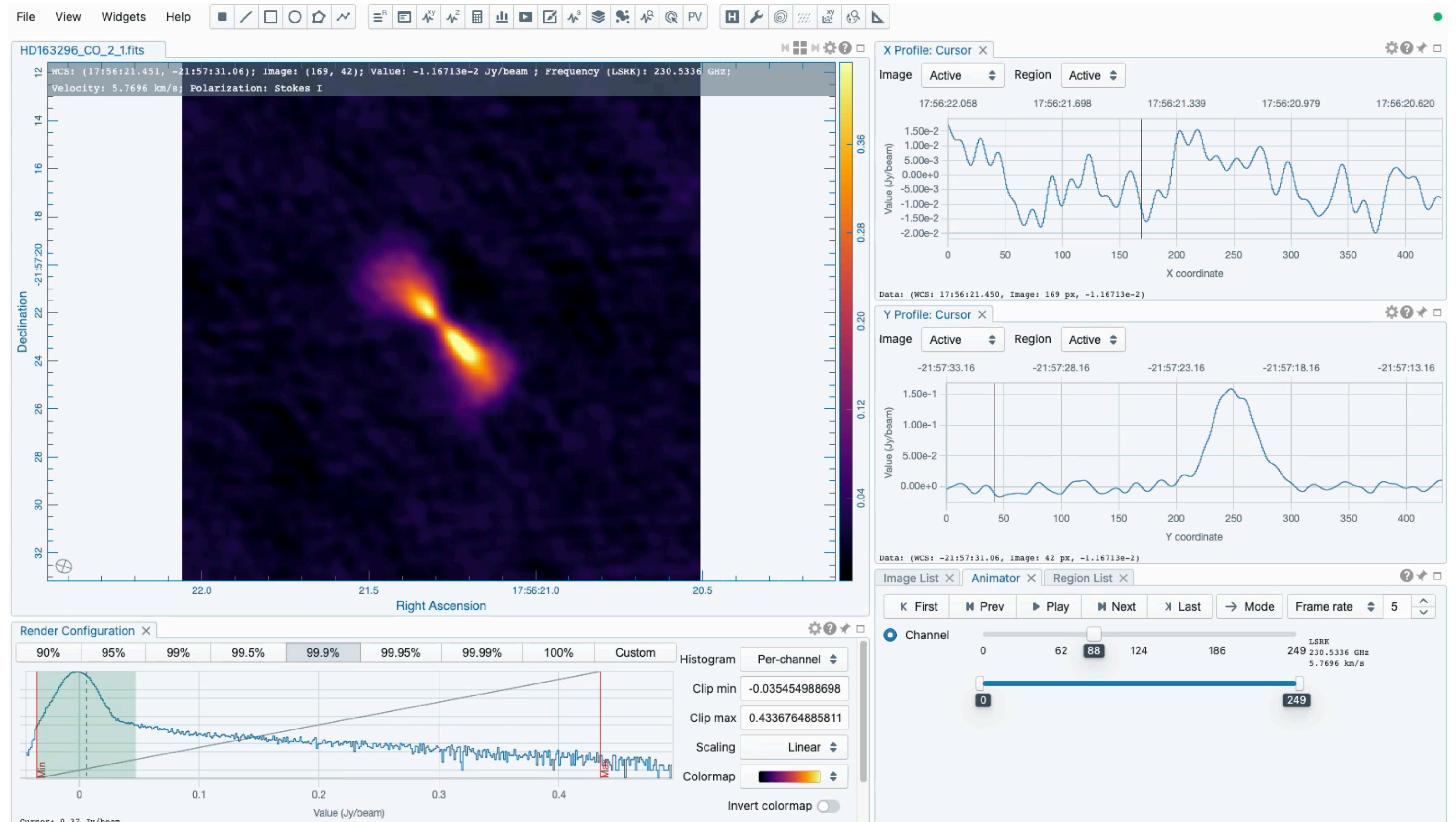
- The PV map generator extracts a slice from an image cube along a line region (offset v.s. velocity)
- The generated PV image is automatically appended
- May save a PV image via “File -> Save image”
- Spectral convention can be changed with the image view settings dialog
- Projection distortion is considered when the offset axis is computed



# Image analytics

## PV map generator - interactive preview

- A scalable version of KARMA-kpvslice is implemented in v4-beta
- A downsampled cube can be created for PV preview purpose
- By dragging the PV cut, the PV preview image is rendered in the PV preview widget



The interface displays the following data and controls:

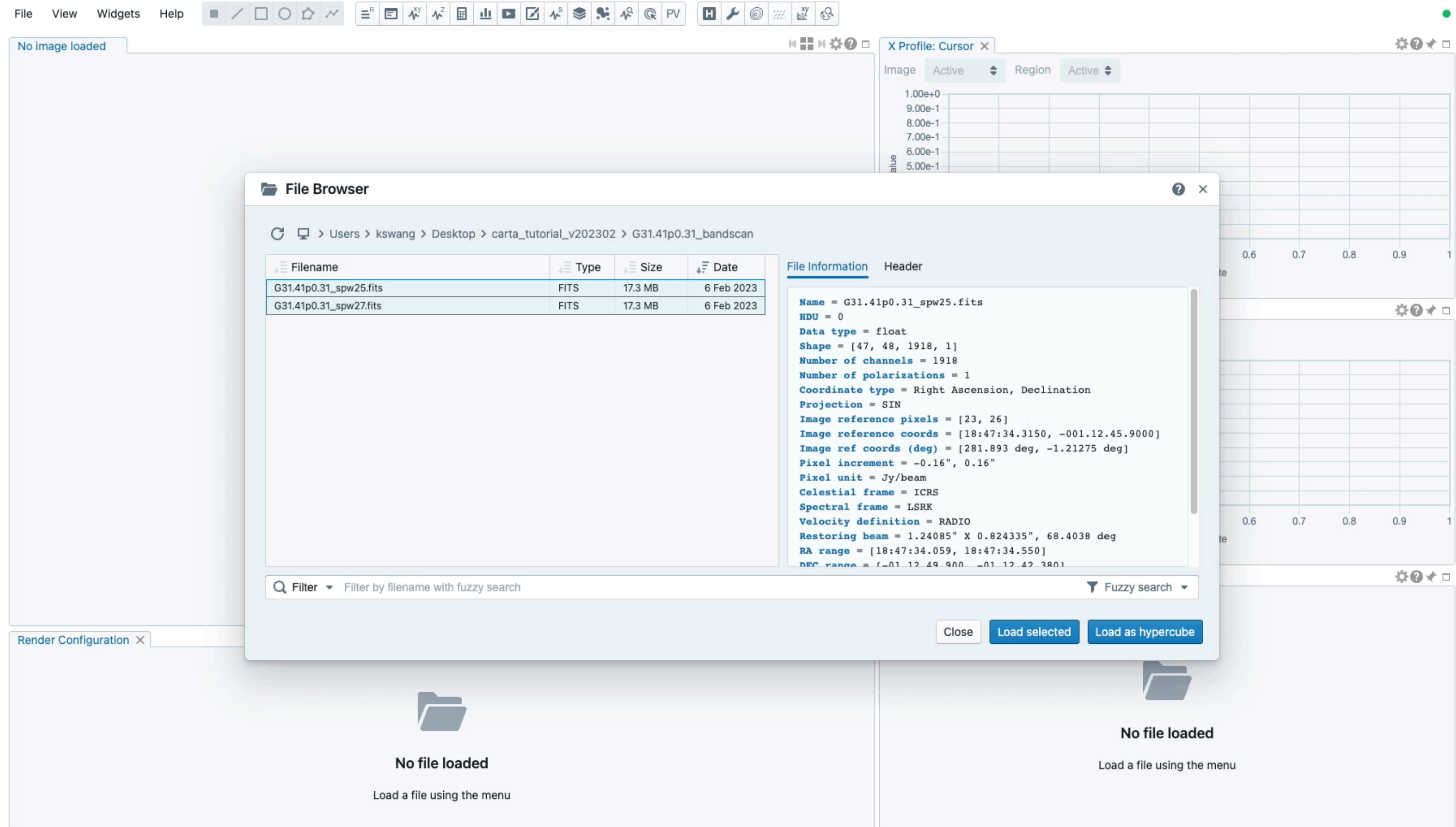
- File Name:** HD163296\_CO\_2\_1.fits
- WCS:** (17:56:21.451, -21:57:31.06); Image: (169, 42); Value: -1.16713e-2 Jy/beam; Frequency (LSRK): 230.5336 GHz; Velocity: 5.7696 km/s; Polarization: Stokes I
- X Profile:** X coordinate vs Value (Jy/beam). Data: (WCS: 17:56:21.450, Image: 169 px, -1.16713e-2)
- Y Profile:** Y coordinate vs Value (Jy/beam). Data: (WCS: -21:57:31.06, Image: 42 px, -1.16713e-2)
- Render Configuration:** Histogram, Clip min: -0.035454988698, Clip max: 0.4336764885811, Scaling: Linear, Colormap, Invert colormap.
- Channel Selector:** Channel range from 0 to 249, currently set to 88. LSRK: 230.5336 GHz, 5.7696 km/s.



# Image analytics

## Spectral line ID

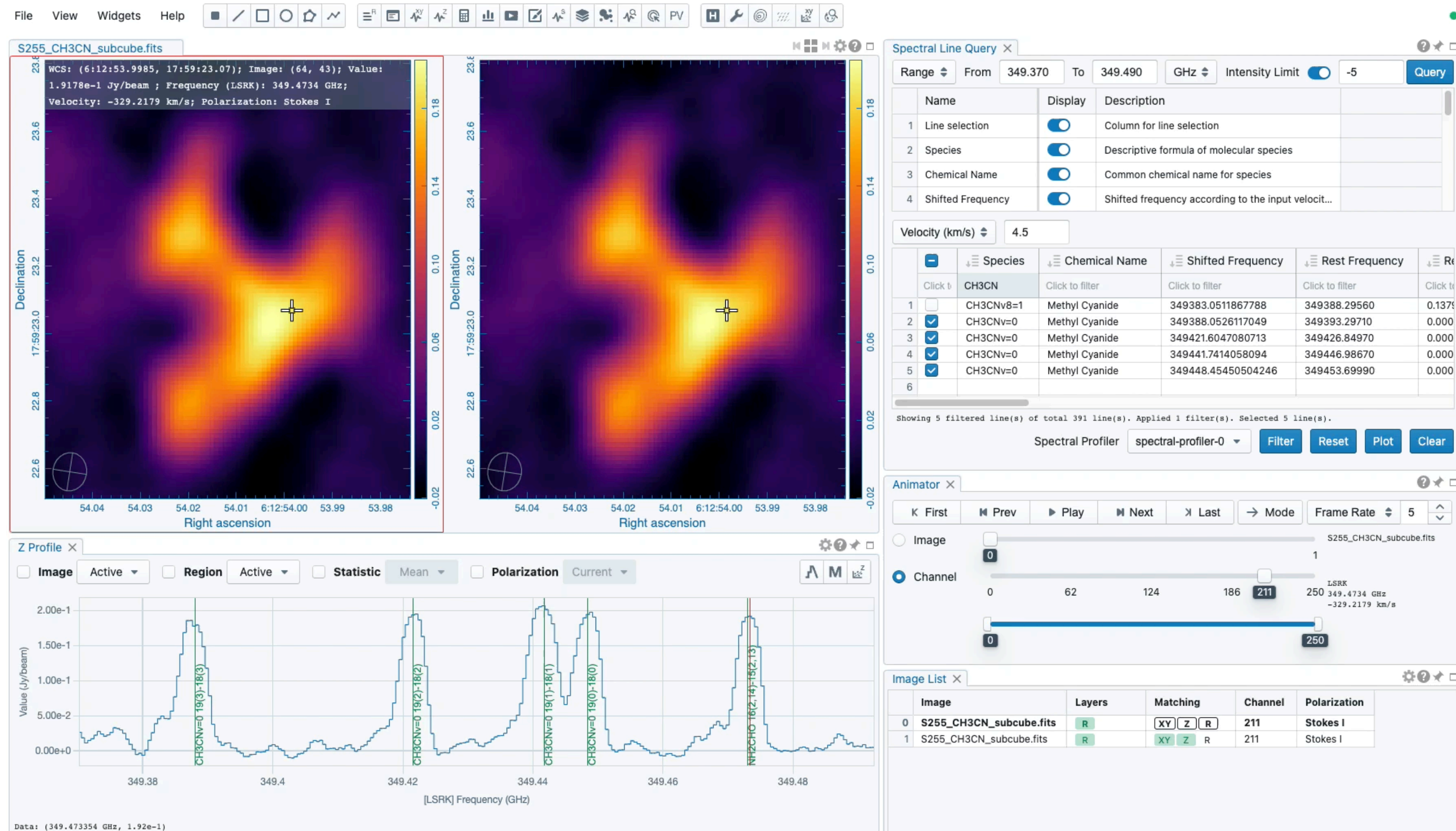
- Spectral line IDs from the Splatalogue (<https://splatalogue.online/>) can be overlaid on a spectrum for line identification
- In this special use case, we need to match the cubes in “frequency” via the settings dialog of the image list widget in order to compare images
- Use the line table to filter and select target lines/species for ID overplotting
- Future enhancement
  - Offline database
  - Automatic line identification




# Image analytics

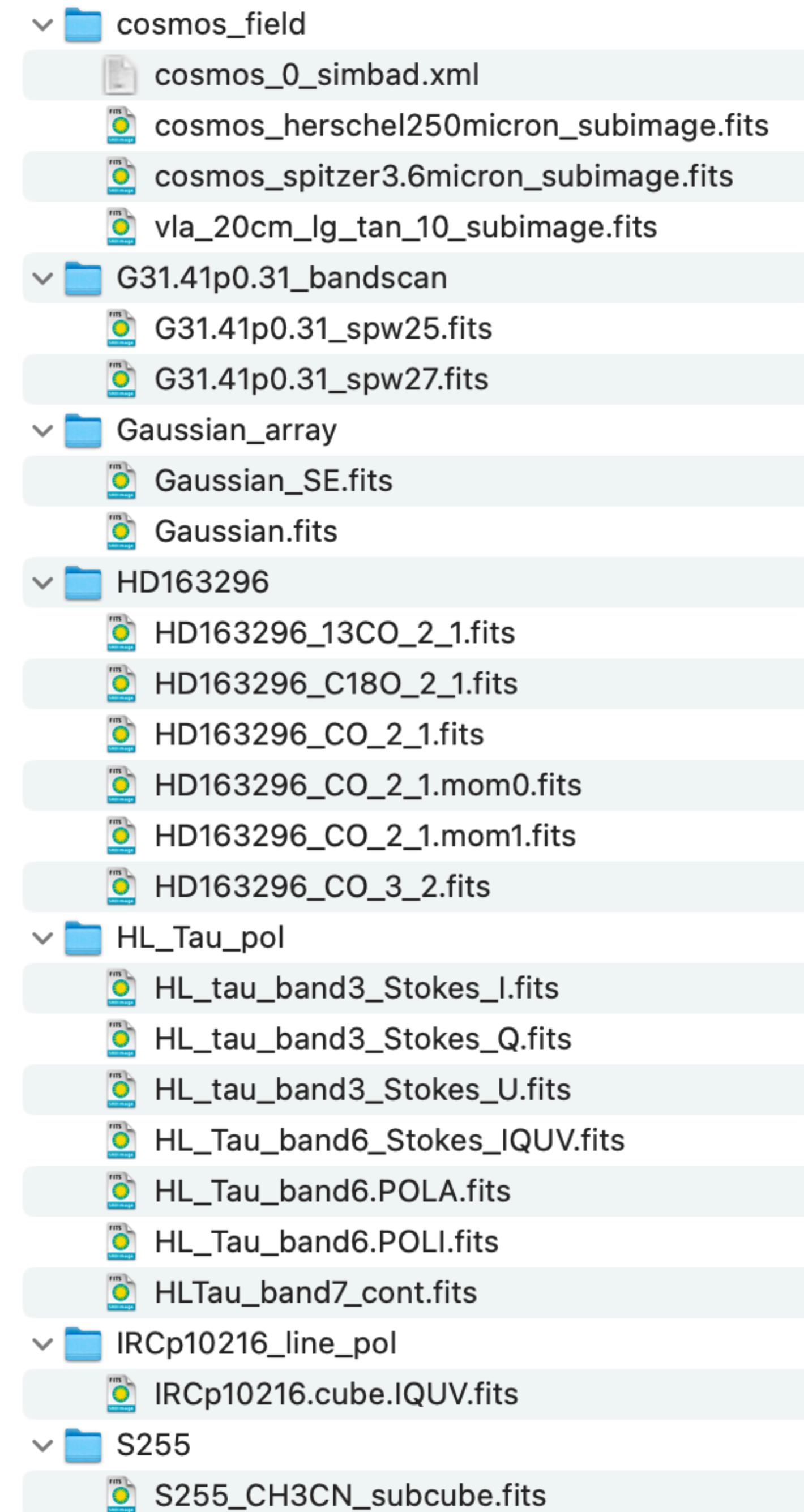
## Rest frequency shifting

- Frequency to velocity conversion depends on the RESTFRQ header
- The RESTFRQ header of each loaded image can be temporarily modified via the image list widget to enable a new conversion for line matching
- This applies to the spectral axis of the PV image too



# Exercise 3/4

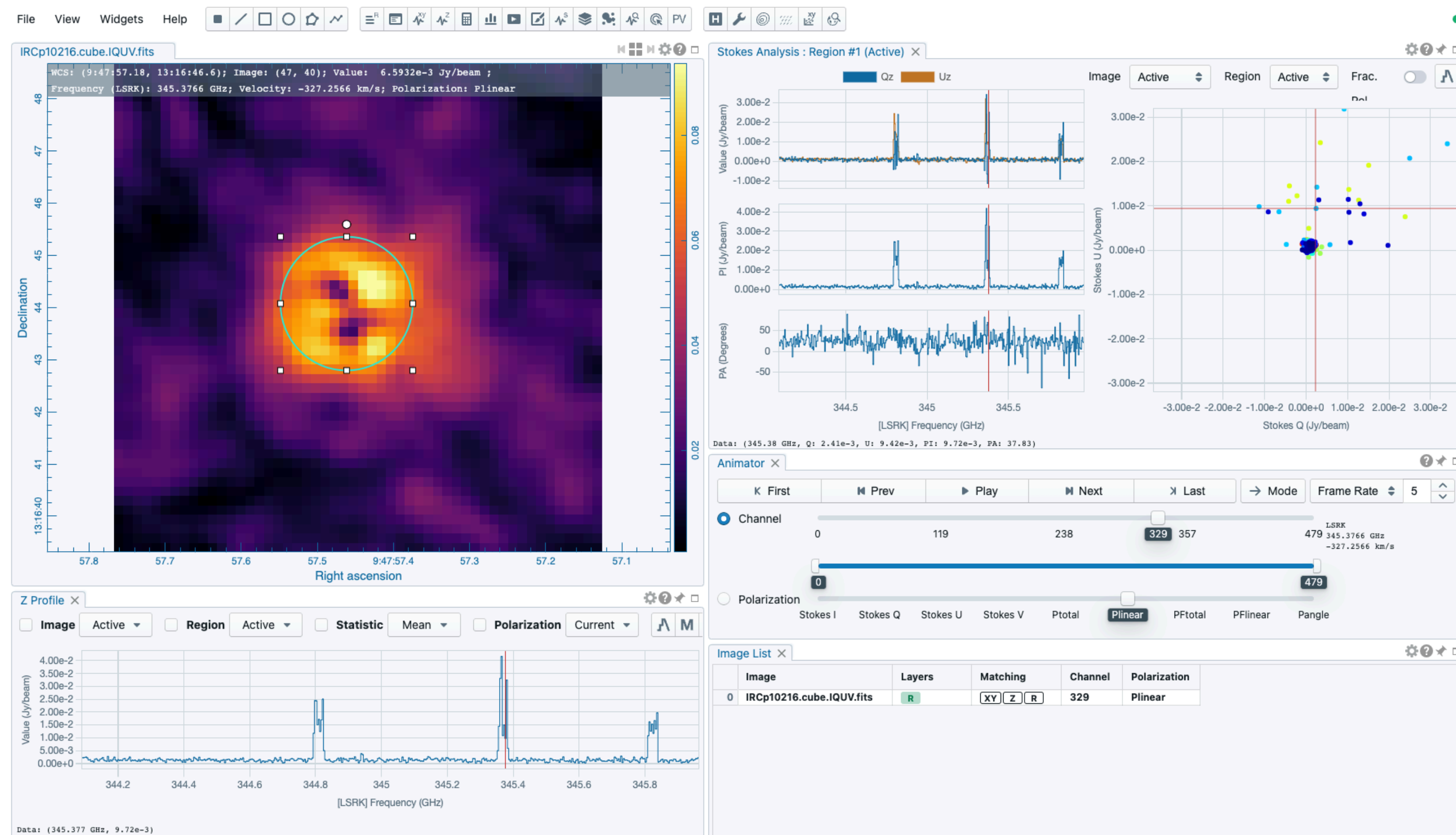
- **Try to generate some moment images**
  - Use images in HD163296 folder or S255 folder
- **Try to generate a PV image**
  - Use images in HD163296 folder or S255 folder
- **Try to label spectral line IDs**
  - Use images in S255 folder (try CH<sub>3</sub>CN at ~4 km/s)
  - Use images in G31.41p0.31\_bandscan folder (try C<sub>2</sub>H<sub>5</sub>OH “beer!”  ) at ~98 km/s)
- **Try to match spectral lines in the velocity space by setting new rest frequencies**
  - Use images in S255 folder and match  
CH<sub>3</sub>CN J19-18 K=3 at 349393.2971 GHz  
NH<sub>2</sub>CHO 16(2,14)-15(2,13) at 349479.5473 MHz



# Polarization cube visualization and analysis

## Stokes analysis widget and computed polarization components

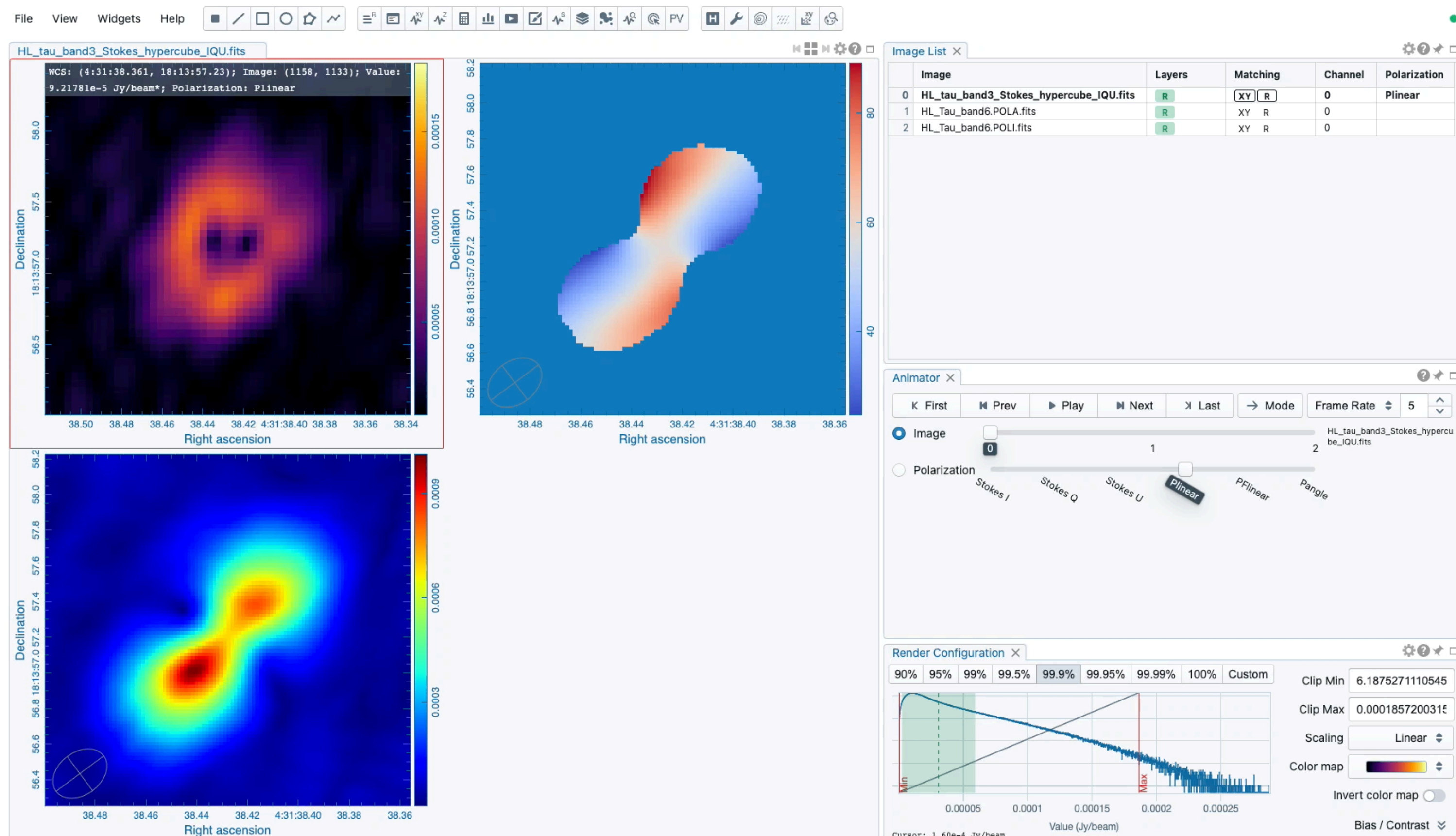
- When a Stokes cube is loaded, a set of plots is generated in the Stokes analysis widget
  - Q v.s. U profile and scatter plot (Faraday rotation)
  - Pol. I and Pol. A profiles
- Use the animator to switch to different Stokes (native) and other (on-the-fly) computed components



# Polarization cube visualization and analysis

## Vector field rendering

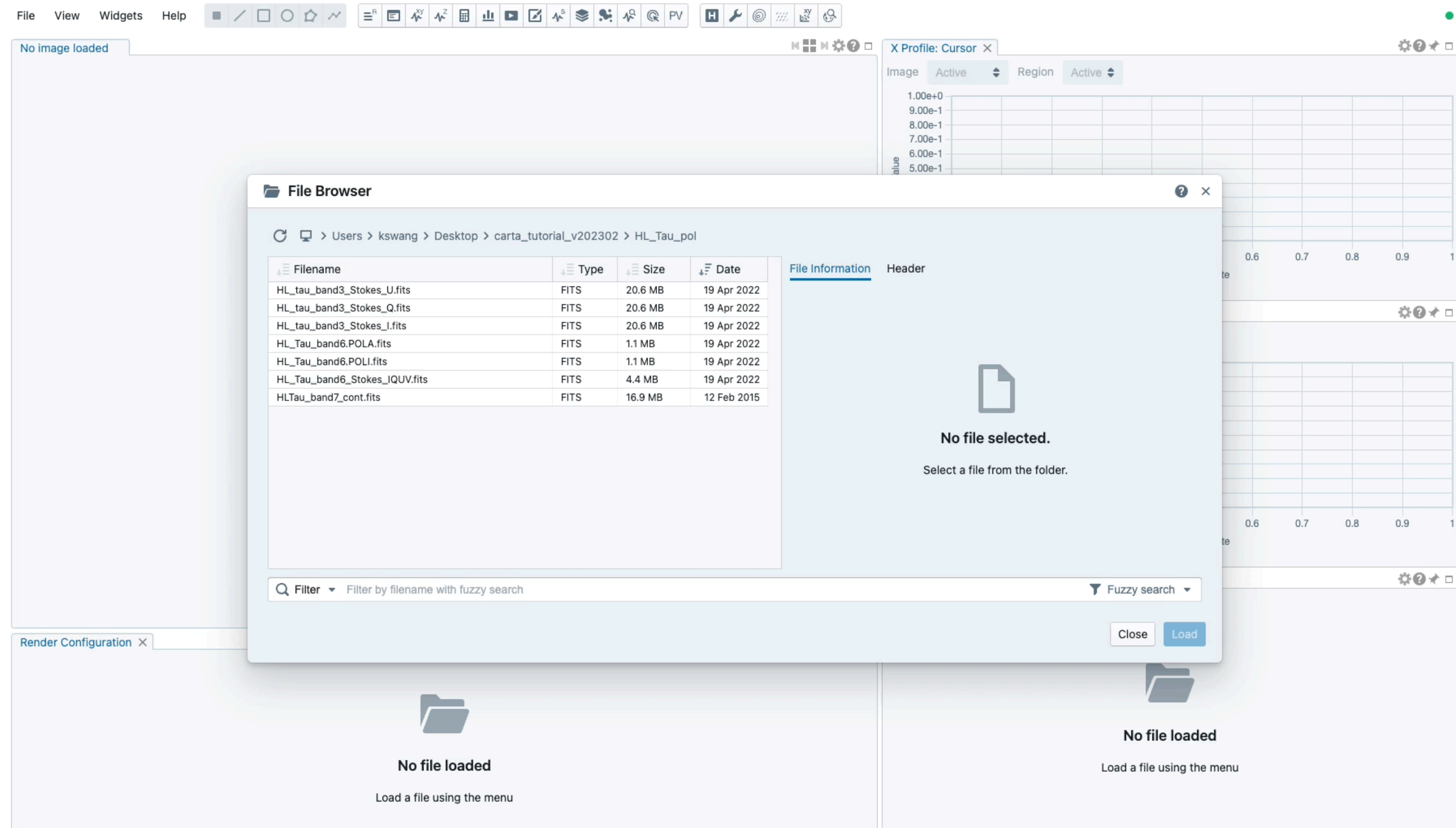
- A linear polarization field can be computed and rendered from a Stokes cube
- A linear polarization angle field can be rendered from a pre-calculated image
- An optional angle offset can be applied (e.g., +90 deg to infer B-field)
- A scalar field can also be rendered
- Matched images share their vector field rendering



# Polarization cube visualization and analysis

## Forming a Stokes hypercube

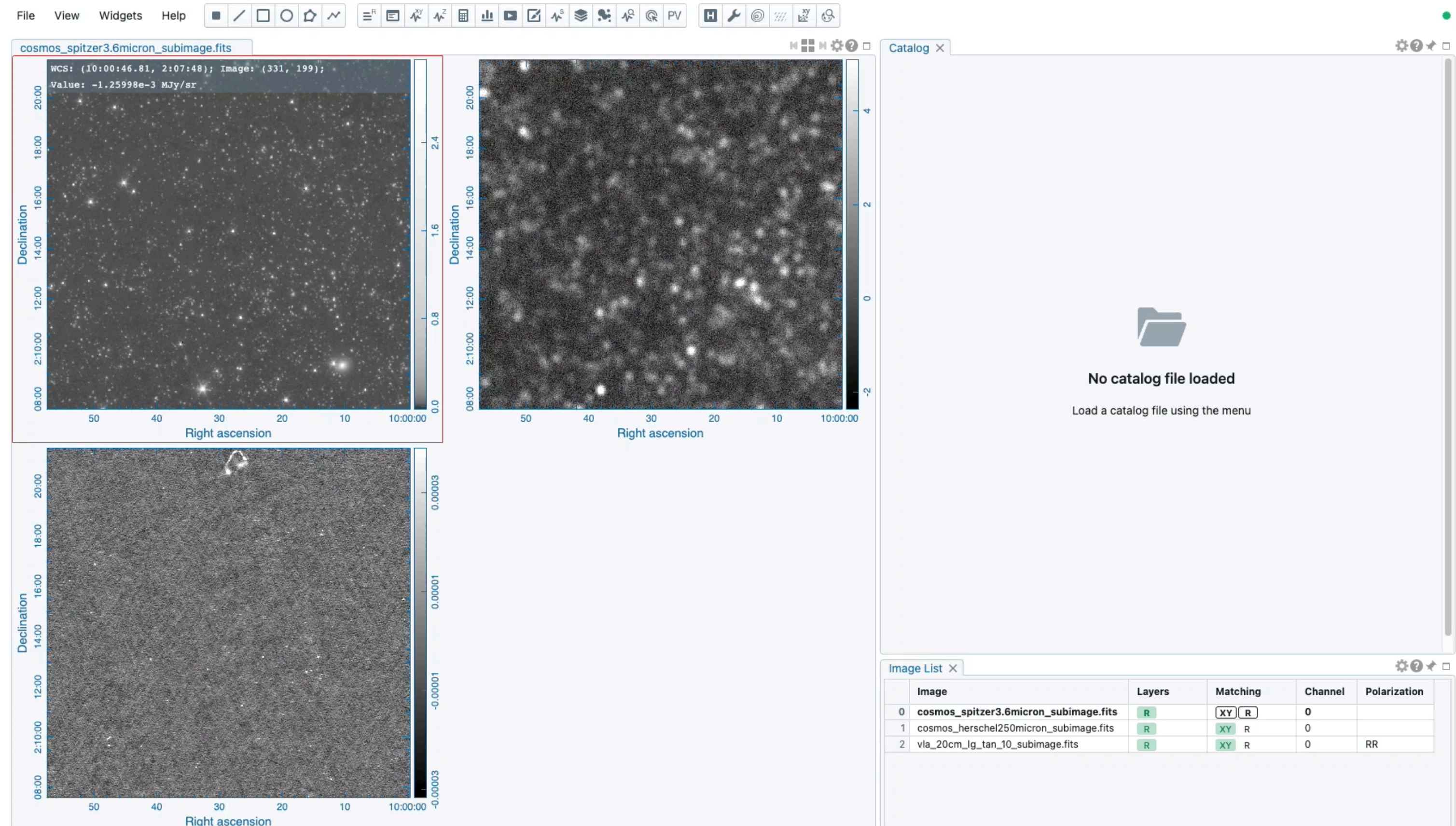
- If Stokes I, Q, U, and V are as individual files, you can use the file browser to form a Stokes hypercube and treat the result as a single (virtual) file
- Perform analysis with
  - animator
  - Stokes analysis widget
  - Spectral profiler widget
  - Vector field rendering dialog
  - ...



# Catalog visualization

## Linked rendering

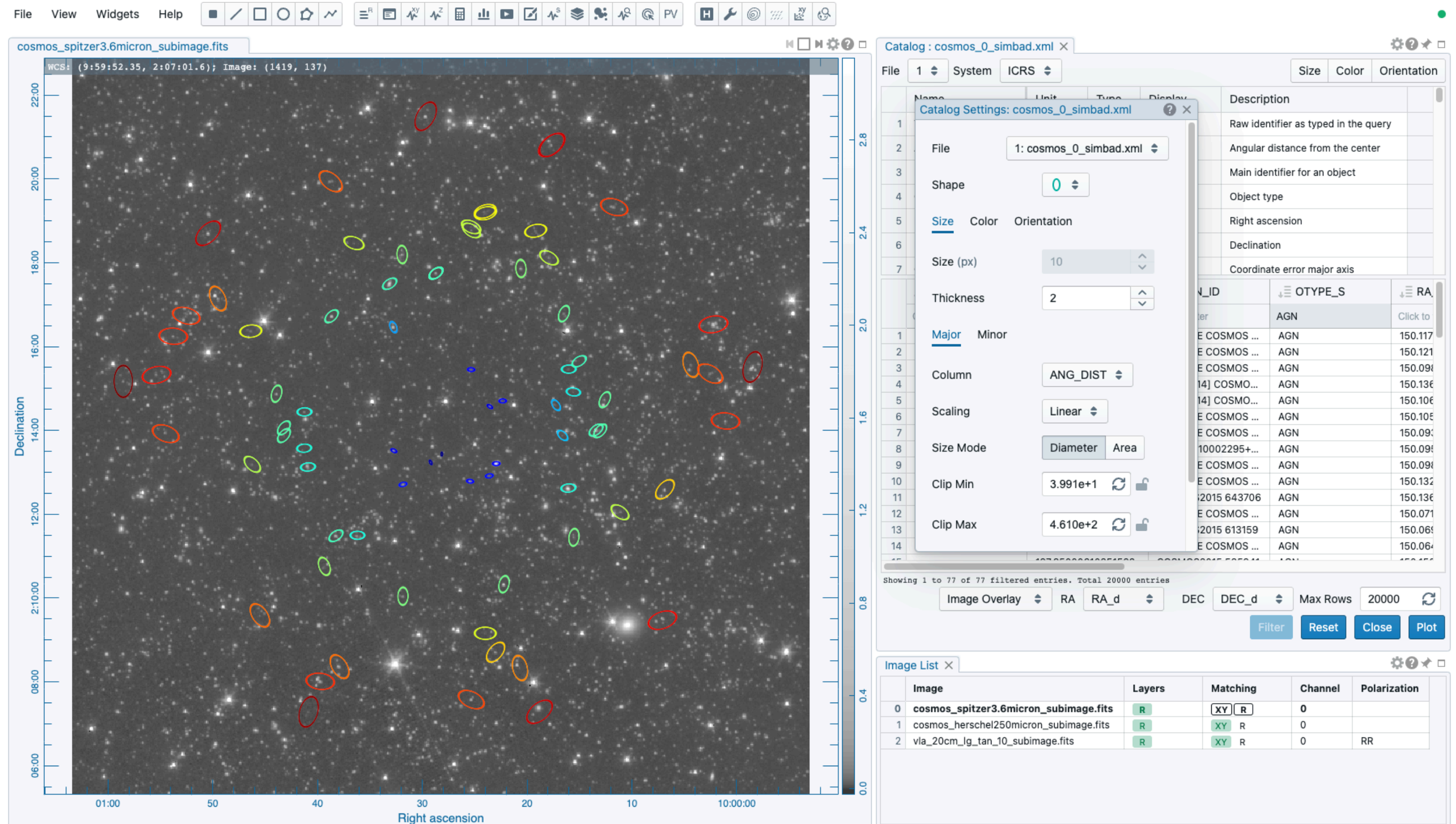
- Offline catalog (“File -> Import catalog”): FITS and VOTable format
- Online catalog query
- The catalog widget supports filtering
- Catalog can be rendered and inter-linked as
  - Image overlay (GPU-accelerated, WebGL2)
  - 2D scatter plot
  - histogram
- Matched images share their catalog image overlay rendering



# Catalog visualization

## Marker-based catalog rendering

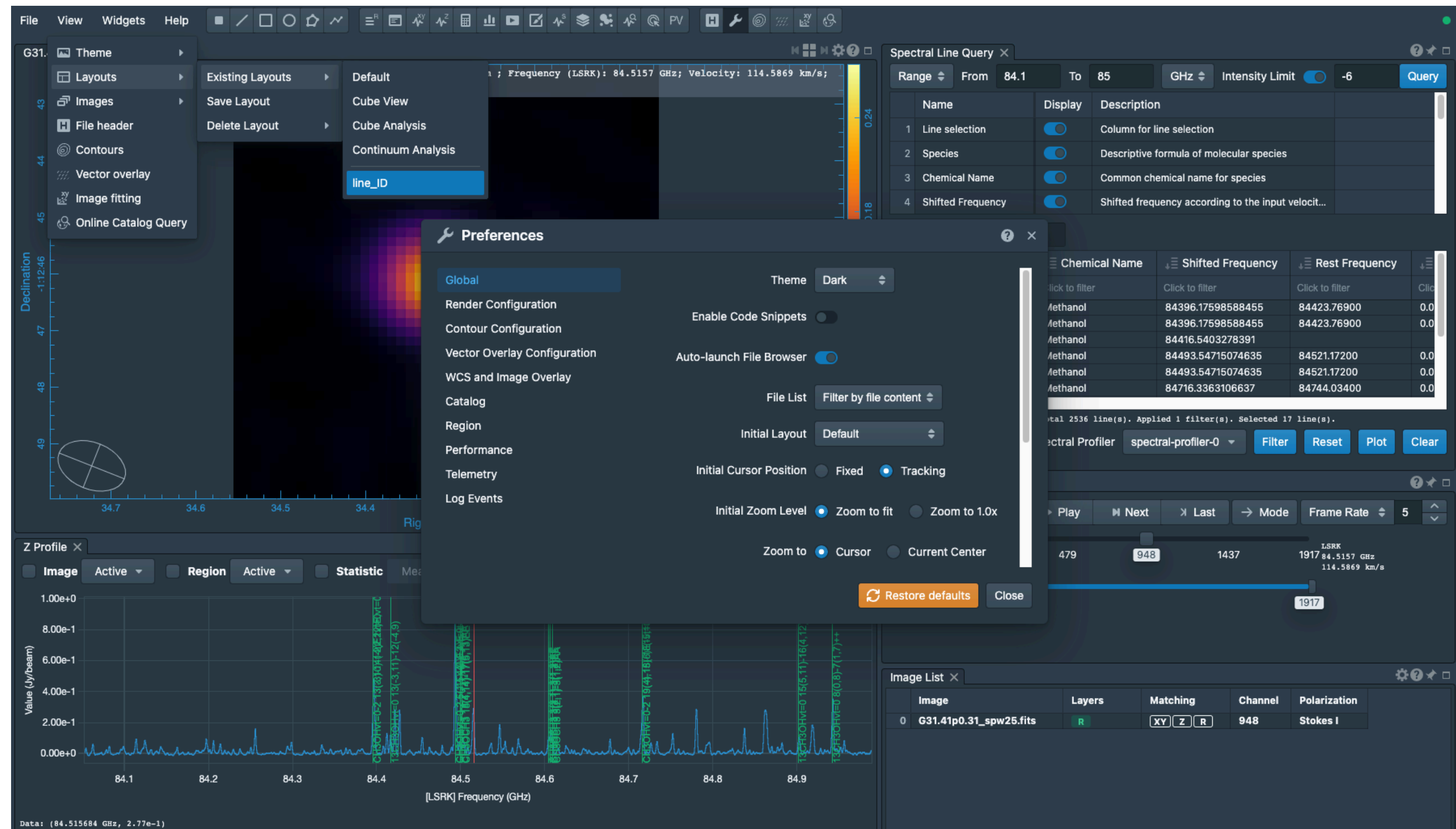
- Image overlay as column-mapped markers
- Size mapping
- Color mapping
- Orientation mapping



# GUI customization

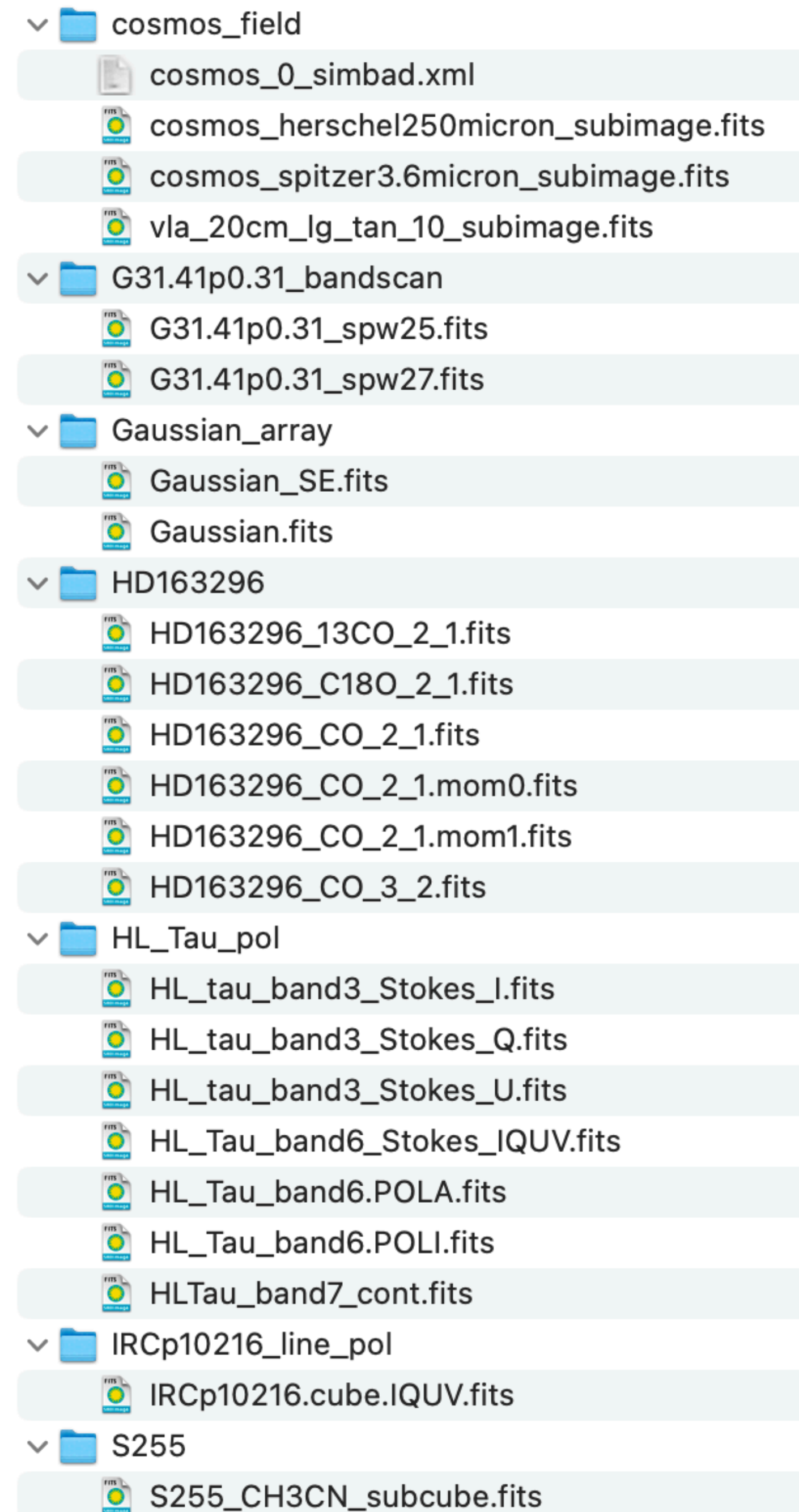
## Custom layouts and preferences

- A custom layout can be
  - saved (“View -> Layouts -> Save layout”)
  - reused (“View -> Layouts -> Existing layouts”)
- Use the preference dialog (“File -> Preferences”) to customize the GUI such as
  - default layout
  - default colormap for raster rendering
  - region creation modes (center-to-corner or corner-to-corner)
  - Image pan modes (drag-to-pan or click-to-pan)
  - and many many more!



# Exercise 4/4 and Q&A

- **Load a Stokes cube and explore its context with the Stokes analysis widget and the animator**
  - Use images in `IRCp10216_line_pol` (Stokes analysis widget and animator)
  - Use images in `HL_Tau_pol` (animator)
- **Load a Stokes cube or a polarization angle image to render a polarization vector field**
  - Use images in `HL_Tau_pol` or images in `IRCp10216_line_pol`
- **Load a catalog file, filter the catalog, and rendering it as an catalog image overlay**
  - Use images and the catalog in `cosmos_field` folder
- **Explore the preferences dialog**



# Thank you~

## We hope CARTA can make your life easier 😊



Please contact [support@carta.freshdesk.com](mailto:support@carta.freshdesk.com) for any questions/comments



<https://cartavis.org>

DOI 10.5281/zenodo.3377984

Cite CARTA!  
This project needs your support!

The screenshot shows the CARTA website homepage. The background is a grayscale astronomical image of a spiral galaxy. The word 'CARTA' is written in large blue letters. Below it, a paragraph describes the tool: 'Cube Analysis and Rendering Tool for Astronomy, is a next-generation image visualization and analysis tool designed for ALMA, VLA, and SKA pathfinders.' At the bottom left, there are three buttons: 'Installation', 'User Manual', and 'Helpdesk'. Below these buttons is a blue box with the text 'New release: v4.1 January 2024'. At the top right, there is a navigation menu with links for HOME, FEATURES, GALLERY, ROADMAP, INSTALLATION, TEAM, and ABOUT. To the right of the menu are four small logos: ASIAA, IDIA, NRAO, and the University of Alberta logo.