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

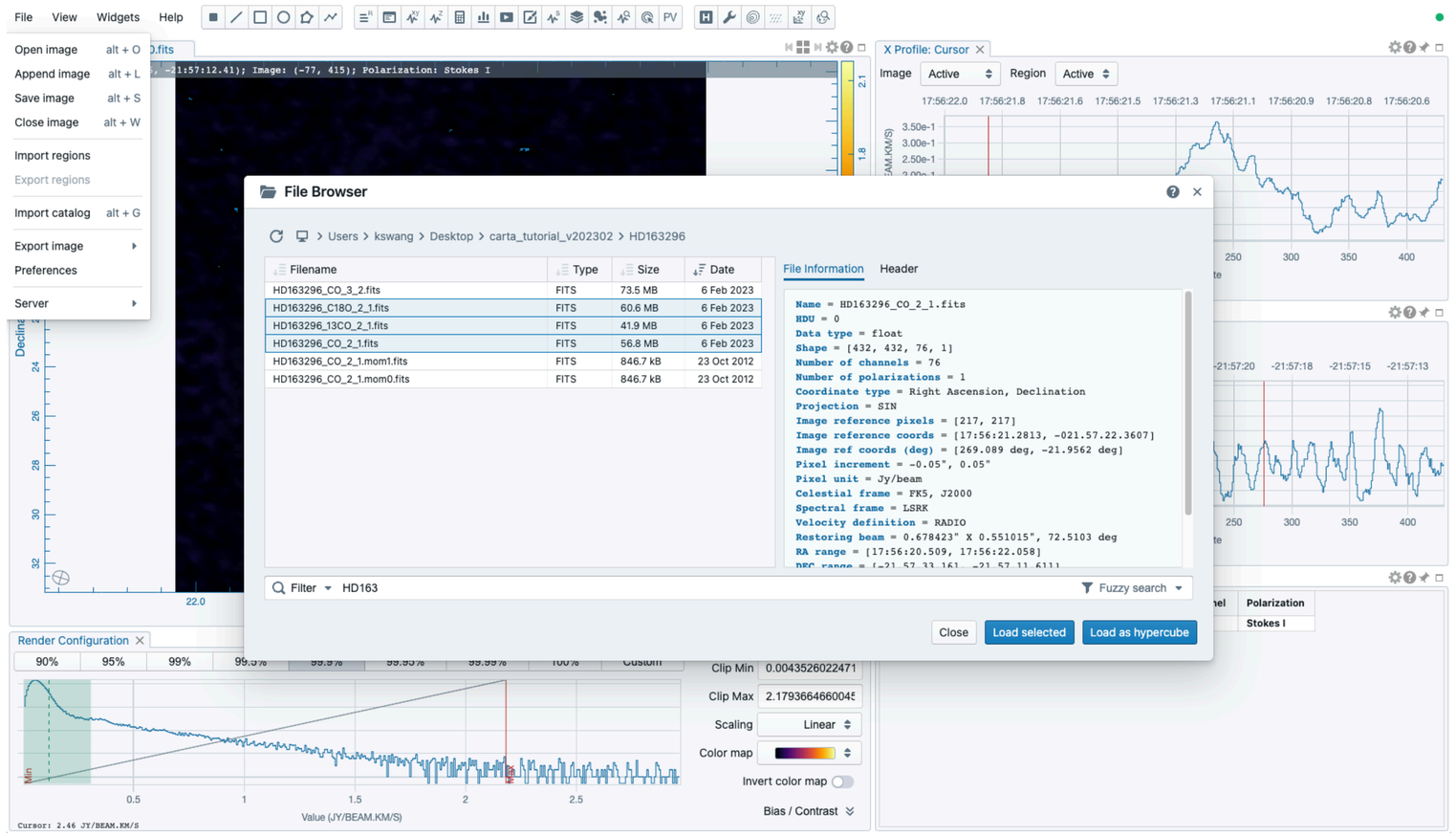
- cosmos_field
  - cosmos_0_simbad.xml
  - cosmos_herschel250micron_subimage.fits
  - cosmos_spitzer3.6micron_subimage.fits
  - vla_20cm_lg_tan_10_subimage.fits
- G31.41p0.31_bandscan
  - G31.41p0.31_spw25.fits
  - G31.41p0.31_spw27.fits
- Gaussian_array
  - Gaussian_SE.fits
  - Gaussian.fits
- HD163296
  - 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-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)



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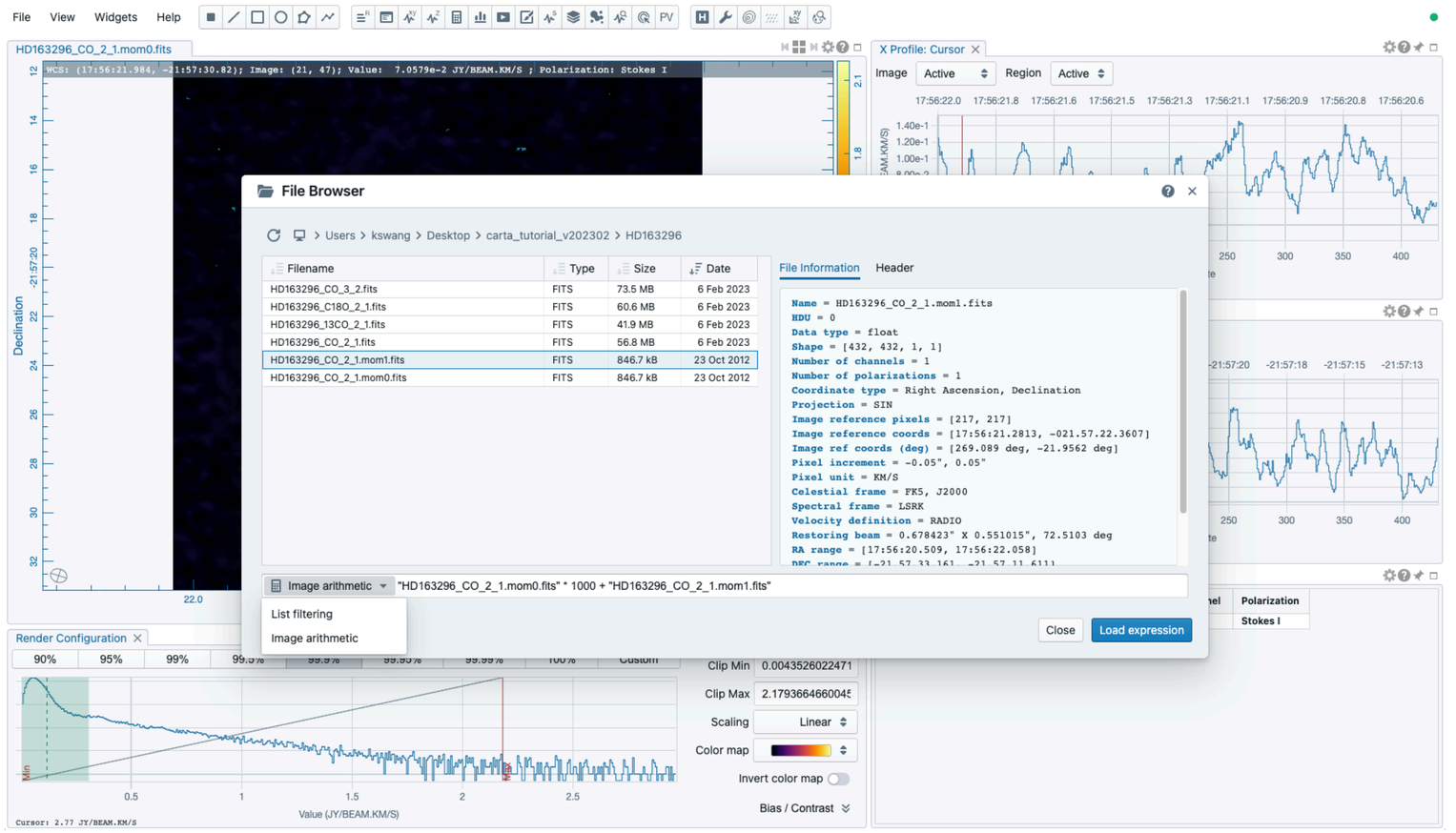


How to load images

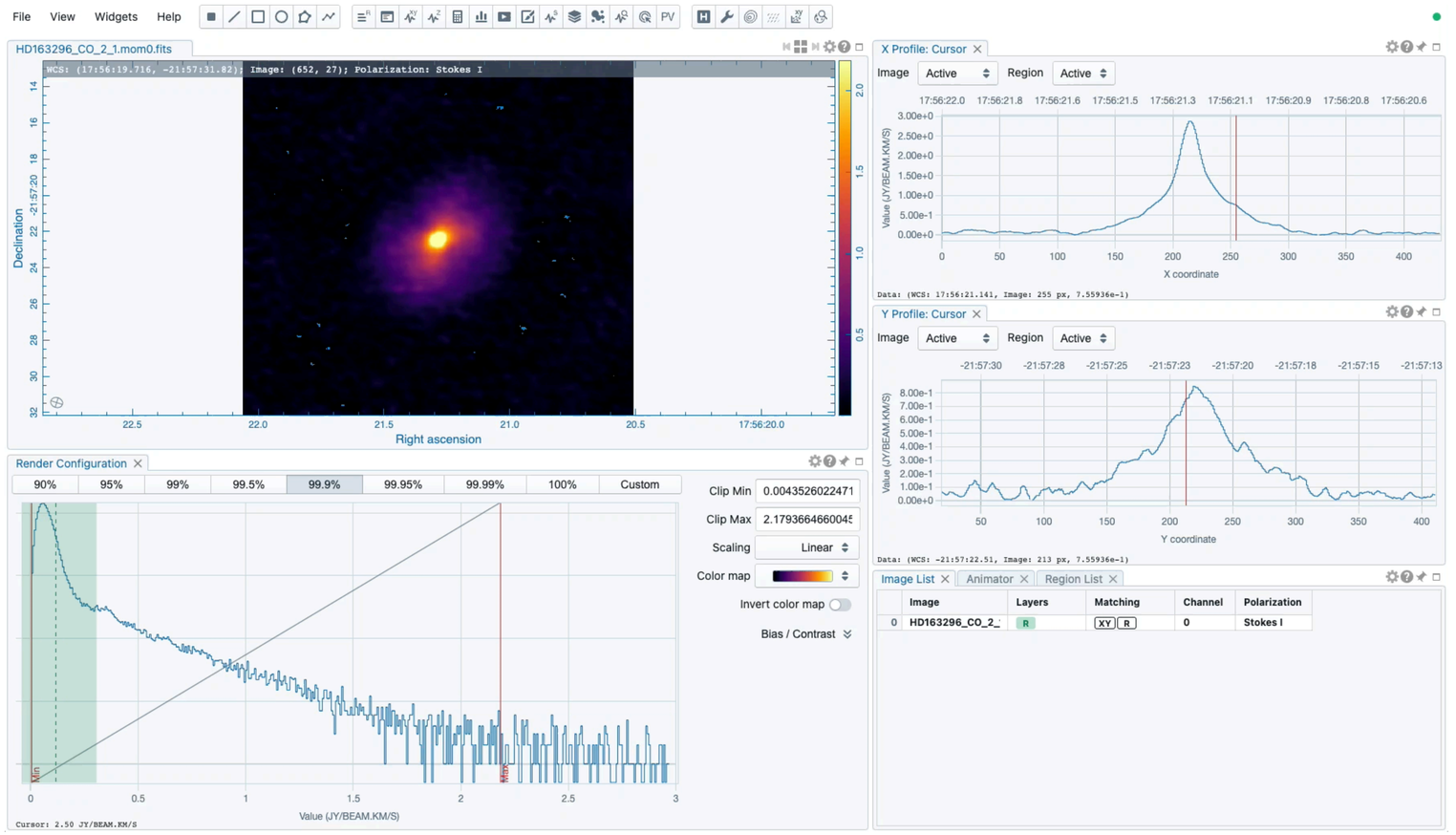
Graphical user interface (GUI) v.s. commendline user interface (CLI)

- 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]`

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



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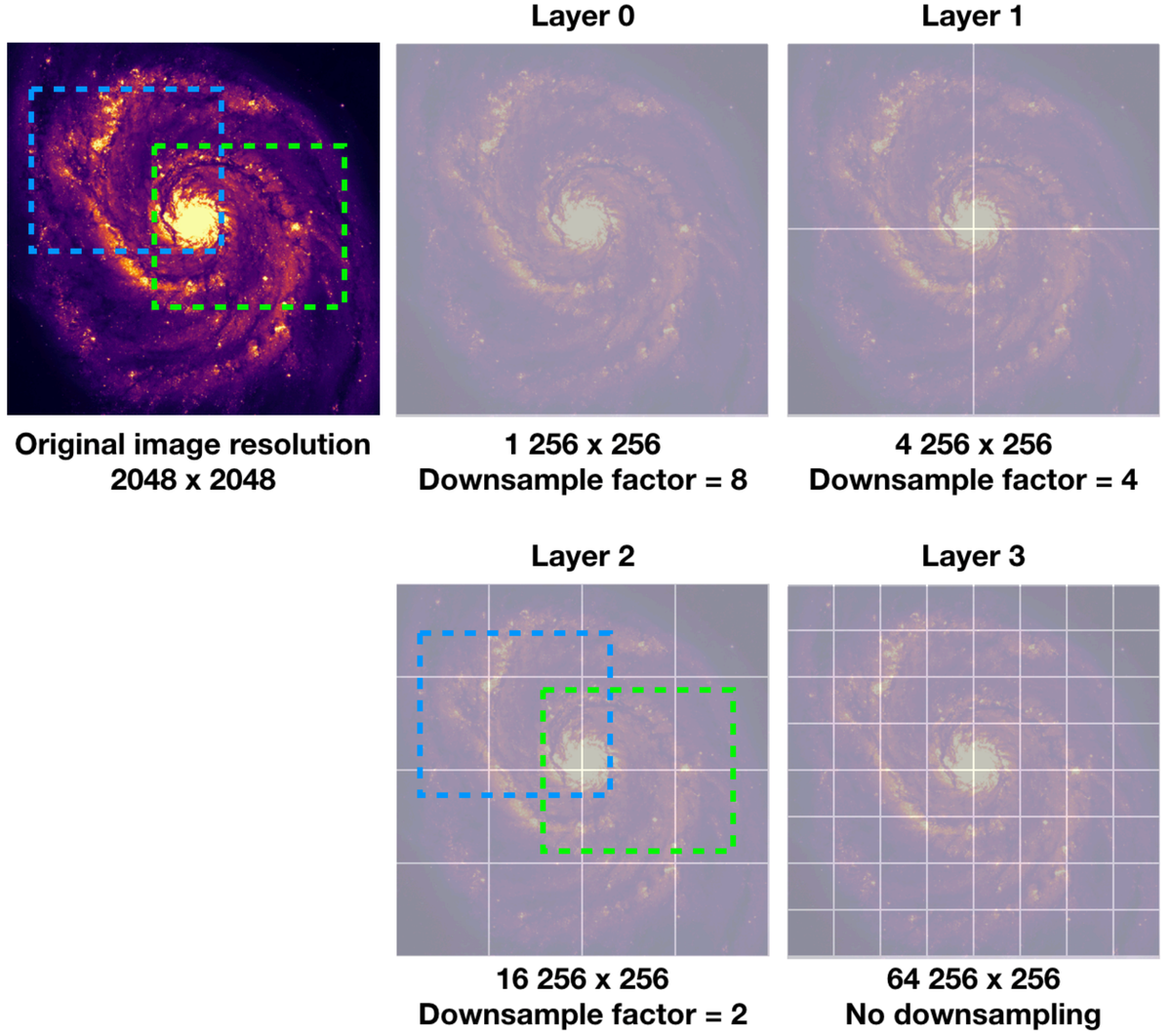
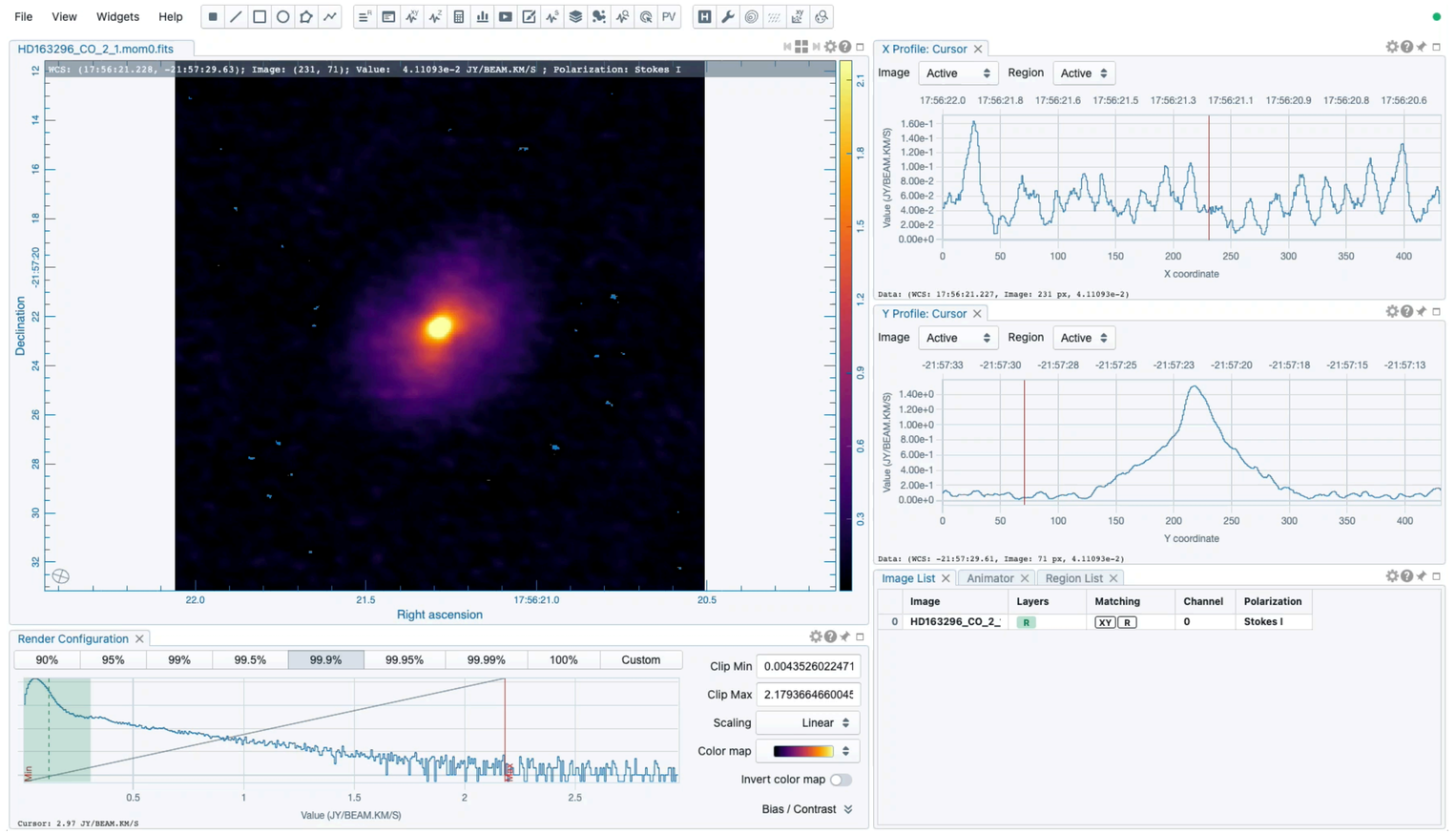


How to render images

Contour image rendering

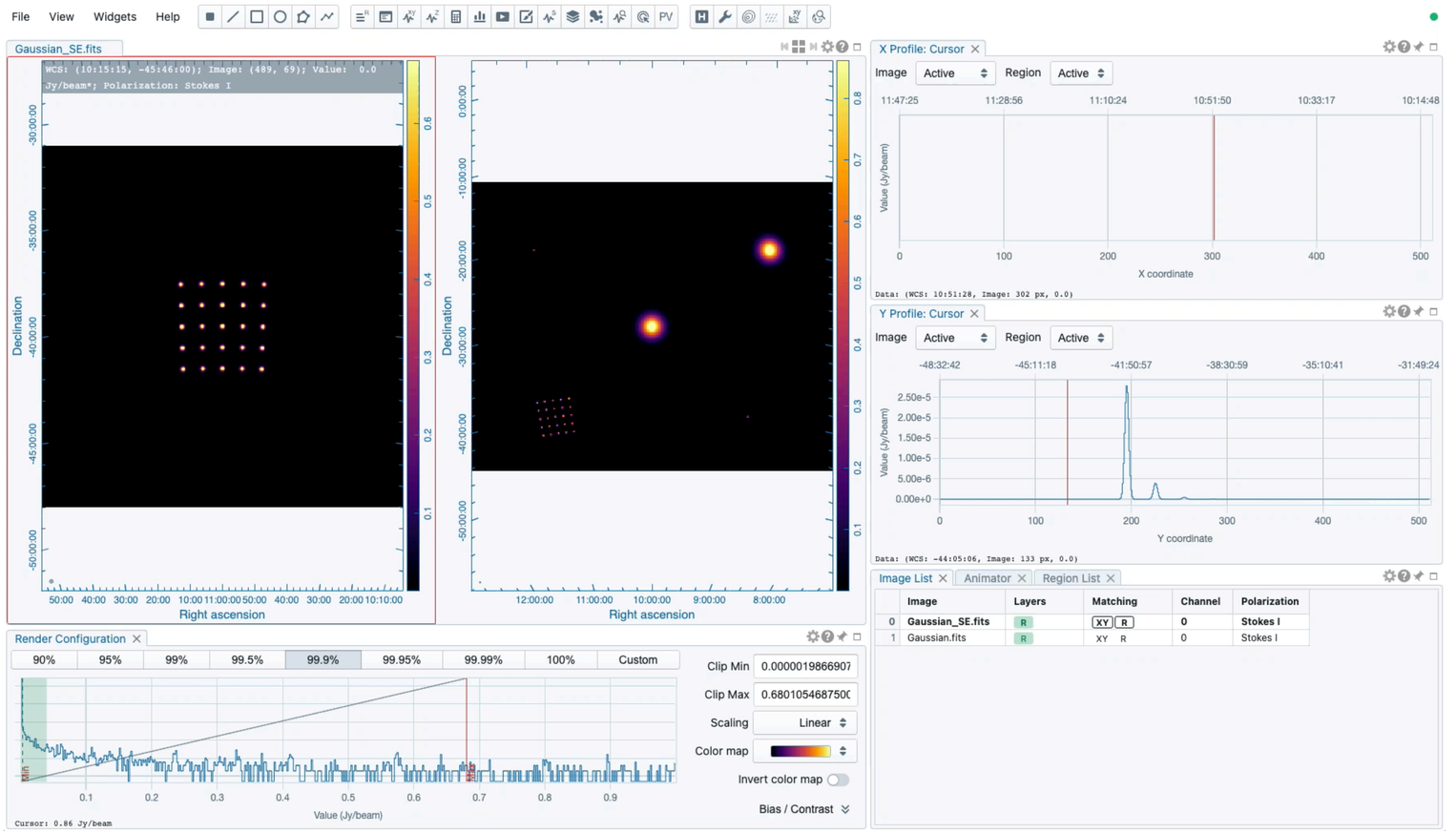
- Use contour configuration dialog for contour rendering
- Flexible
  - Level definition
  - Smoothing scheme
  - Styling
- Contour rendering:
  - GPU-accelerated (WebGL2)
  - Contour vertices are computed in parallel



How to match images

Spatial matching

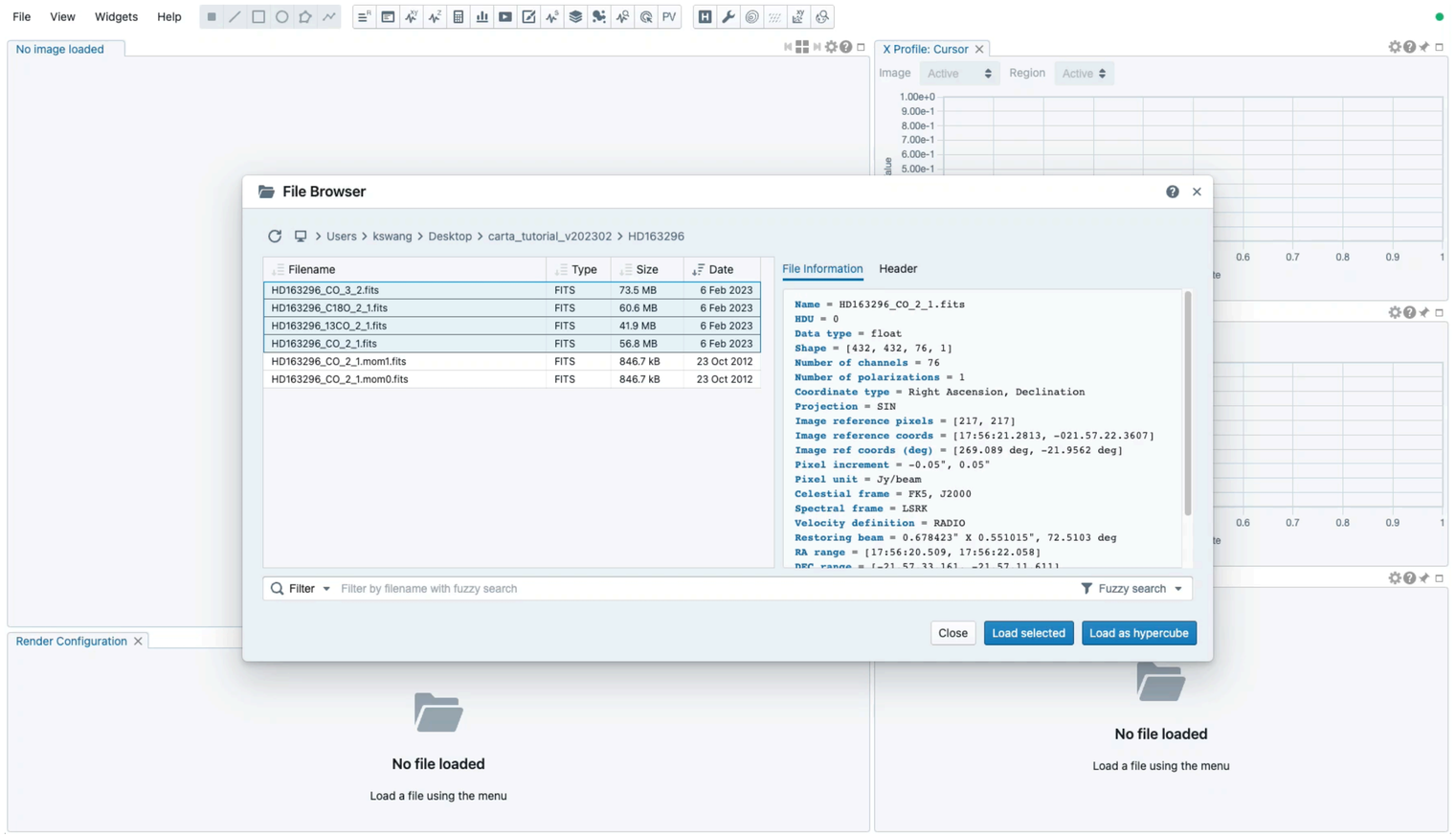
- Multiple images can be matched spatially so image panning and zooming are synchronized.
- Use the image list widget to perform image matching
- Matched images share their
  - contour / vector field / catalog rendering
  - region set
- Reference image v.s. secondary images



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



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

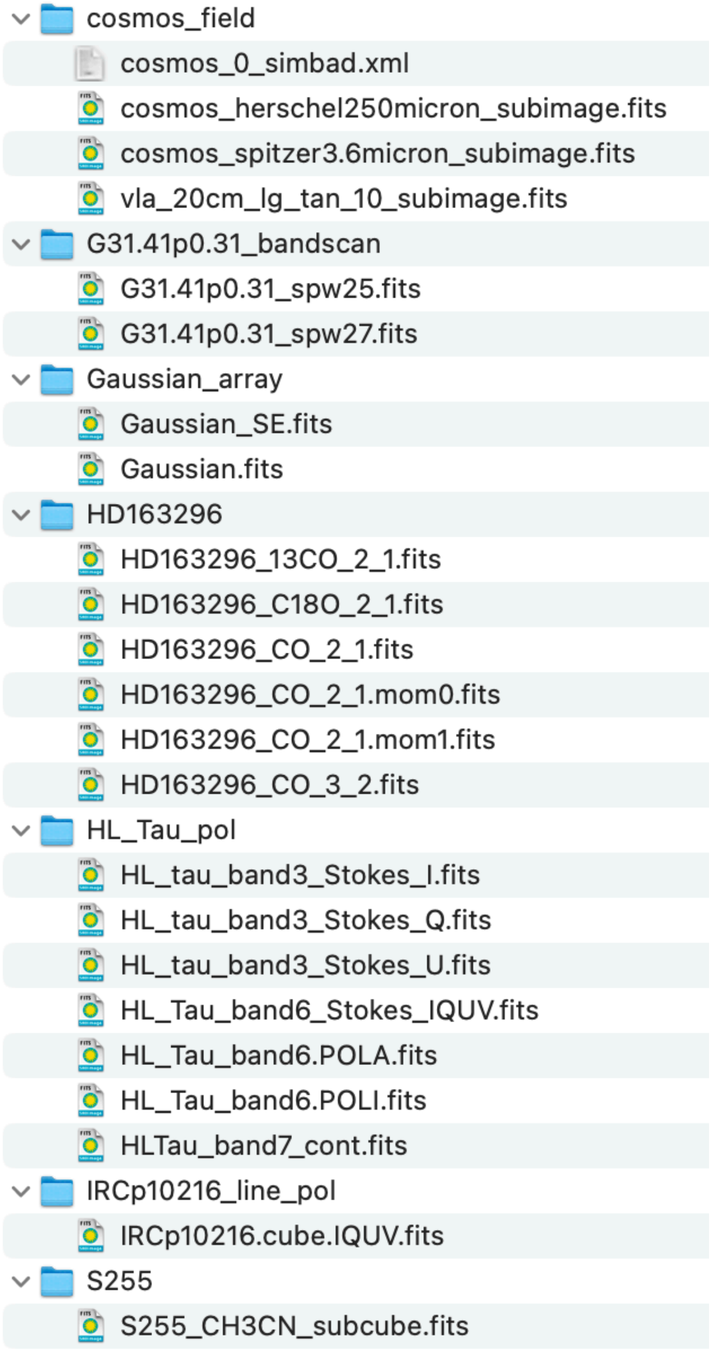


Image analytics

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

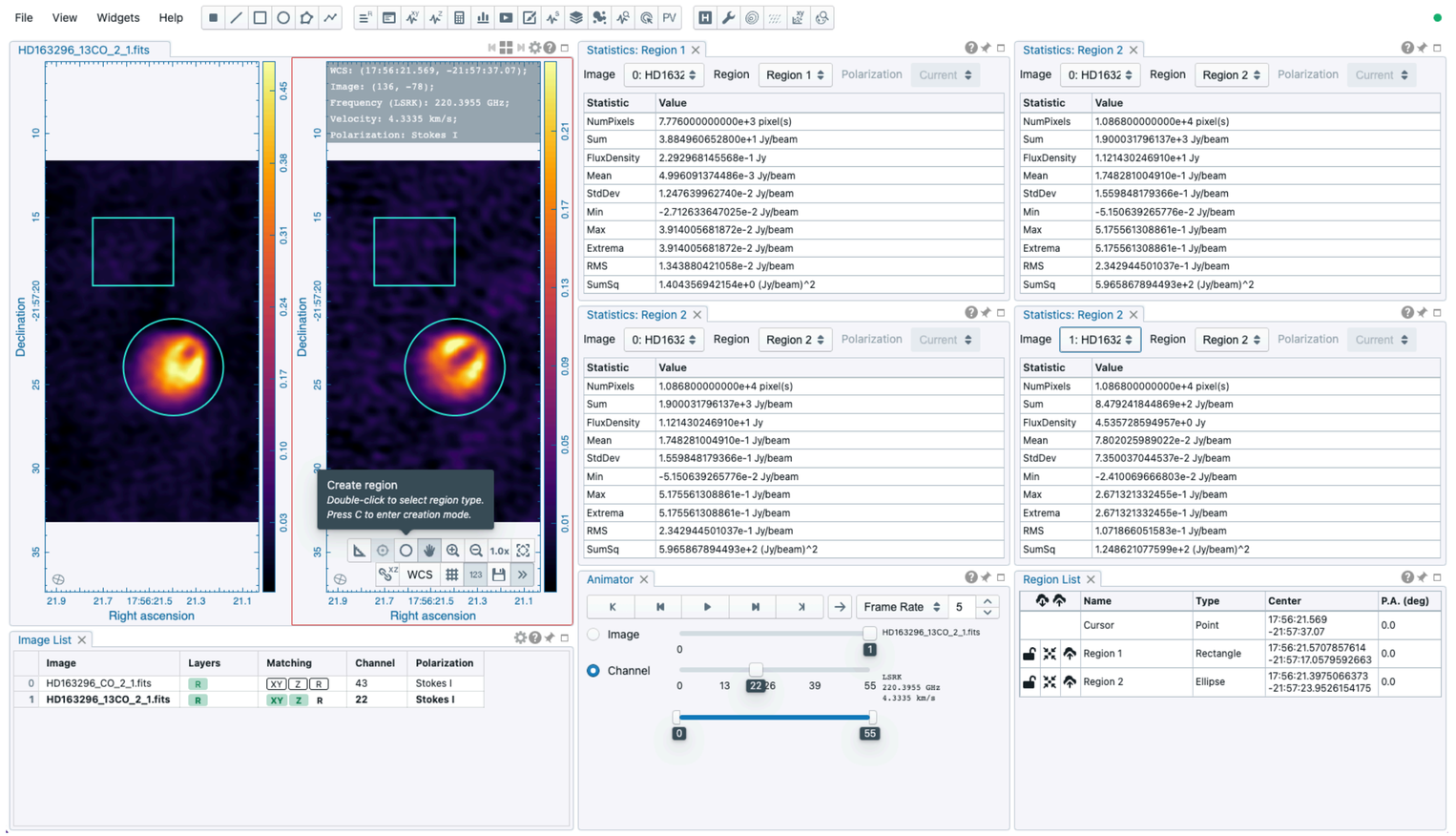


Image analytics

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

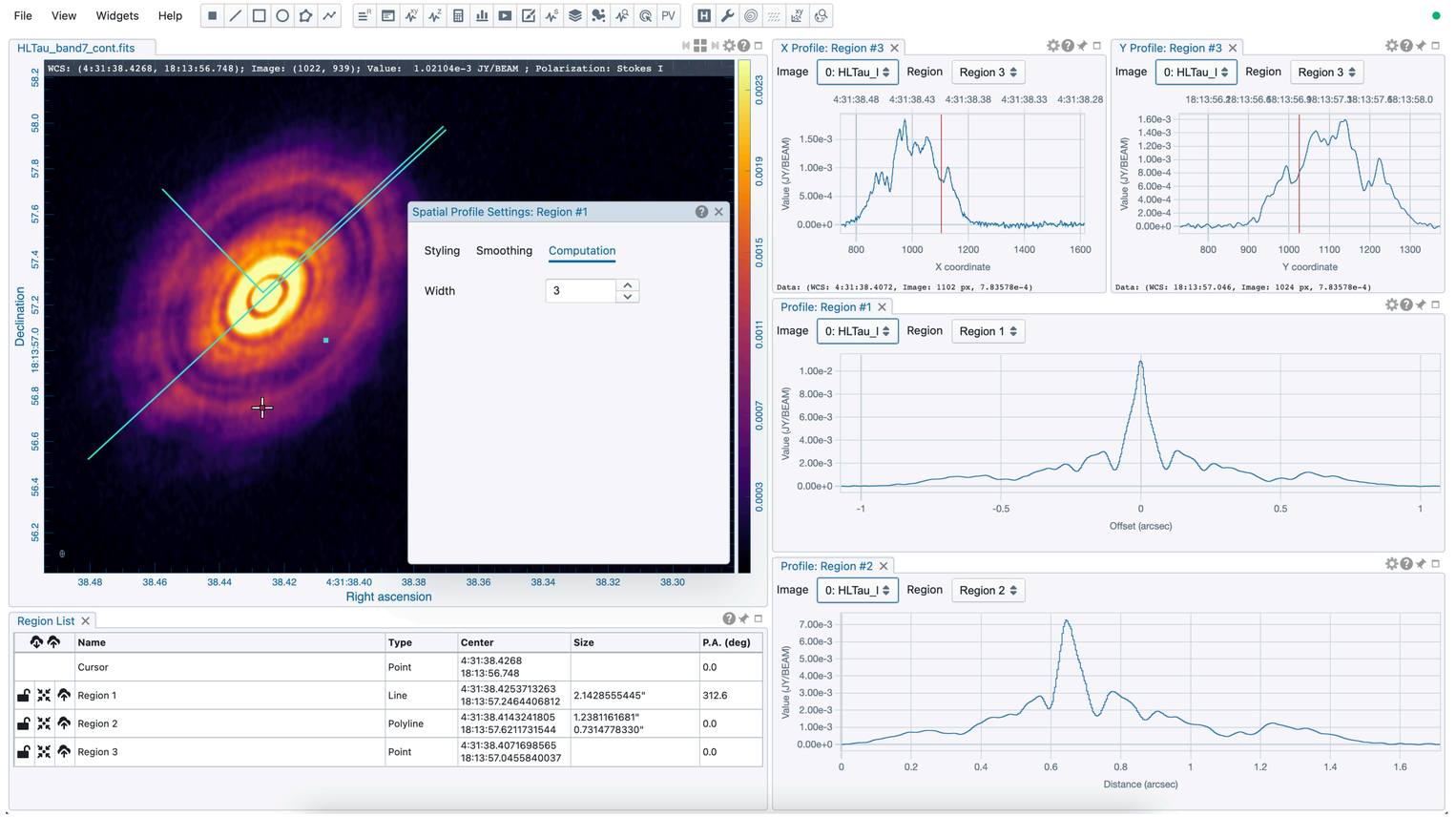


Image analytics

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

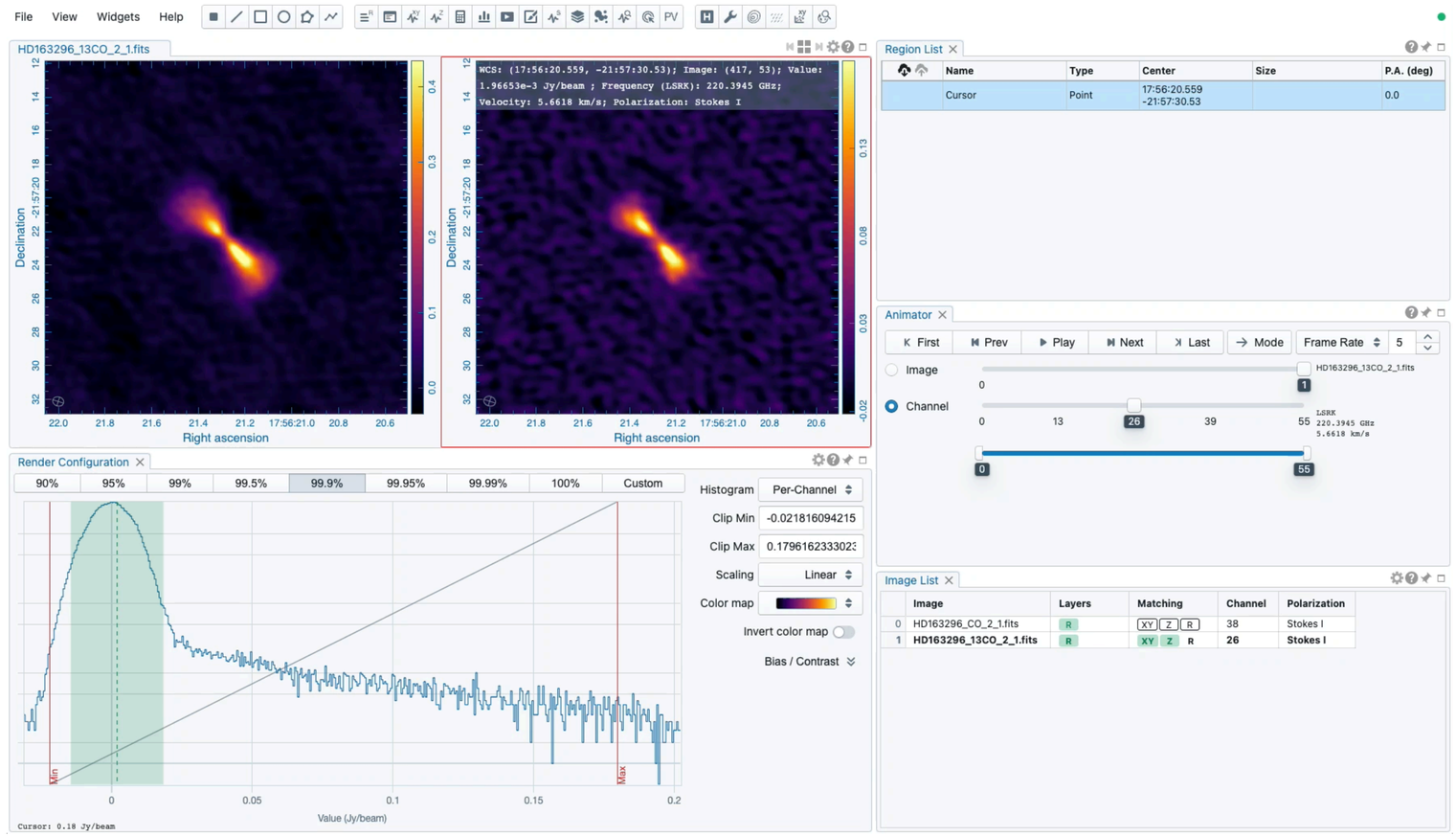


Image analytics

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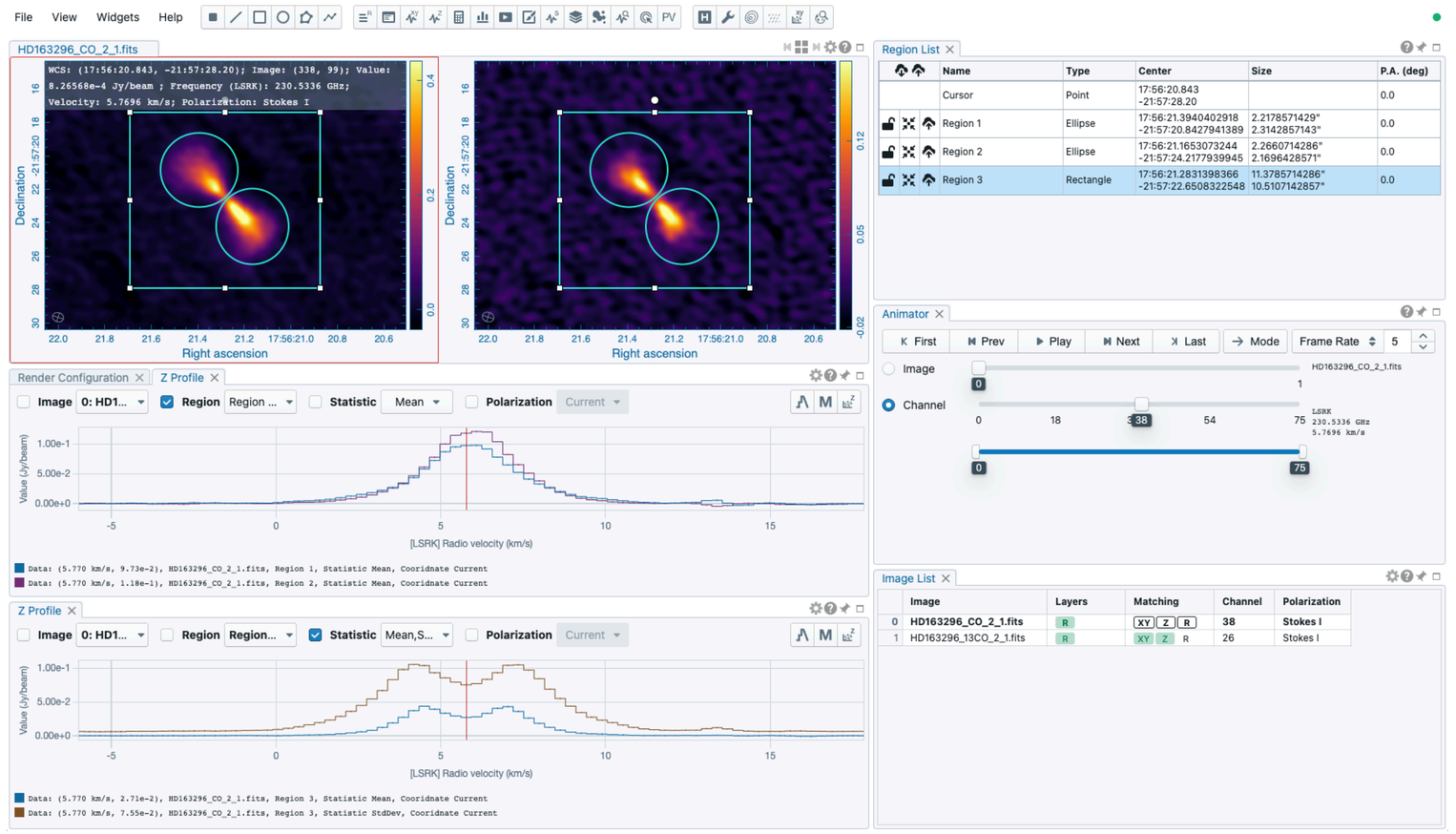


Image analytics

Profile smoothing

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

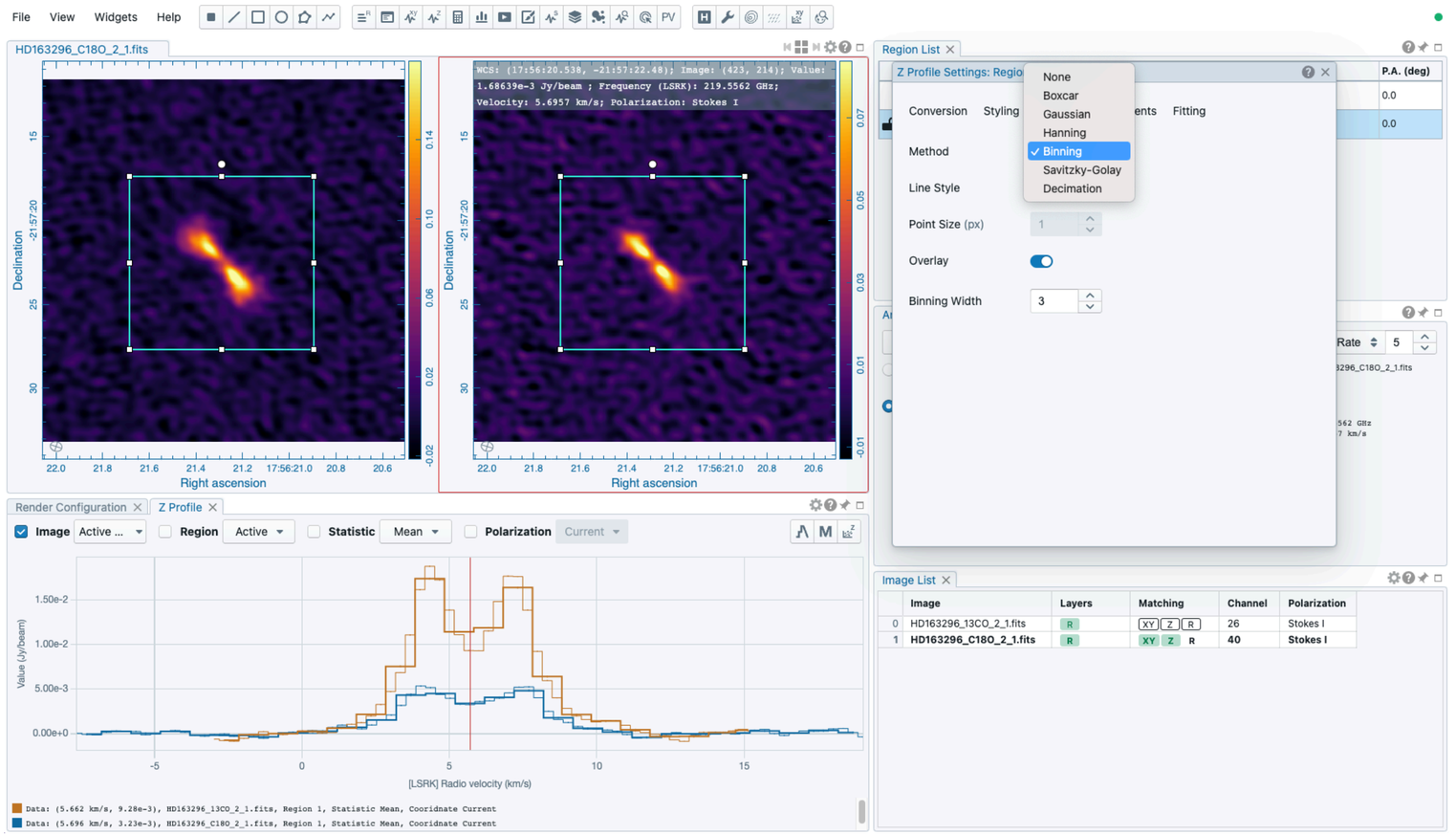


Image analytics

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

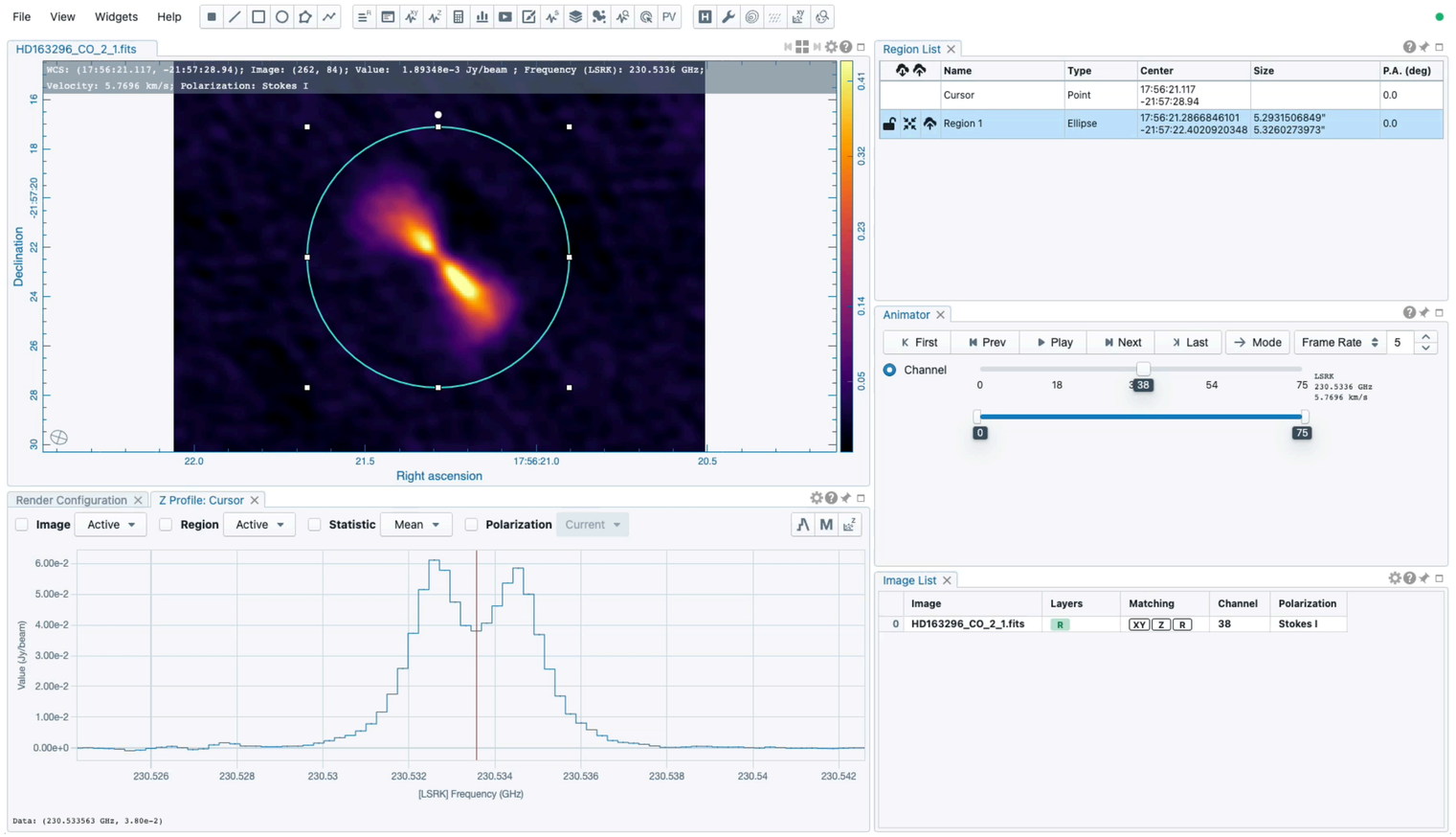
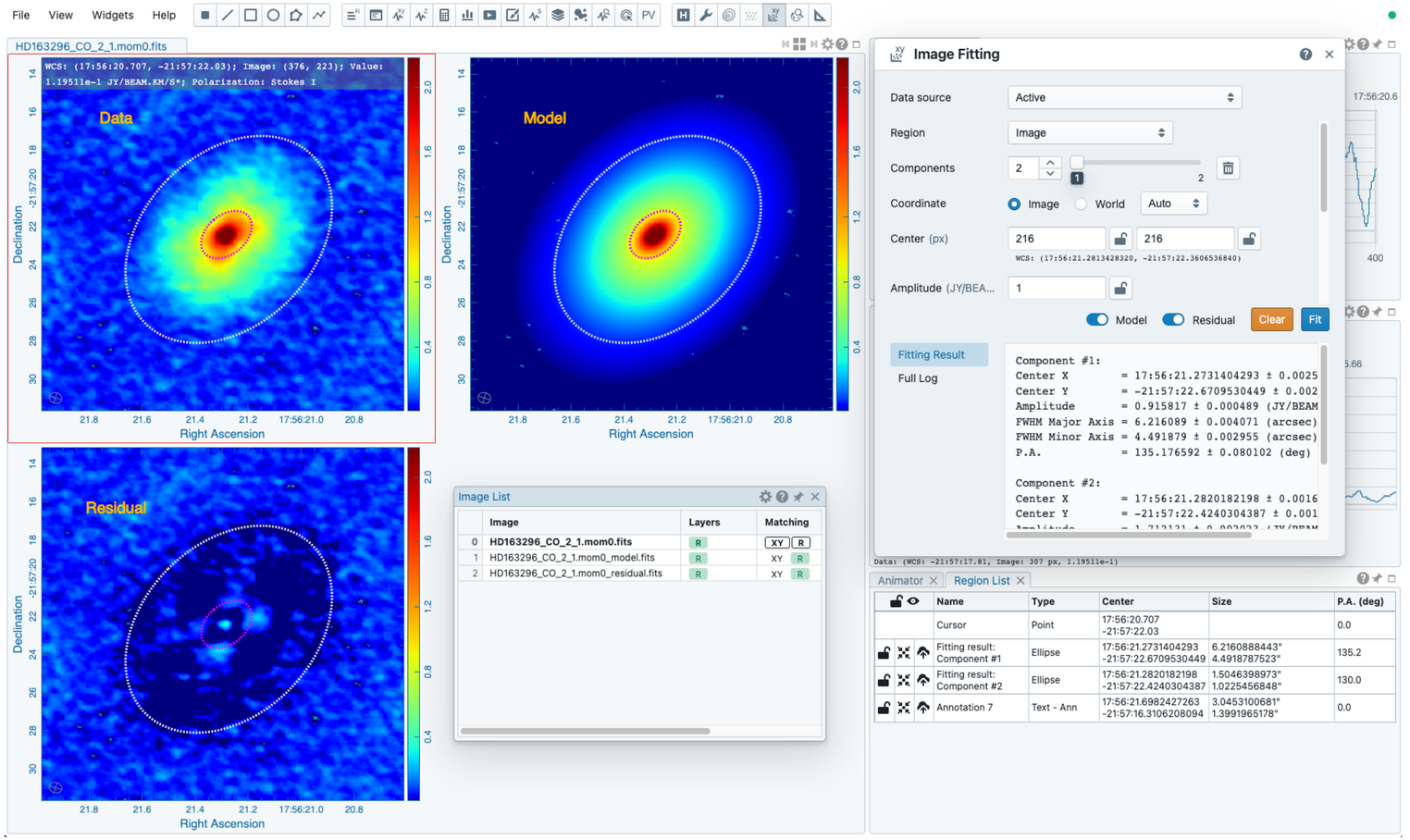


Image analytics

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

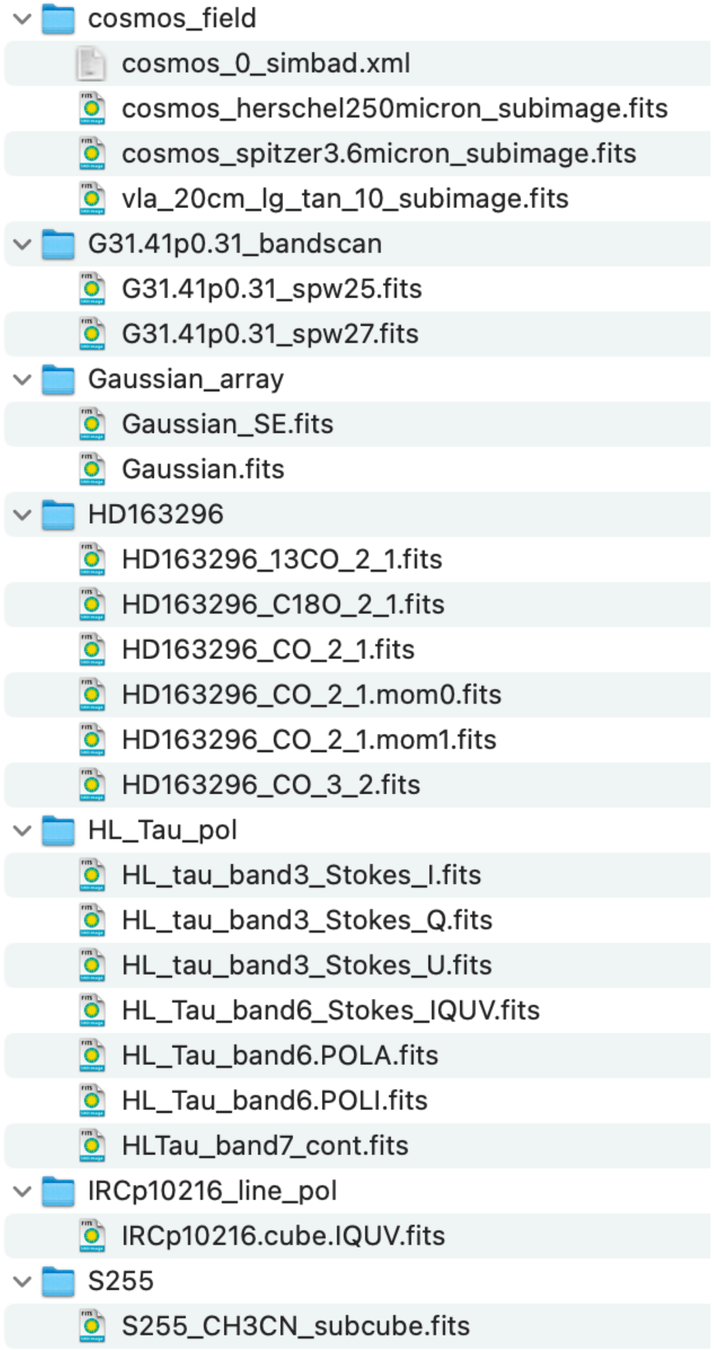


Image analytics

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”

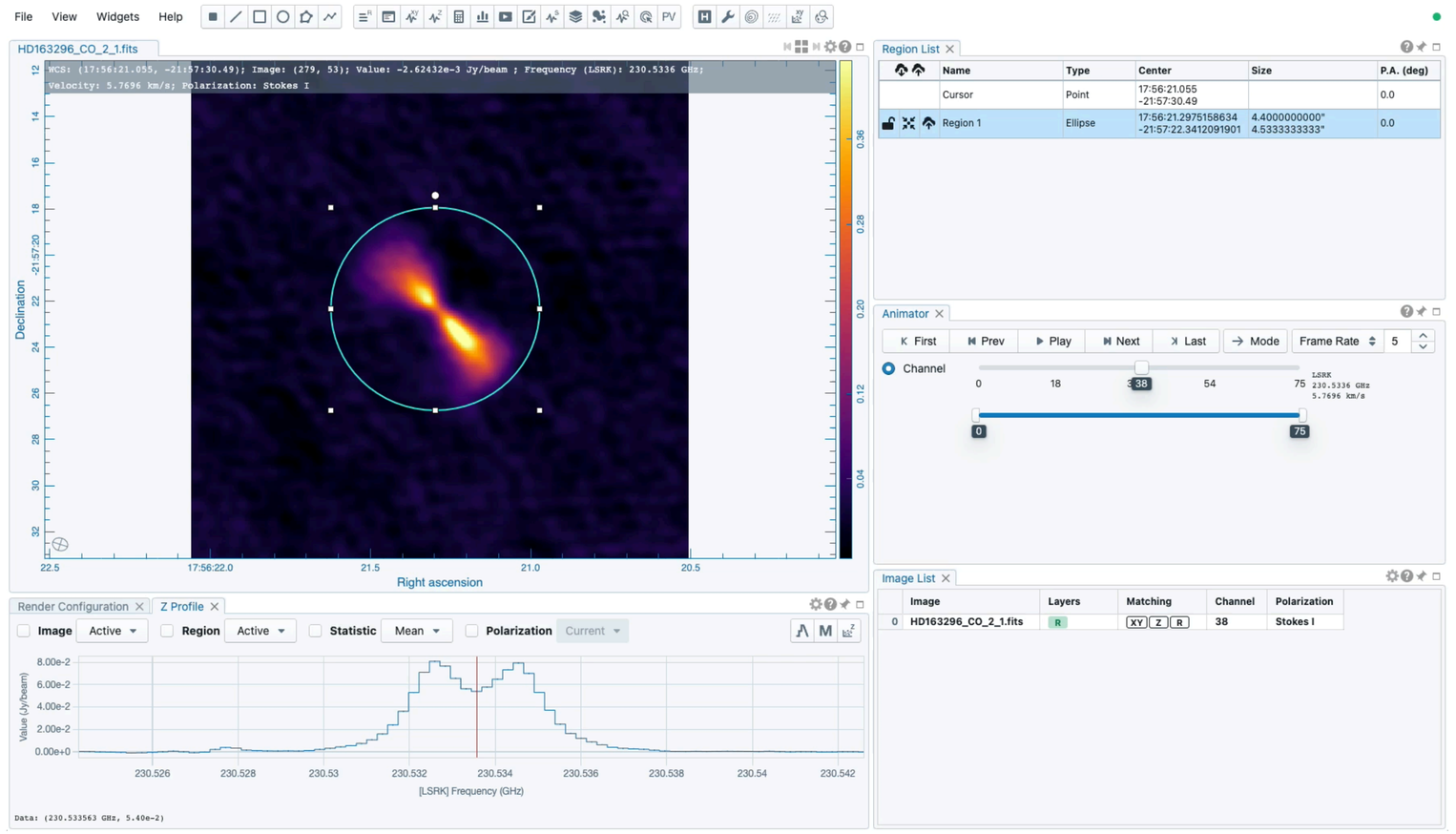


Image analytics

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

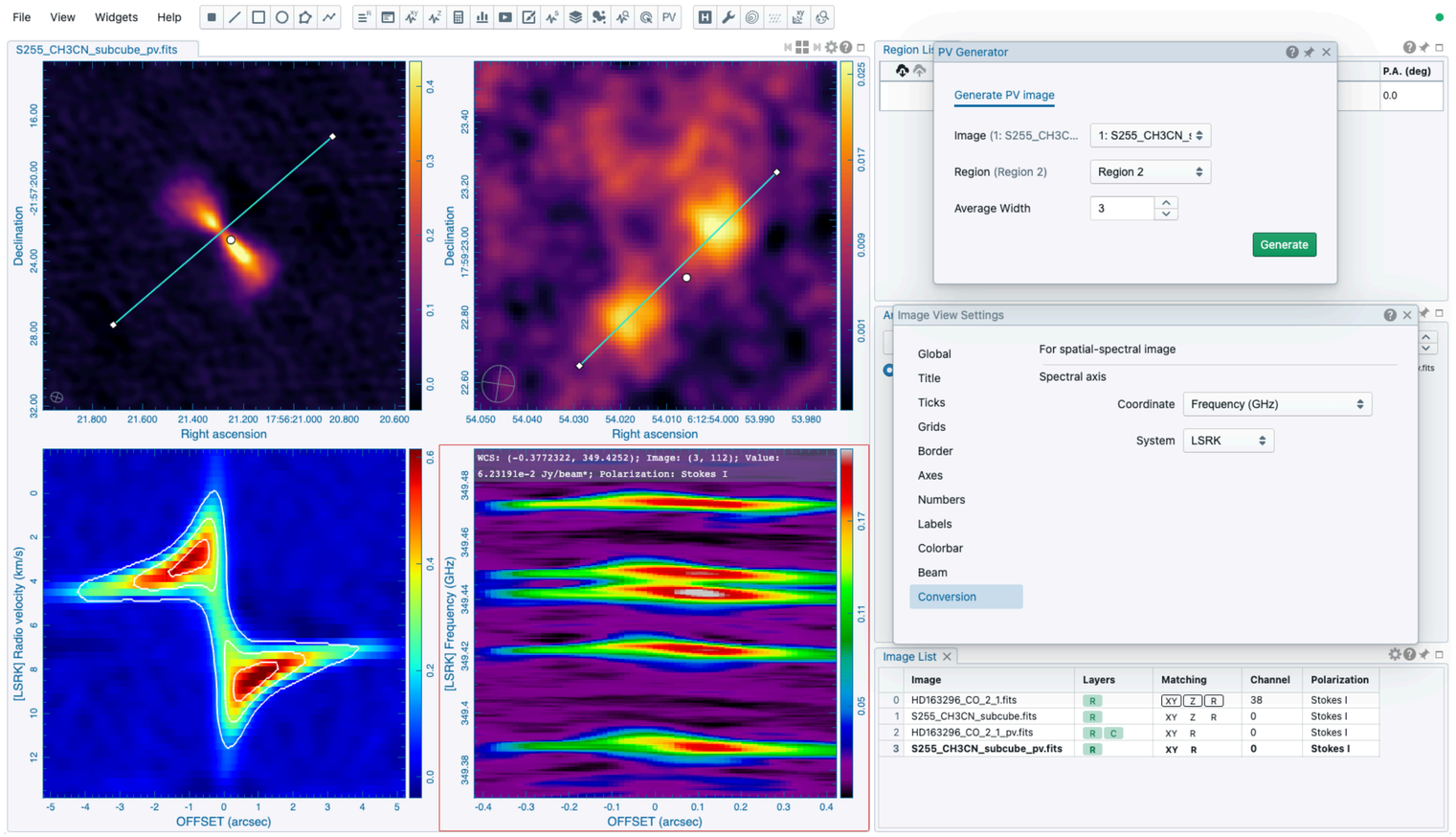


Image analytics

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

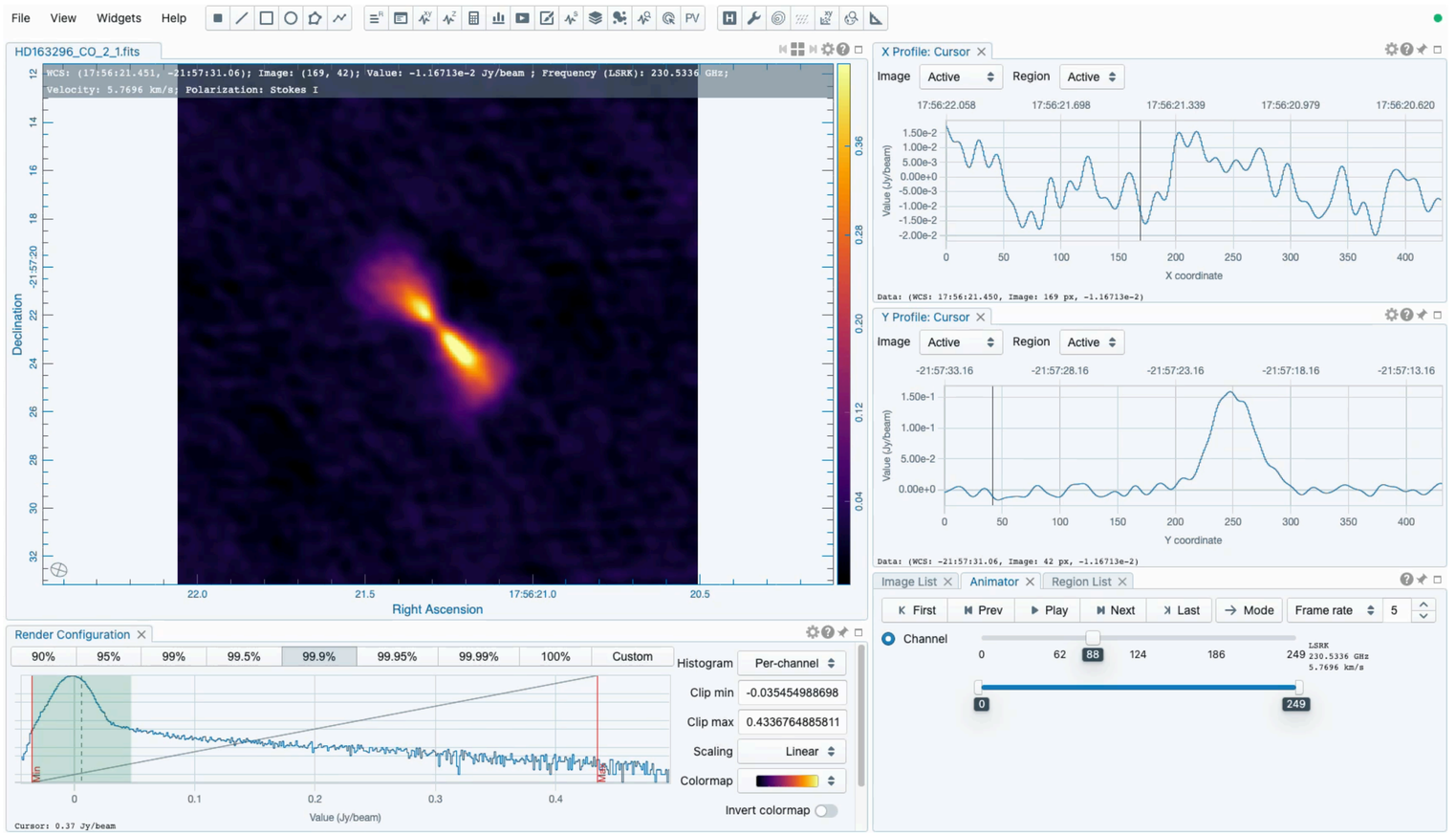


Image analytics

Spectral line ID

- Spectral line IDs from the Splatalogue (https://splatalogue.online/) can be over plotted 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

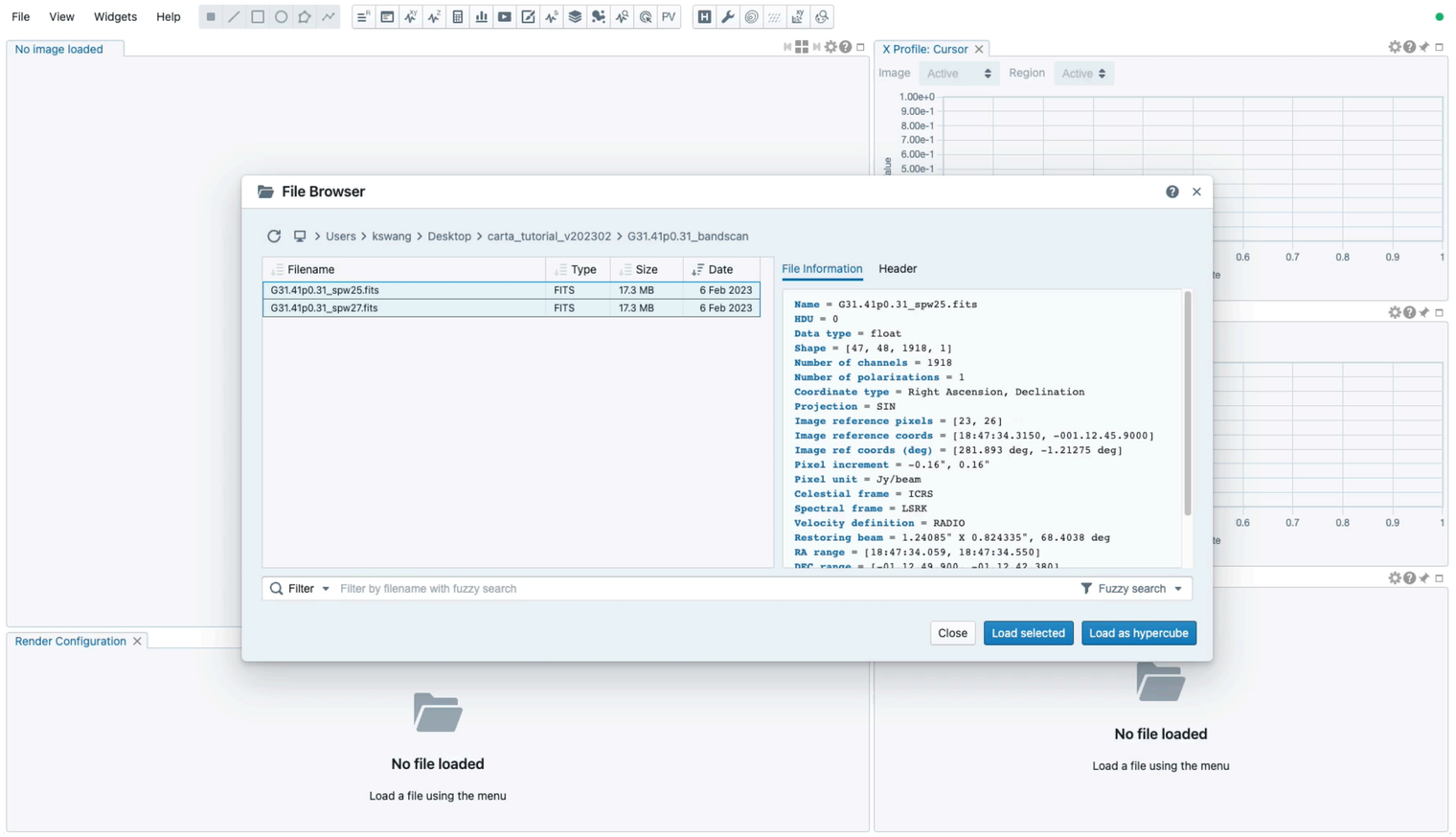
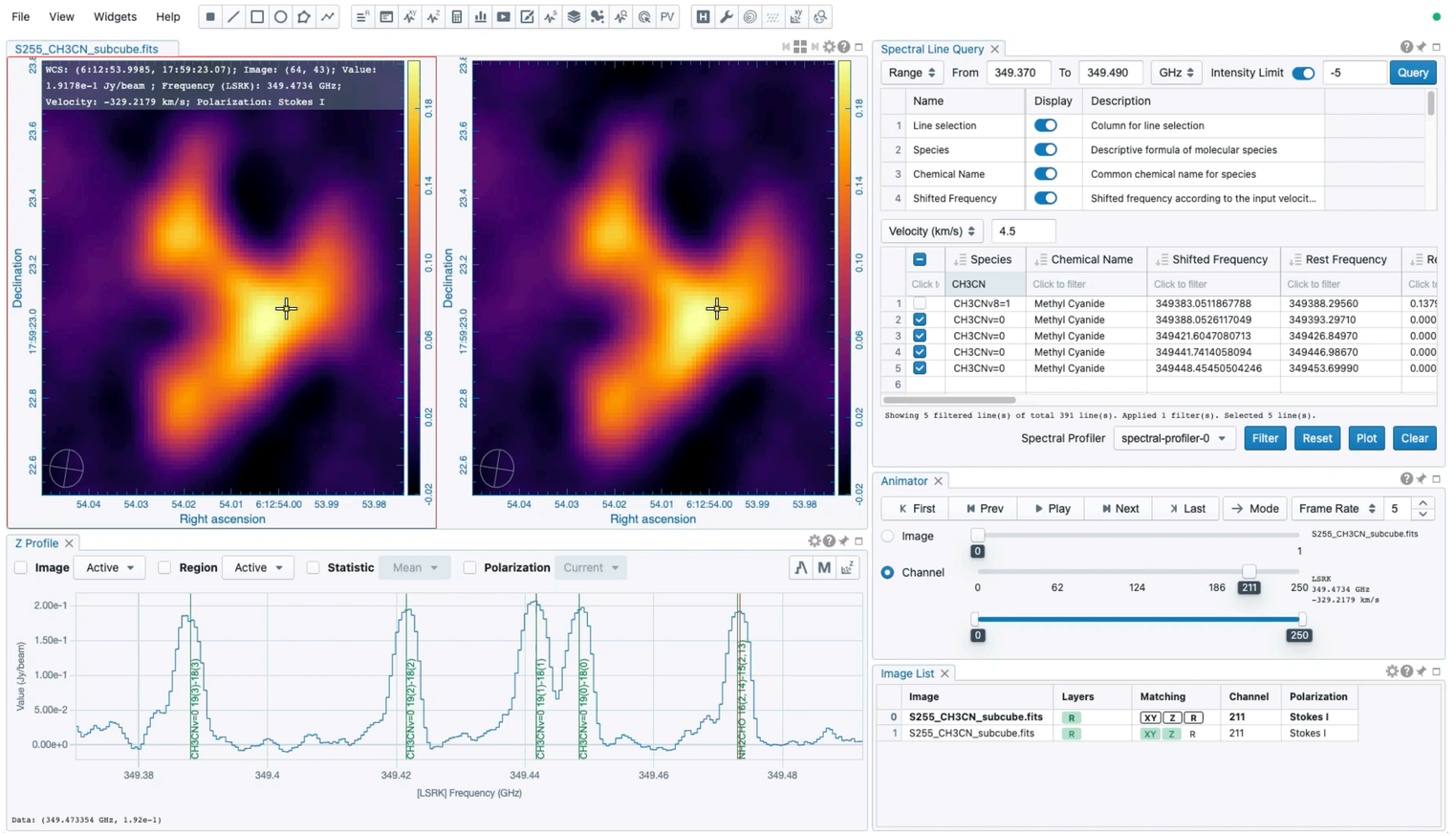


Image analytics

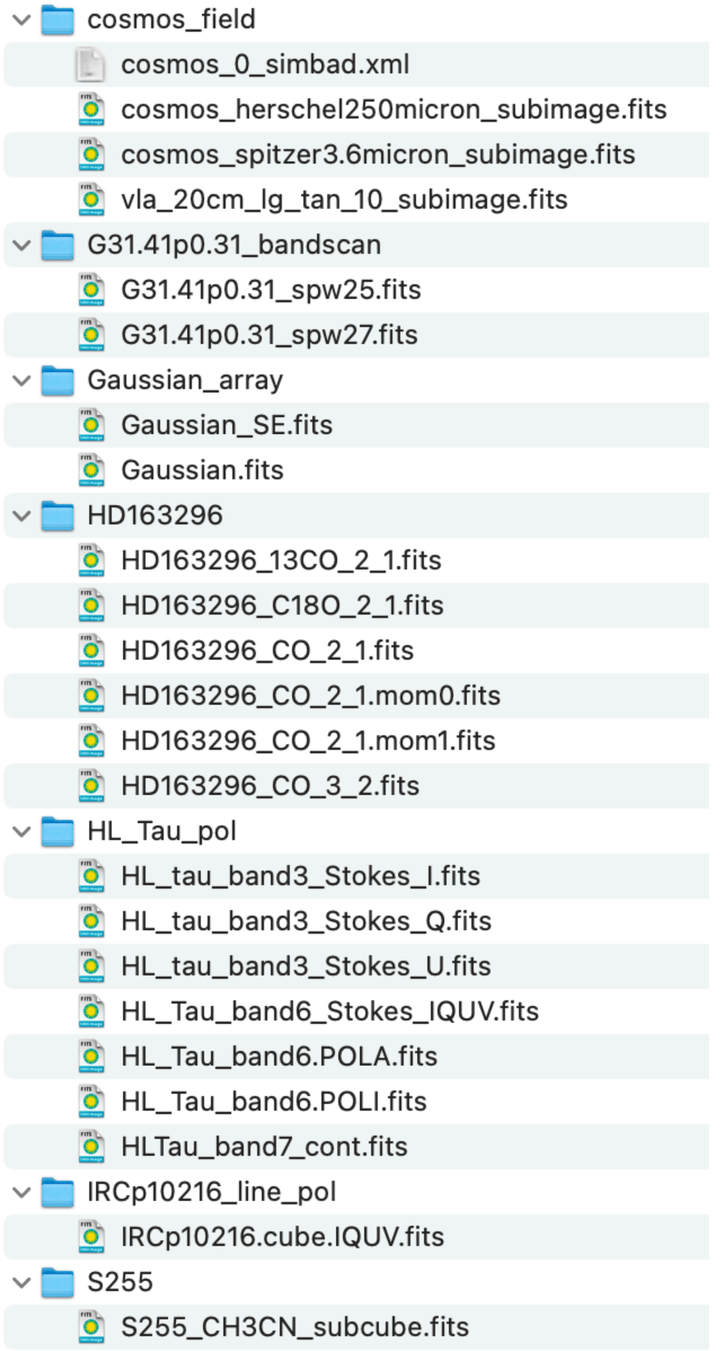
Rest frequency shifting

- 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

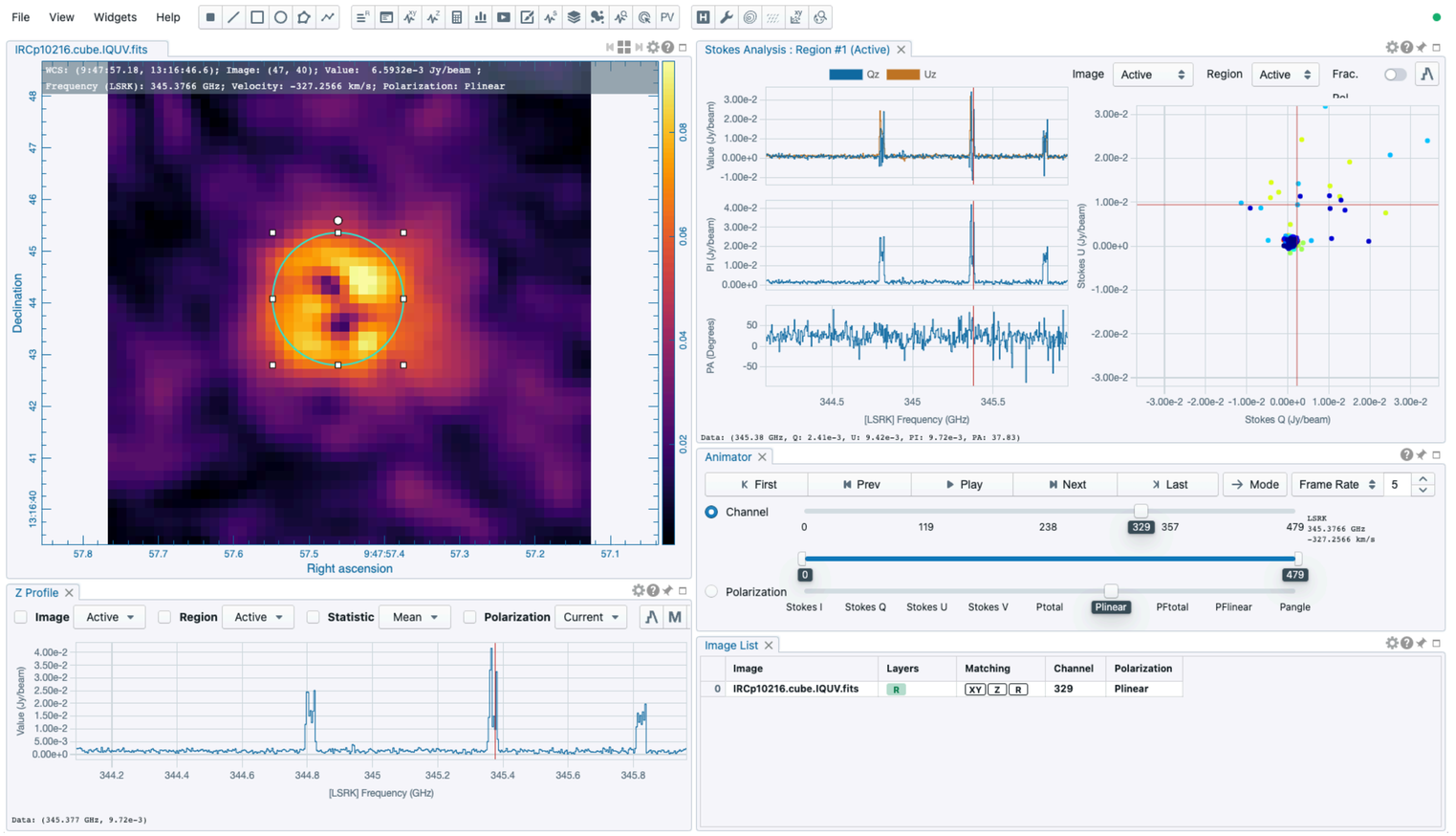
- **Try to generate some moment images**
  - Use images in `HD163296` folder or `S255` folder
- **Try to generate a PV image**
  - Use images in `HD163296` folder or `S255` folder
- **Try to label spectral line IDs**
  - Use images in `S255` folder (try CH3CN at ~4 km/s)
  - Use images in `G31.41p0.31_bandscan` folder (try C2H5OH “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
    CH3CN J19-18 K=3 at 349393.2971 GHz
    NH2CHO 16(2,14)-15(2,13) at 349479.5473 MHz



Polarization cube visualization and analysis

Stokes analysis widget and computed polarization components

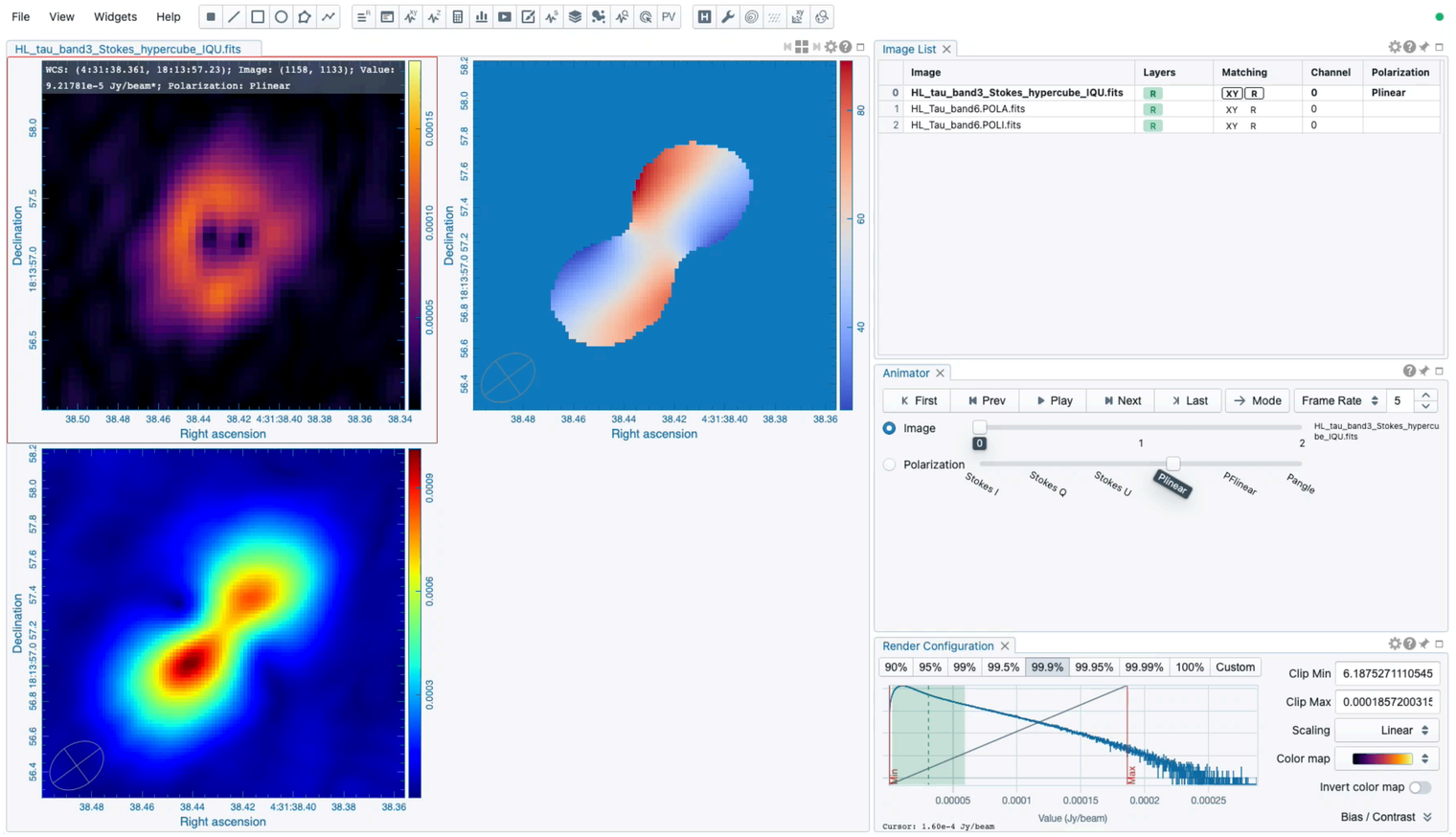
- When a Stokes cube is loaded, a set of plots is generated in the Stokes analysis widget
  - Q v.s. U profile and scatter plot (Faraday rotation)
  - Pol. I and Pol. A profiles
- Use the animator to switch to different Stokes (native) and other (on-the-fly) computed components



Polarization cube visualization and analysis

Vector field rendering

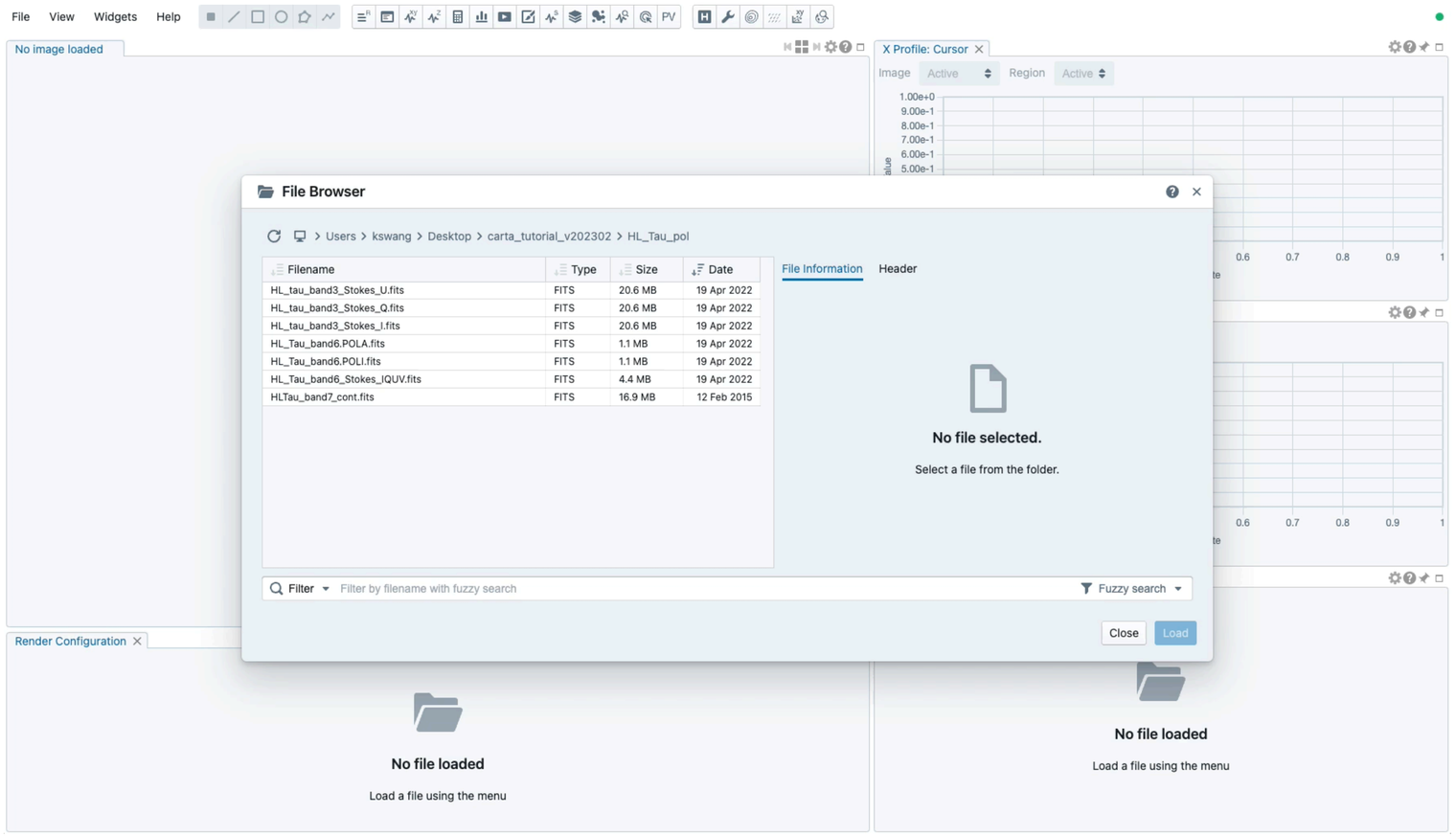
- A linear polarization field can be computed and rendered from a Stokes cube
- A linear polarization angle field can be rendered from a pre-calculated image
- An optional angle offset can be applied (e.g., +90 deg to infer B-field)
- A scalar field can also be rendered
- Matched images share their vector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



Polarization cube visualization and analysis

Forming a Stokes hypercube

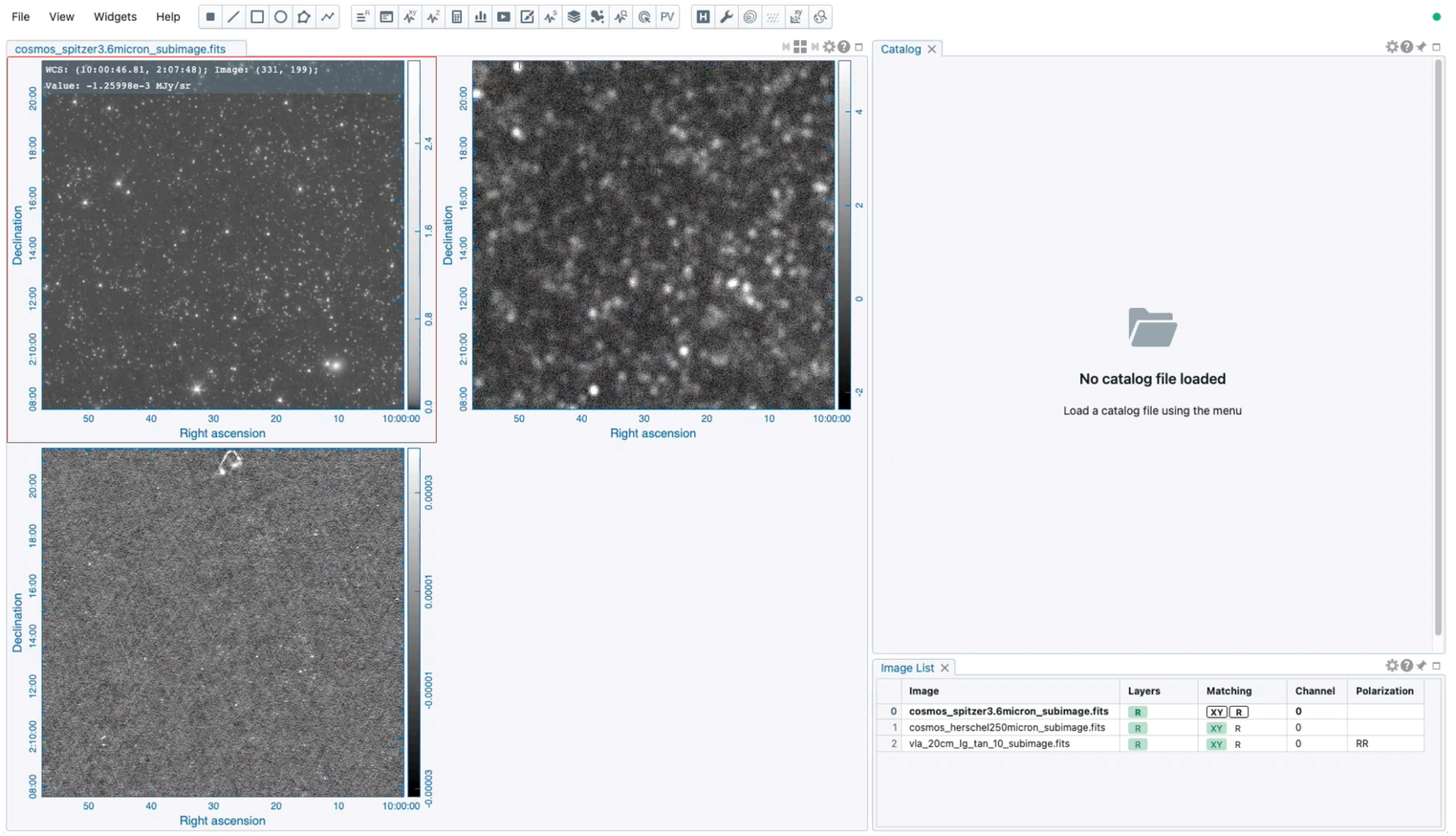
- If Stokes I, Q, U, and V are as individual files, you can use the file browser to form a Stokes hypercube and treat the result as a single (virtual) file
- Perform analysis with
  - animator
  - Stokes analysis widget
  - Spectral profiler widget
  - Vector field rendering dialog
  - …



Catalog visualization

Linked rendering

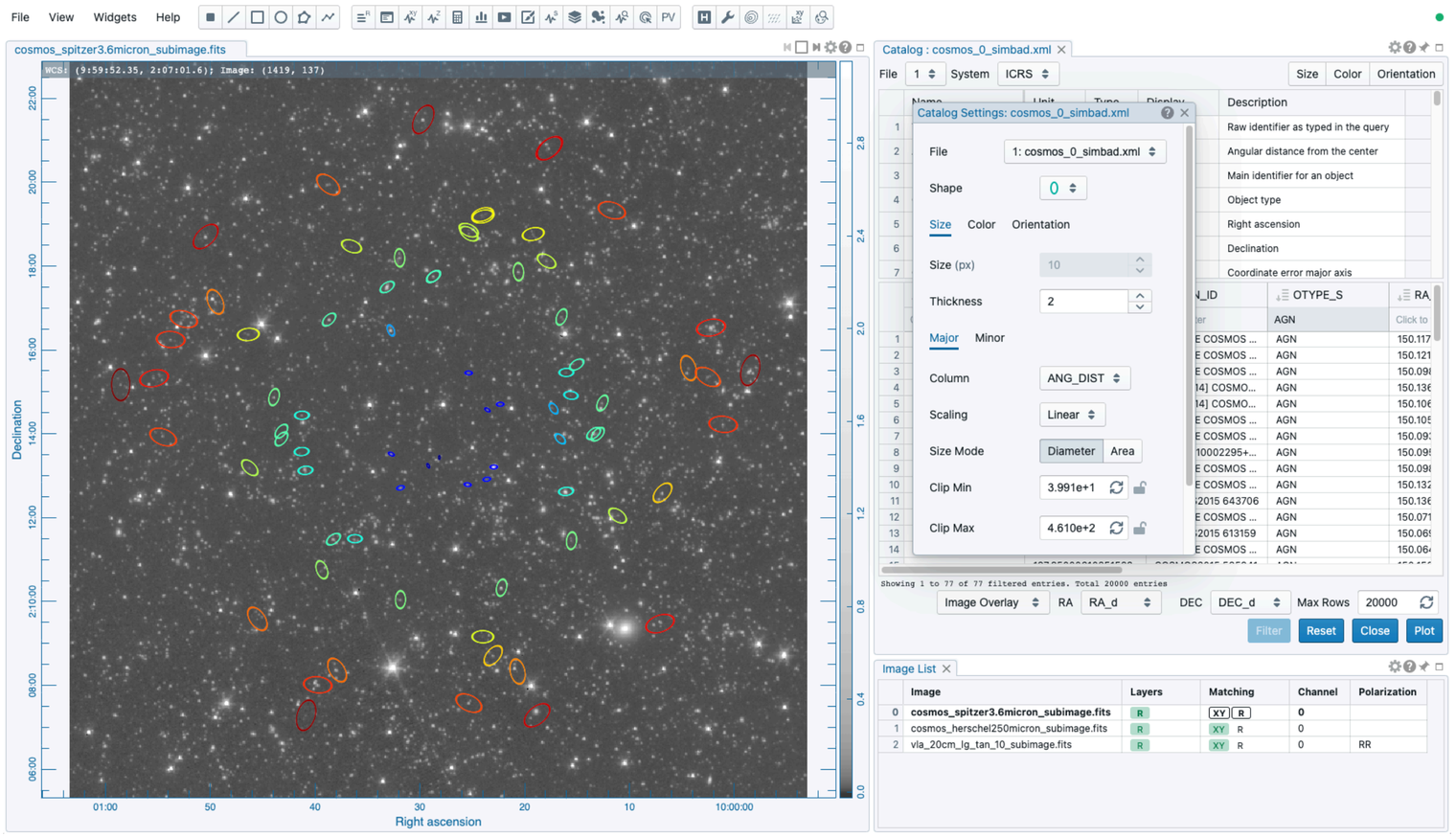
- Offline catalog (“File -> Import catalog”): `FITS` and `VOTable` format
- Online catalog query
- The catalog widget supports filtering
- Catalog can be rendered and inter-linked as
  - Image overlay (GPU-accelerated, WebGL2)
  - 2D scatter plot
  - histogram
- Matched images share their catalog image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



Catalog visualization

Marker-based catalog rendering

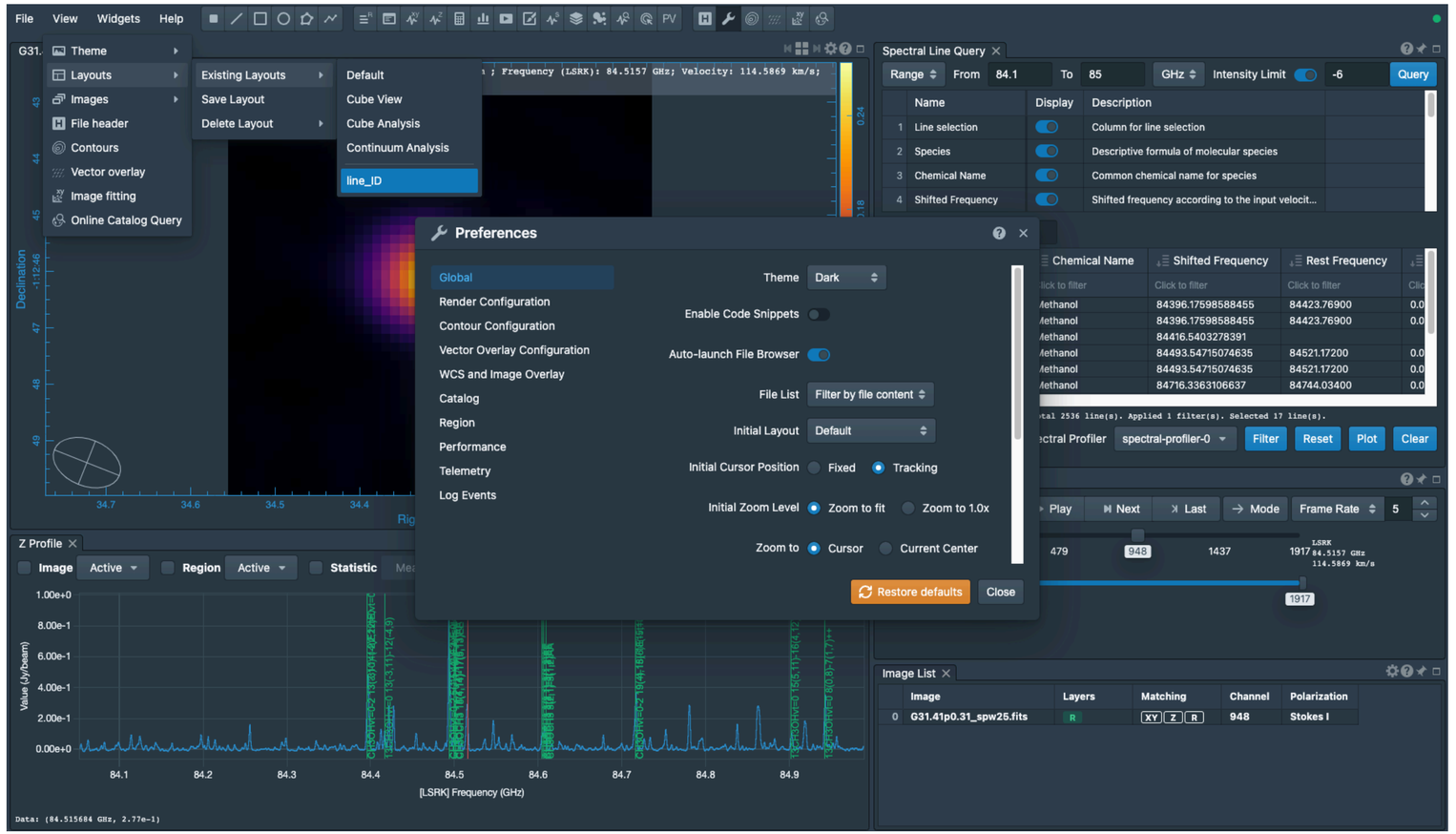
- Image overlay as column-mapped markers
  - Size mapping
  - Color mapping
  - Orientation mapping



GUI customization

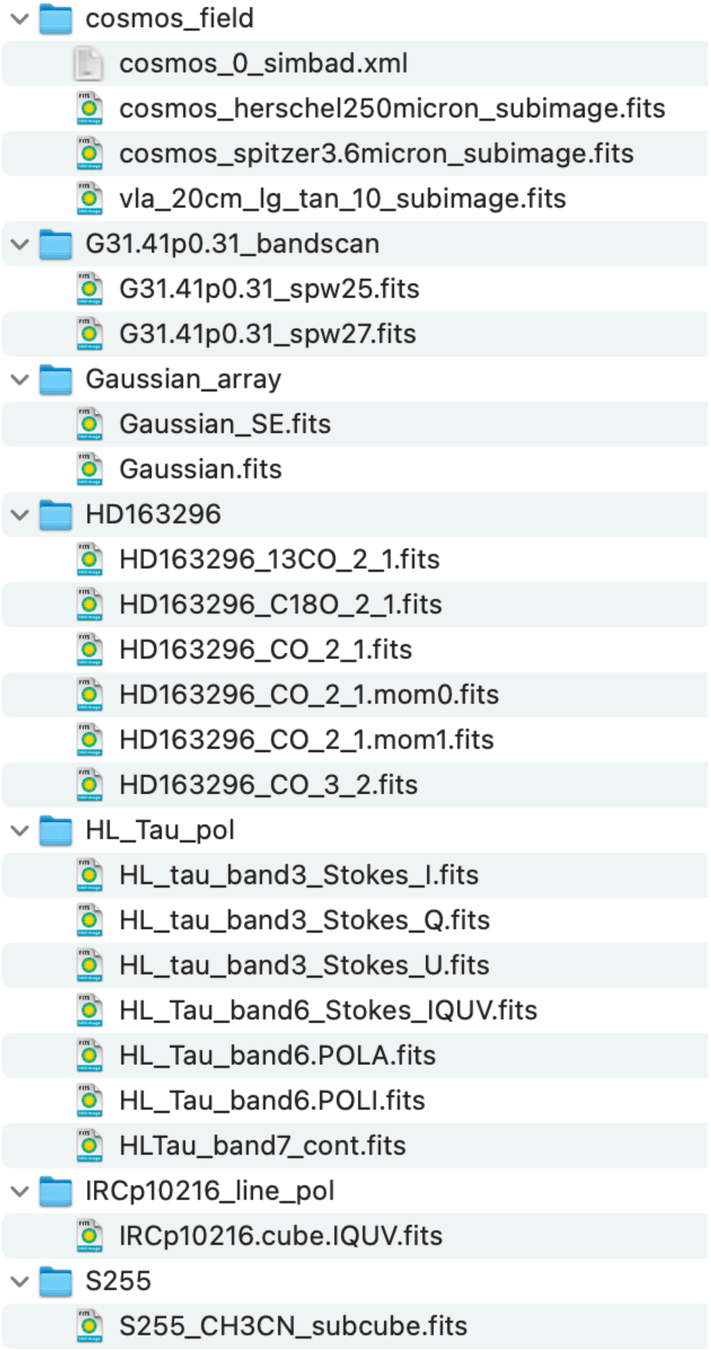
Custom layouts and preferences

- 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 for any questions/comments

https://cartavis.org

DOI 10.5281/zenodo.3377984

Cite CARTA!
This project needs your support!