CARTA 3: Cube Analysis and Rendering Tool for Astronomy

Juergen Ott

CARTA

Cube Analysis and Rendering Tool for Astronomy

Project: ASIAA, IDIA, NRAO, U Alberta

Webpage: https://cartavis.org

Github: https://github.com/CARTAvis

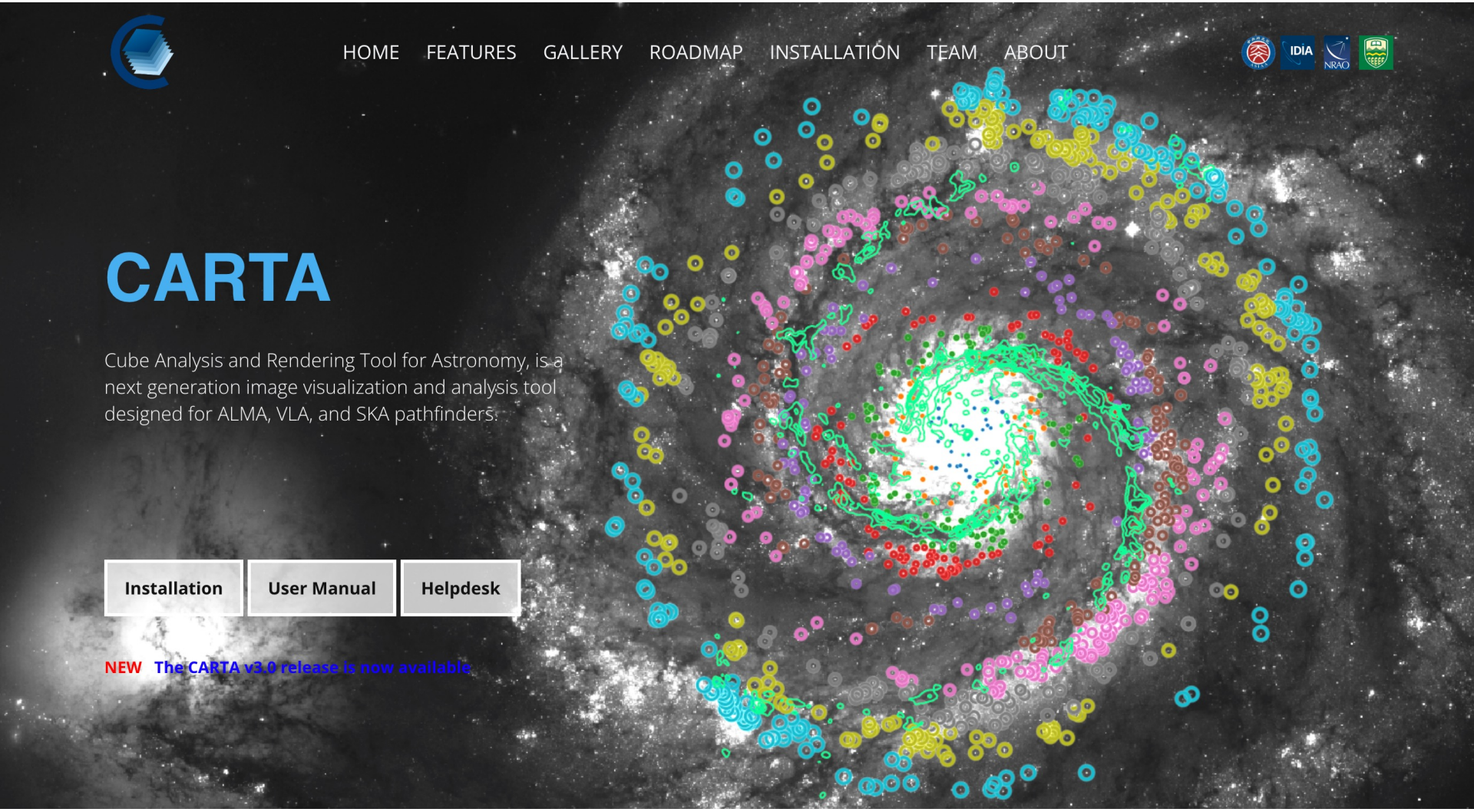
Goal: To build a high performance, versatile image for large data cubes and image in astronomy

Use cases:

- CASA viewer replacement (excluding interactive clean and visibility display)
- Archive interface for images from SKA precursors, ALMA, NRAO SRDP
- Stand alone analysis tool
- Scriptable interface (publication ready images, interaction for analysis)
- Collaborative tool

Current release version 3.0 (release date Aug 23, 2022)

CARTA on cartavis.org



System Requirements

From catravis.org “Obtaining CARTA”:

v3.0-beta.3

Supported operating systems:

- Ubuntu Linux: 18.04 LTS (Bionic Beaver), 20.04 LTS (Focal Fossa)
- Red Hat Enterprise Linux: 7, 8
- macOS: 10.15 (Catalina), 11 (Big Sur), 12 (Monterey)

Site deployment

Packages

Ubuntu | RHEL7 | CentOS7 | RHEL8 | AlmaLinux | macOS

Ubuntu 18.04 and 20.04 packages are available from our PPA.

```
sudo add-apt-repository ppa:cartavis-team/carta
sudo apt-get update
sudo apt install carta-beta
```

To start CARTA, please refer to the user manual How to Run CARTA.

Stand-alone application

macOS Electron Desktop | Ubuntu Linux AppImage | Red Hat Linux AppImage

The Red Hat Linux AppImage does not require root access. You simply download, extract, and run it. It uses your default web browser to display the CARTA graphical interface. The AppImage has been tested to run on Red Hat Enterprise Linux (RHEL) 7 and 8, as well as CentOS 7 and AlmaLinux 8.

Installation:

Either click the Download button below or run:

```
wget https://github.com/CARTAvis/carta/releases/download/v3.0.0-beta.3/CARTA-v3.0.0-beta.3-redhat.tgz
```

Extract the tarball:

```
tar -xzf CARTA-v3.0.0-beta.3-redhat.tgz
```

Operation:

To start CARTA, please refer to the user manual How to Run CARTA.

Note: If you wish to run the AppImage inside a Docker container, or you system has trouble with FUSE, please prefix with the following environment variable:

```
APPIMAGE_EXTRACT_AND_RUN=1 ./CARTA-v3.0.0-beta.3-redhat.AppImage
```

Browsers: from carta.readthedocs.io “How to run CARTA?”:

Please note that the CARTA GUI is run in the web browser environment. The supported browsers are:

- Google Chrome (tested with v91)
- Firefox (tested with v89)
- Safari (tested with v14.1)

Other browsers might be supported but they are not tested.

Warning

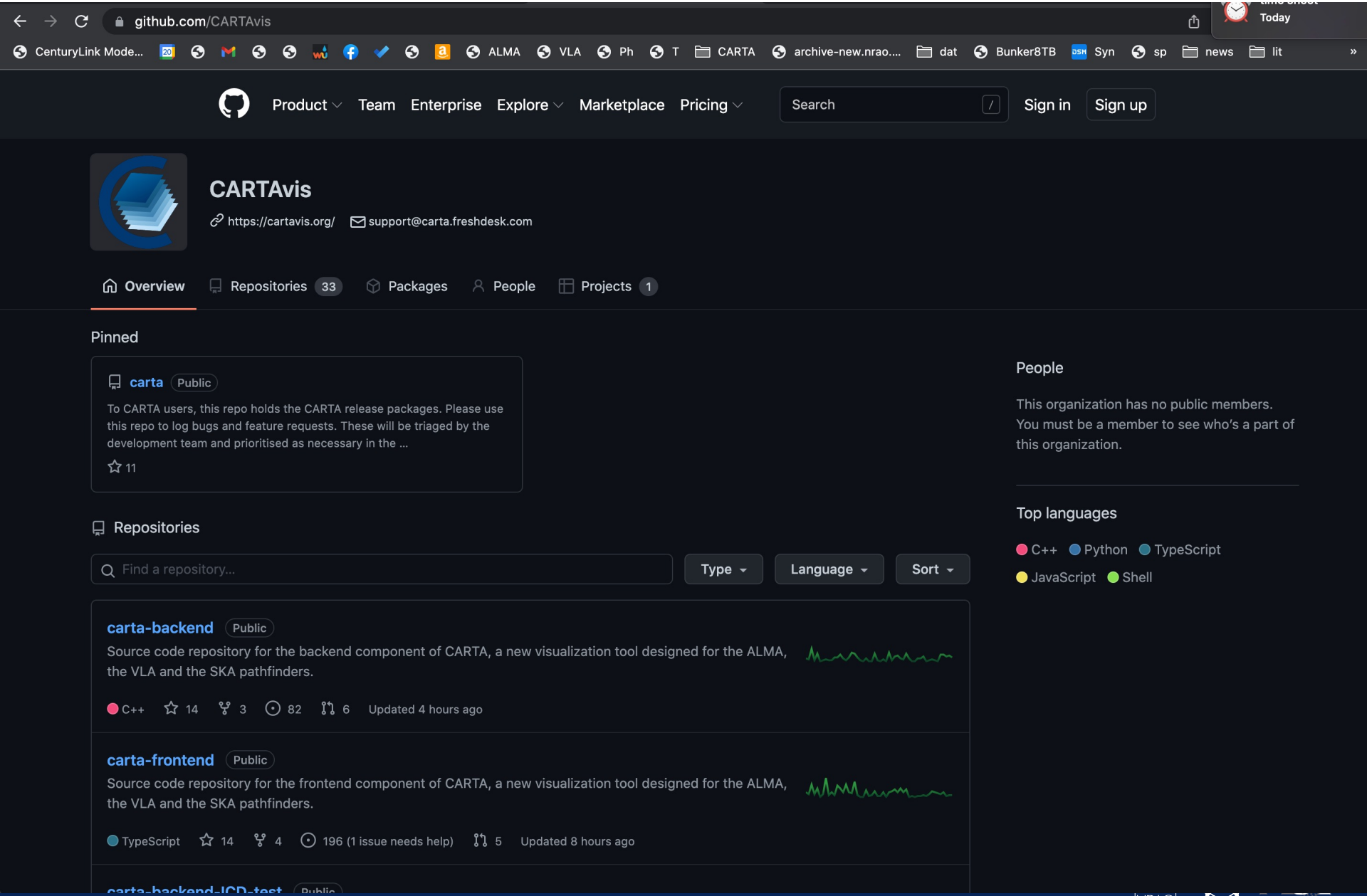
At the moment, there is a layout issue with the Safari browser, which affect usability and user experience significantly. macOS users should try to avoid using Safari to run CARTA.

Note

CARTA requires WebGL in order to render images properly. WebGL2 is also required to render catalog overlay properly. Please ensure WebGL and WebGL2 are enabled in your browser.

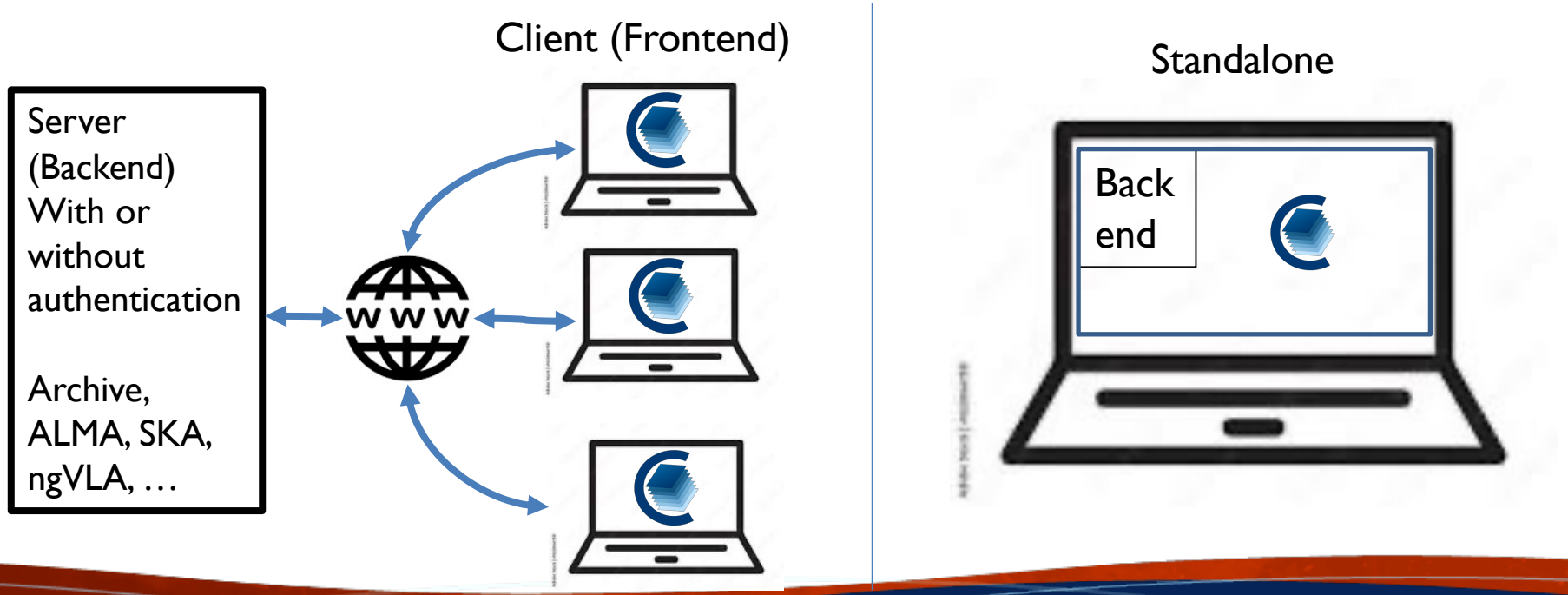
Note: system/browser must be support webGL 2.0
If not, then CARTA widget will pop up, but image display will be single color
Test URL:
https://get.webgl.org/webgl2/
May require upgrade or downgrade of video card driver

CARTA on github.com/CARTAvis



CARTA architecture

- A focus is on the performance for large datasets (1 TB loads in seconds)
  - Memory efficient image loading
  - Parallelization and GPU-accelerated rendering
  - Progressive and responsive update of spectral profile
  - Tiled image rendering
- Image formats: CASA, fits, gzipped fits, MIRIAD, HDF5 image (cube)
- OS: MacOS, Ubuntu, RHEL
- CARTA is built as a server-client infrastructure, launched separately or in a stand-alone version in a single instance



CARTA Features

Viewing:

- Image rendering with (global) min/max clipping, scaling functions and color maps
- Image panning, zooming, etc.
- Multi-panel
- Hardcopy
- Image/region saving
- Image blinking
- Image WCS matching spatially and spectrally
- Contours with different generators, colors, color maps
- Catalog overlays
- Setting of rest frequency
- Vector overlays
- Complex image display
- LEL image arithmetic before display
- Generating computed polarization quantities (eg. linear polarization intensity) of a Stokes cube on the fly
- Setting a new rest frequency when saving a subimage

CARTA Features

Tools/Analysis:

- Regions: rotating box, ellipses, polygons, line, point, polyline
- Spatial (X,Y) and spectral (Z) profiles
- Spectral profiles can convert spectral axis labels (velocity, frequency, wavelength)
- Histogram
- Image/Region Statistics
- Stokes analysis widget
- Moment generator
- pV diagram
- Spectral line labelling
- Spectral smoothing
- Distance measuring tool
- Intensity conversion
- 2D Gaussian fitting of sources in image
- Line and polyline region spectral profiler

CARTA Features

Other:

- Server-client infrastructure for remote image access
- Server authentication
- Tiled rendering for performance
- Docking and Preferred layouts and layout saving
- Scripting is under active development

CASAviewer vs CARTA

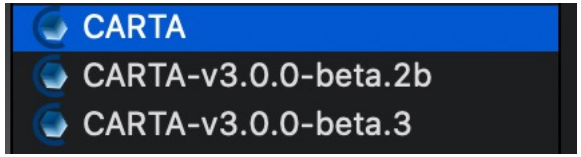
Gaps relative to CASAviewer (green: CARTA development underway; black: future CARTA development; red: likely not implemented in CARTA)

- Complete set of fitting tools → spectral: multiple Gaussians and Lorenzians already available with continuum polynomial; spatial: 2D Gaussian fit
- Source finder tool
- Spectral profile error bar plotting (MUSE/optical feature in CASA)
- Image annotation → v4
- profile annotation
- Rotated cube view (input as ra-dec-channel, view as ra-channel vs dec)
- Scalable output (SVG or PDF)
- Creation of multi-channel plots → v4
- Regions that extend across spectral and stokes planes
- Histogram fitting
- Markers → they have not been widely used in the CASAviewer
- Interactive clean → CASA will develop a visualization tool independent of CARTA
- Full support of CRTF → was not even supported by the CASAviewer
- Save/reload states → v4
- Share states → v4

CARTA – Start

MacOX installed stand-alone:

carta (or click the icon in the Applications folder)



Linux or remote (beta version needs to be downloaded from cartavis.org first):

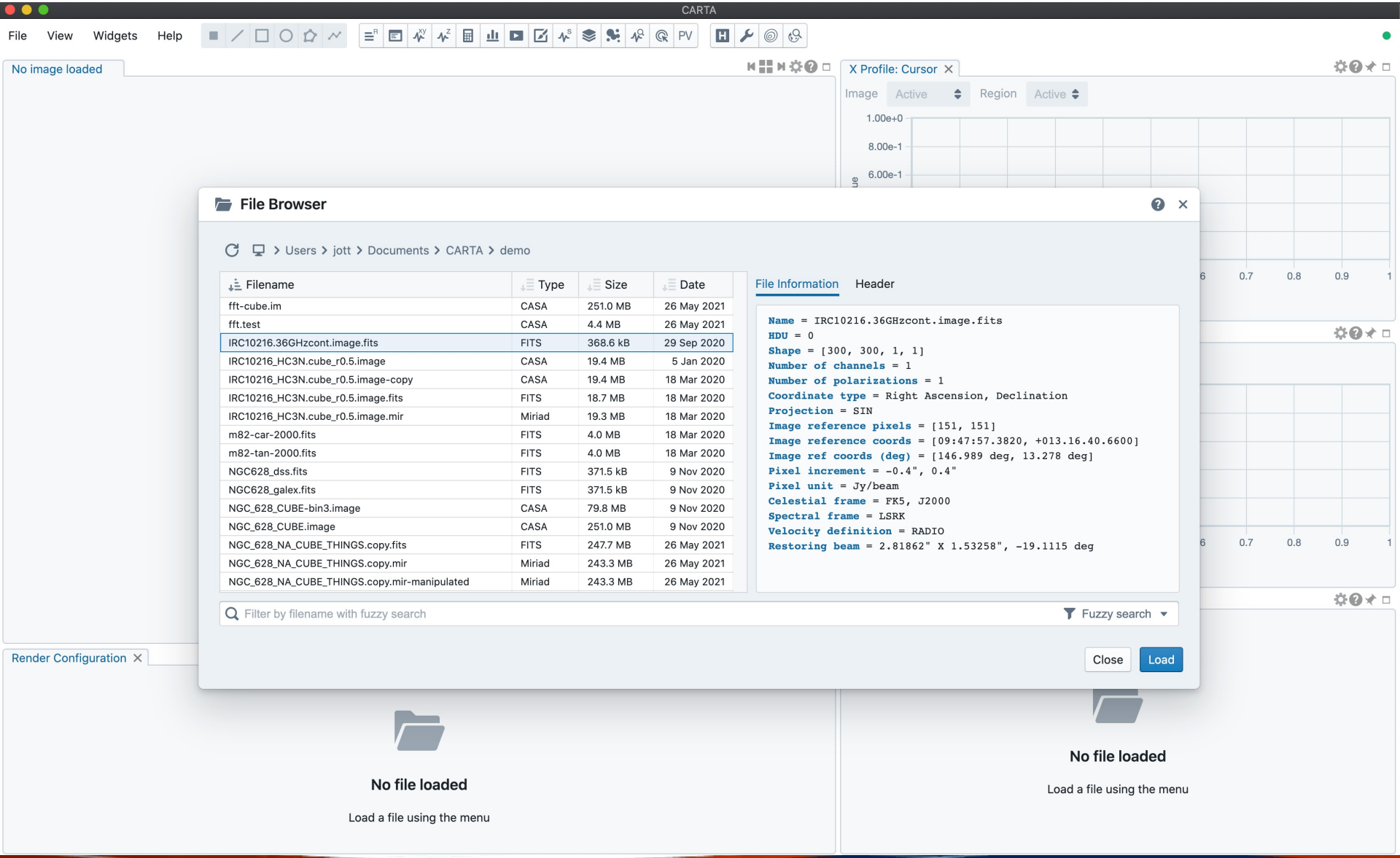
(base) jott@Desktop ~> CARTA-v3.0.0-redhat7.AppImage --no_browser

touch: cannot touch â€/users/jott/.local/share/icons/hicolor/.xdg-icon-resource-dummyâ€: No such file or directory
[2022-04-04 14:49:41.290] [info] Writing to the log file: /users/jott/.carta-beta/log/carta.log
[2022-04-04 14:49:41.290] [info] /tmp/.mount_CARTA-9Qe8SC/bin/carta_backend: Version 3.0.0-beta.2b
[2022-04-04 14:49:41.296] [info] Serving CARTA frontend from /tmp/.mount_CARTA-9Qe8SC/share/carta/frontend
[2022-04-04 14:49:41.296] [warning] Port 3002 is already in use. Trying next port.
[2022-04-04 14:49:41.296] [warning] Port 3003 is already in use. Trying next port.
[2022-04-04 14:49:41.297] [warning] Port 3004 is already in use. Trying next port.
[2022-04-04 14:49:41.297] [warning] Port 3005 is already in use. Trying next port.
[2022-04-04 14:49:41.297] [warning] Port 3006 is already in use. Trying next port.
[2022-04-04 14:49:41.297] [warning] Port 3007 is already in use. Trying next port.
[2022-04-04 14:49:41.297] [info] Listening on port 3008 with top level folder /, starting folder /lustre/aoc/sciops/jott/pipeline/calibrationtest/L-band.
The number of OpenMP worker threads will be handled automatically.
[2022-04-04 14:49:41.297] [info] CARTA is accessible at http://146.88.3.182:3008/?token=ec1836fc-2cd7-468d-9744-a1ac3e8cc995

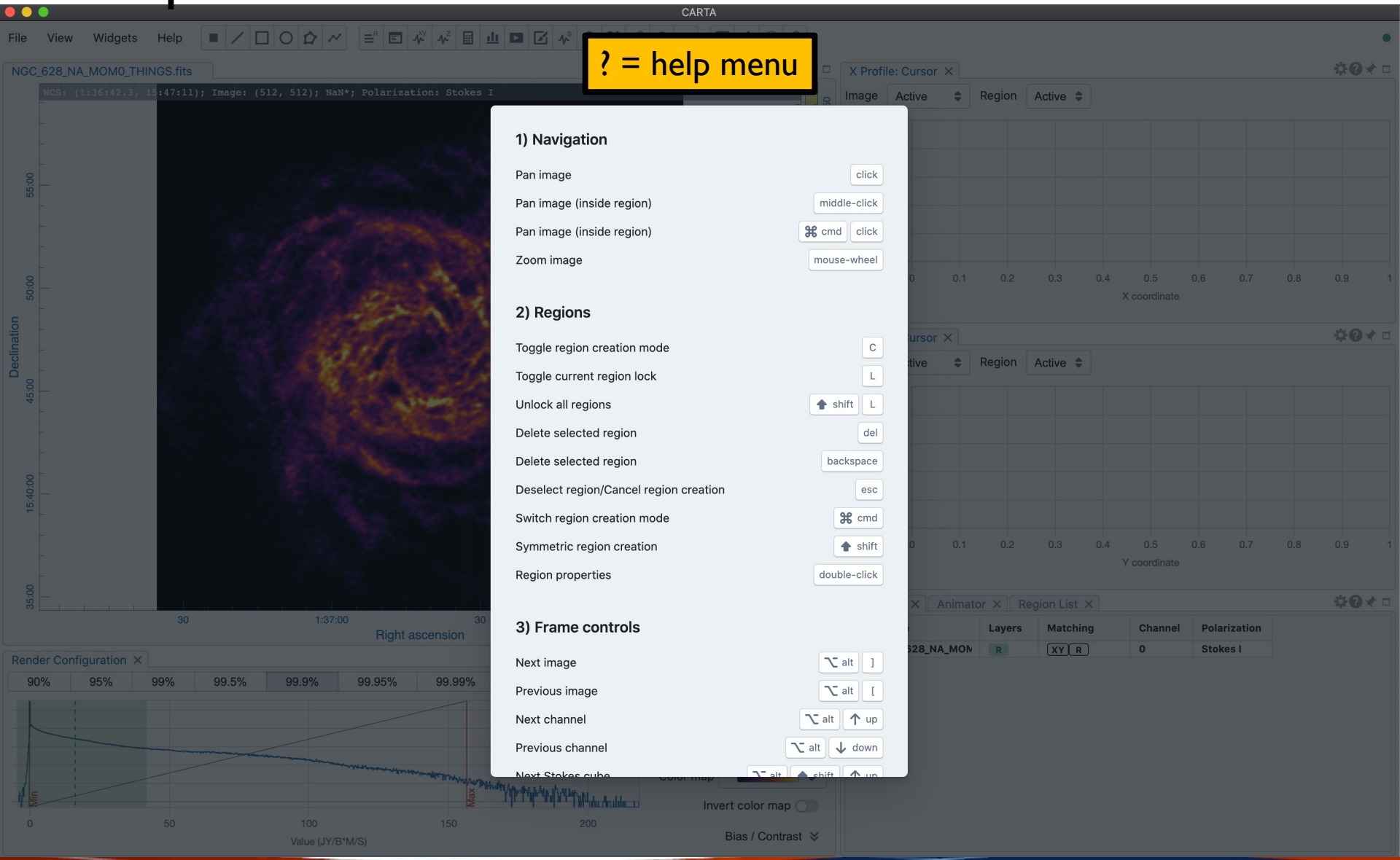
→ Copy and past this URL in your local browser (VPN connection needed if outside NRAO)

carta --no_browser at NRAO will launch v2.0 (3.0 not installed yet)

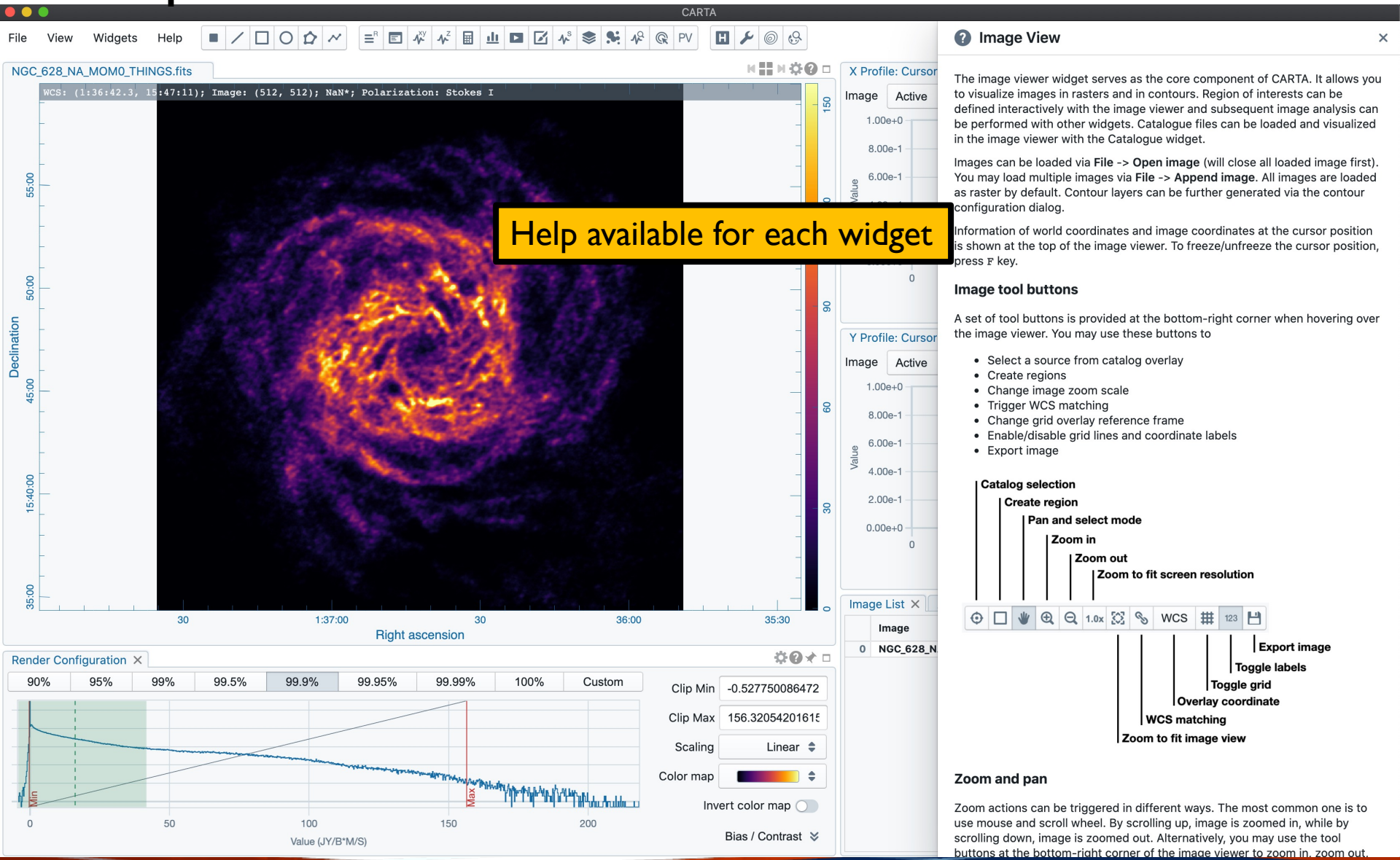
File loading



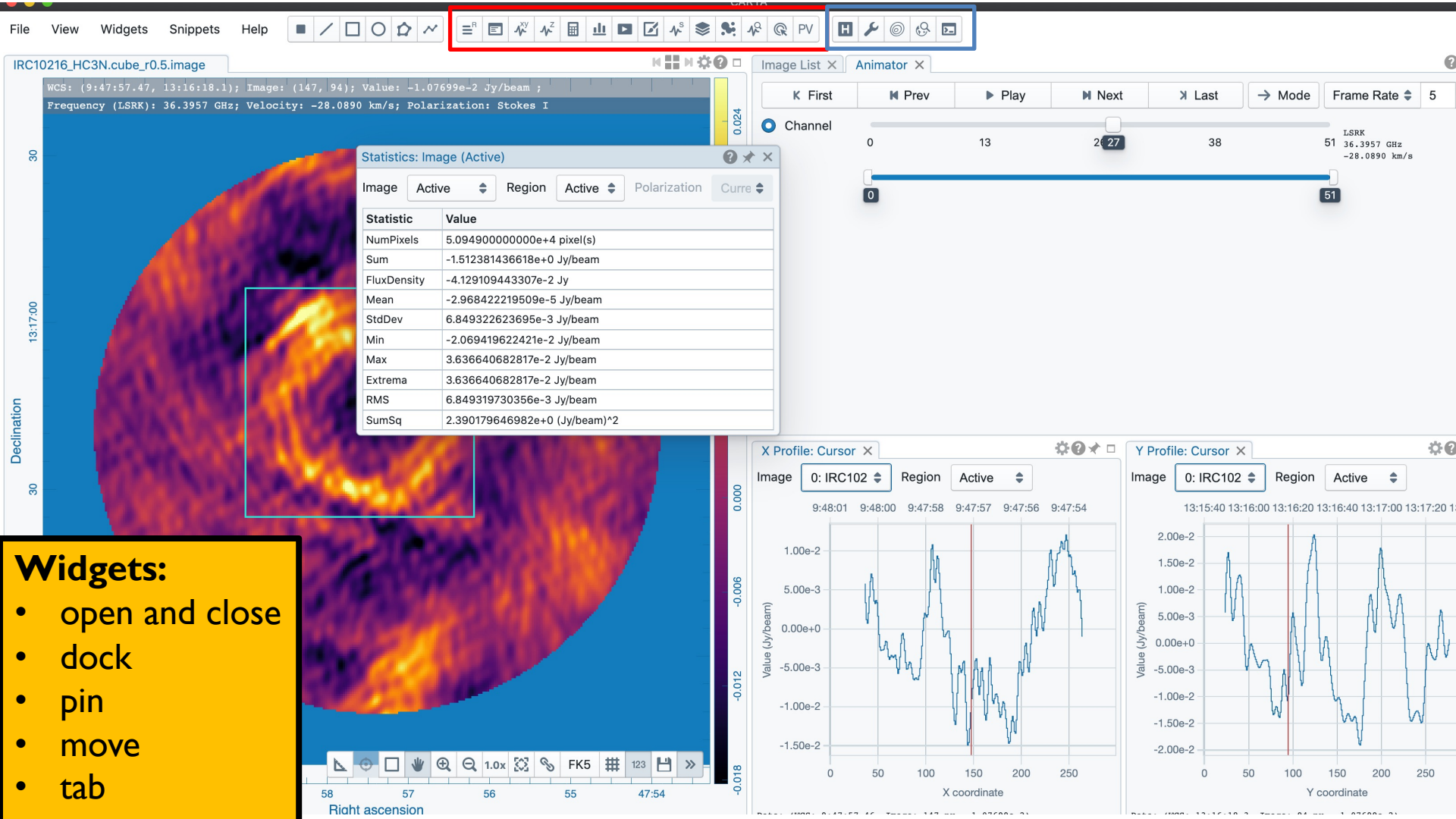
Help


CARTA
File
View
Widgets
Help
? = help menu
NGC_628_NA_MOM0_THINGS.fits
X Profile: Cursor
Image
Active
Region
Active
1) Navigation
Pan image
click
Pan image (inside region)
middle-click
Pan image (inside region)
cmd
click
Zoom image
mouse-wheel
2) Regions
Toggle region creation mode
C
Toggle current region lock
L
Unlock all regions
shift
L
Delete selected region
del
Delete selected region
backspace
Deselect region/Cancel region creation
esc
Switch region creation mode
cmd
Symmetric region creation
shift
Region properties
double-click
3) Frame controls
Next image
alt
]
Previous image
alt
[
Next channel
alt
up
Previous channel
alt
down
Declination
Right ascension
X coordinate
Y coordinate
Render Configuration
90%
95%
99%
99.5%
99.9%
99.95%
99.99%
Value (JY/B*M/S)
Invert color map
Bias / Contrast
Animator
Region List
Layers
Matching
Channel
Polarization
Stokes I

Help


CARTA
File
View
Widgets
Help
NGC_628_NA_MOM0_THINGS.fits
WCS: (1:36:42.3, 15:47:11); Image: (512, 512); NaN*; Polarization: Stokes I
Declination
Right ascension
Help available for each widget
X Profile: Cursor
Y Profile: Cursor
Image
Active
Value
Image List
Render Configuration
90%
95%
99%
99.5%
99.9%
99.95%
99.99%
100%
Custom
Clip Min
-0.527750086472
Clip Max
156.32054201615
Scaling
Linear
Color map
Invert color map
Bias / Contrast
Min
Max
Value (JY/B*M/S)
Image View
The image viewer widget serves as the core component of CARTA. It allows you to visualize images in rasters and in contours. Region of interests can be defined interactively with the image viewer and subsequent image analysis can be performed with other widgets. Catalogue files can be loaded and visualized in the image viewer with the Catalogue widget.
Images can be loaded via File -> Open image (will close all loaded image first). You may load multiple images via File -> Append image. All images are loaded as raster by default. Contour layers can be further generated via the contour configuration dialog.
Information of world coordinates and image coordinates at the cursor position is shown at the top of the image viewer. To freeze/unfreeze the cursor position, press F key.
Image tool buttons
A set of tool buttons is provided at the bottom-right corner when hovering over the image viewer. You may use these buttons to
Select a source from catalog overlay
Create regions
Change image zoom scale
Trigger WCS matching
Change grid overlay reference frame
Enable/disable grid lines and coordinate labels
Export image
Catalog selection
Create region
Pan and select mode
Zoom in
Zoom out
Zoom to fit screen resolution
WCS
Export image
Toggle labels
Toggle grid
Overlay coordinate
WCS matching
Zoom to fit image view
Zoom and pan
Zoom actions can be triggered in different ways. The most common one is to use mouse and scroll wheel. By scrolling up, image is zoomed in, while by scrolling down, image is zoomed out. Alternatively, you may use the tool buttons at the bottom-right corner of the image viewer to zoom in, zoom out,

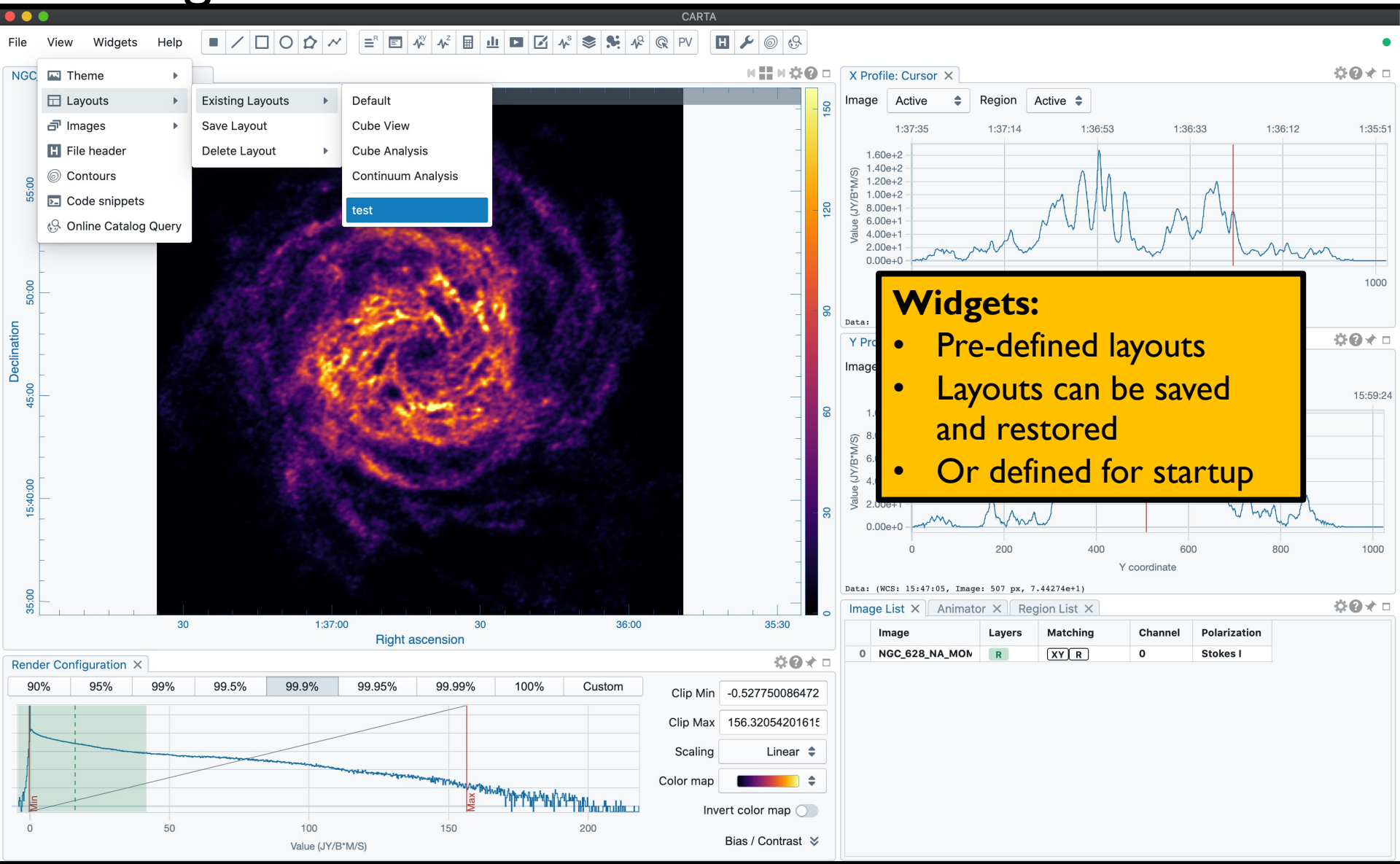
Widgets



Widgets:

- open and close
- dock
- pin
- move
- tab
- rearrange
- resize
- float

Widgets


CARTA
File
View
Widgets
Help
Theme
Layouts
Images
File header
Contours
Code snippets
Online Catalog Query
Existing Layouts
Save Layout
Delete Layout
Default
Cube View
Cube Analysis
Continuum Analysis
test
X Profile: Cursor
Image
Active
Region
Active
Value (JY/B*M/S)
Data:
Widgets:
• Pre-defined layouts
• Layouts can be saved and restored
• Or defined for startup
Declination
Right ascension
Y coordinate
Data: (WCS: 15:47:05, Image: 507 px, 7.44274e+1)
Image List
Animator
Region List
Image
Layers
Matching
Channel
Polarization
NGC_628_NA_MON
Stokes I
Render Configuration
90%
95%
99%
99.5%
99.9%
99.95%
99.99%
100%
Custom
Clip Min
-0.527750086472
Clip Max
Scaling
Linear
Color map
Invert color map
Bias / Contrast
Min
Max
Value (JY/B*M/S)

Widgets

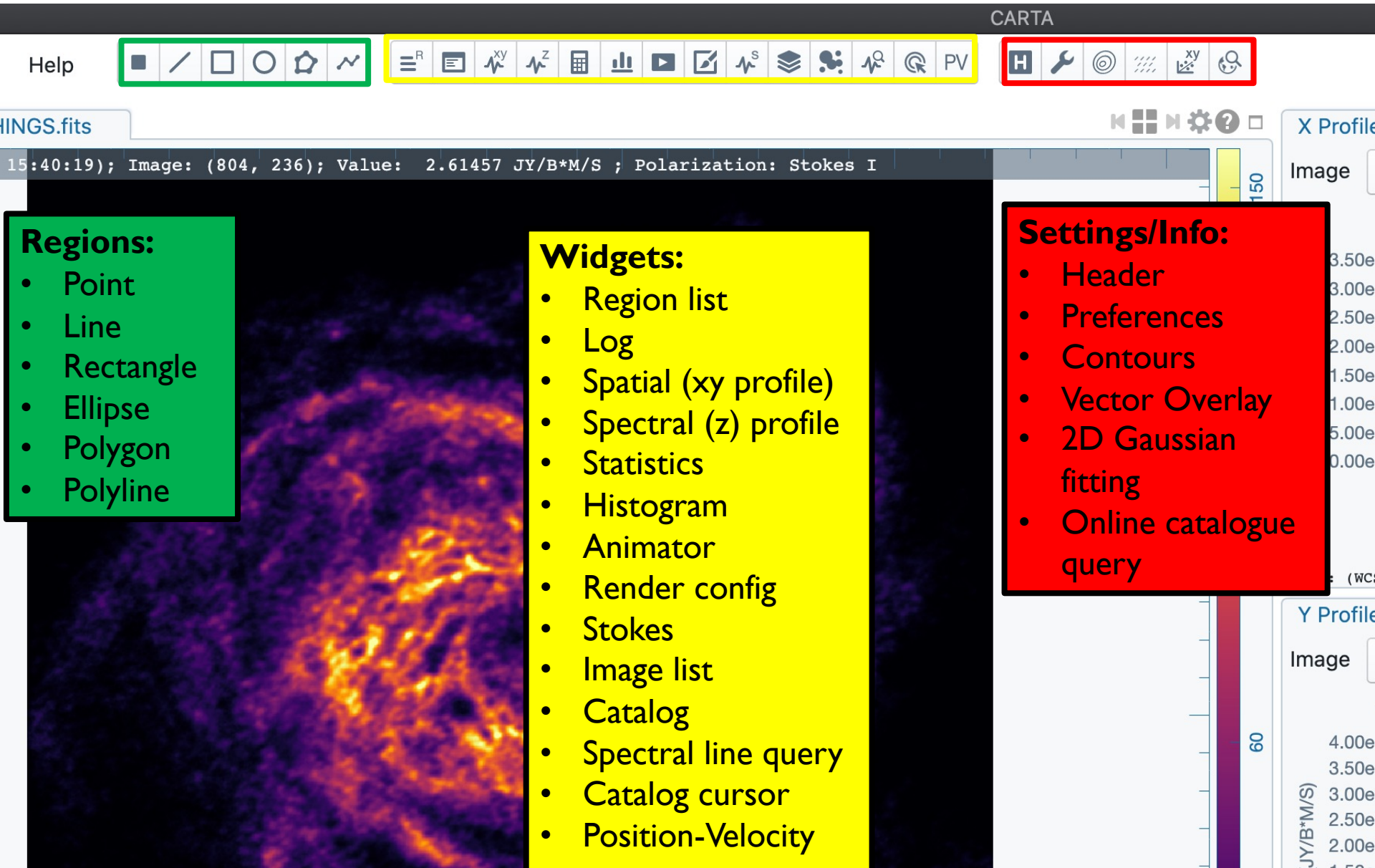

CARTA
Help
PV
HINGS.fits
15:40:19); Image: (804, 236); Value: 2.61457 JY/B*M/S ; Polarization: Stokes I
X Profile
Image
Y Profile
Image
Regions:
• Point
• Line
• Rectangle
• Ellipse
• Polygon
• Polyline
Widgets:
• Region list
• Log
• Spatial (xy profile)
• Spectral (z) profile
• Statistics
• Histogram
• Animator
• Render config
• Stokes
• Image list
• Catalog
• Spectral line query
• Catalog cursor
• Position-Velocity
Settings/Info:
• Header
• Preferences
• Contours
• Vector Overlay
• 2D Gaussian fitting
• Online catalogue query

Image display widget

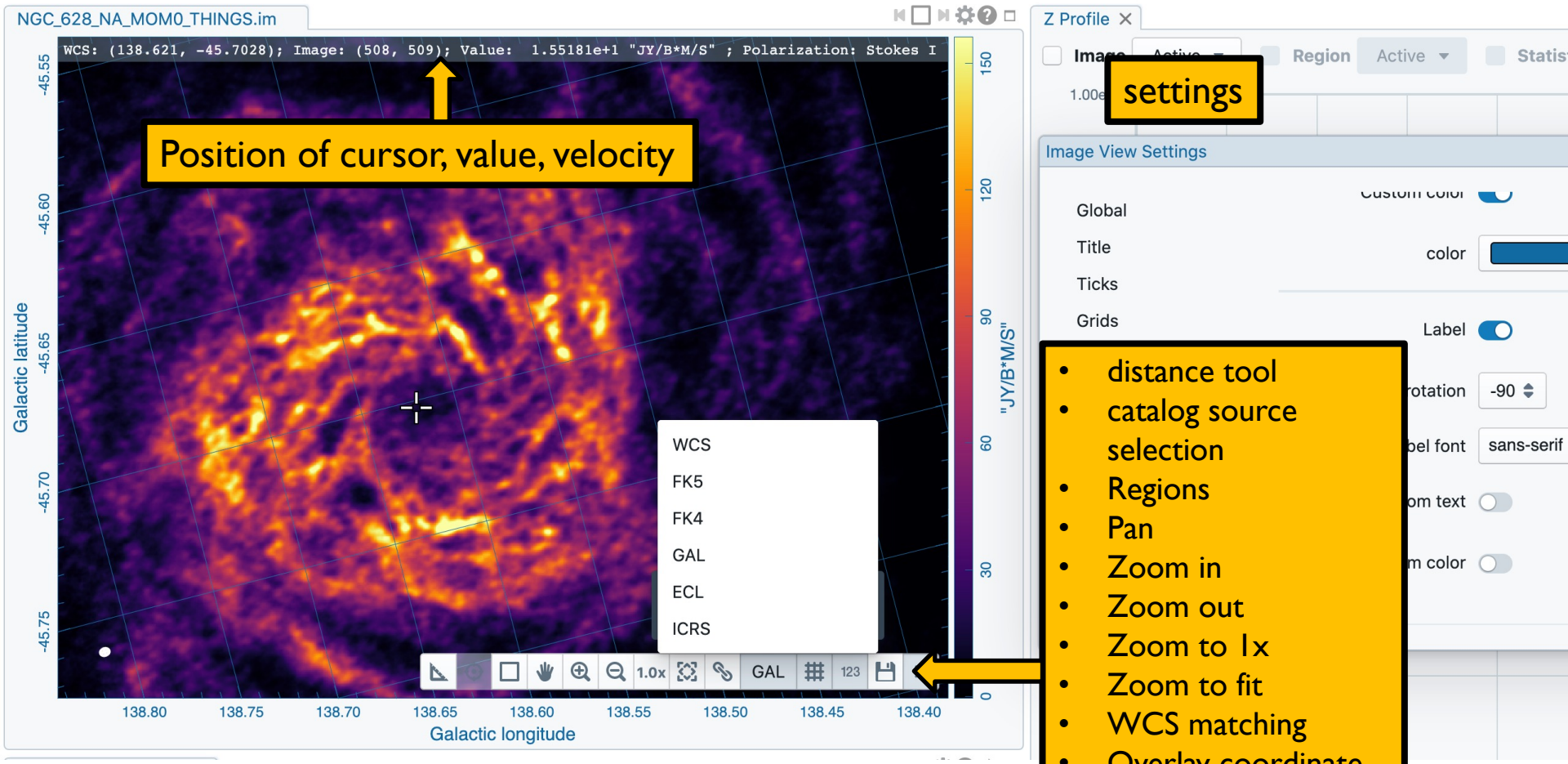
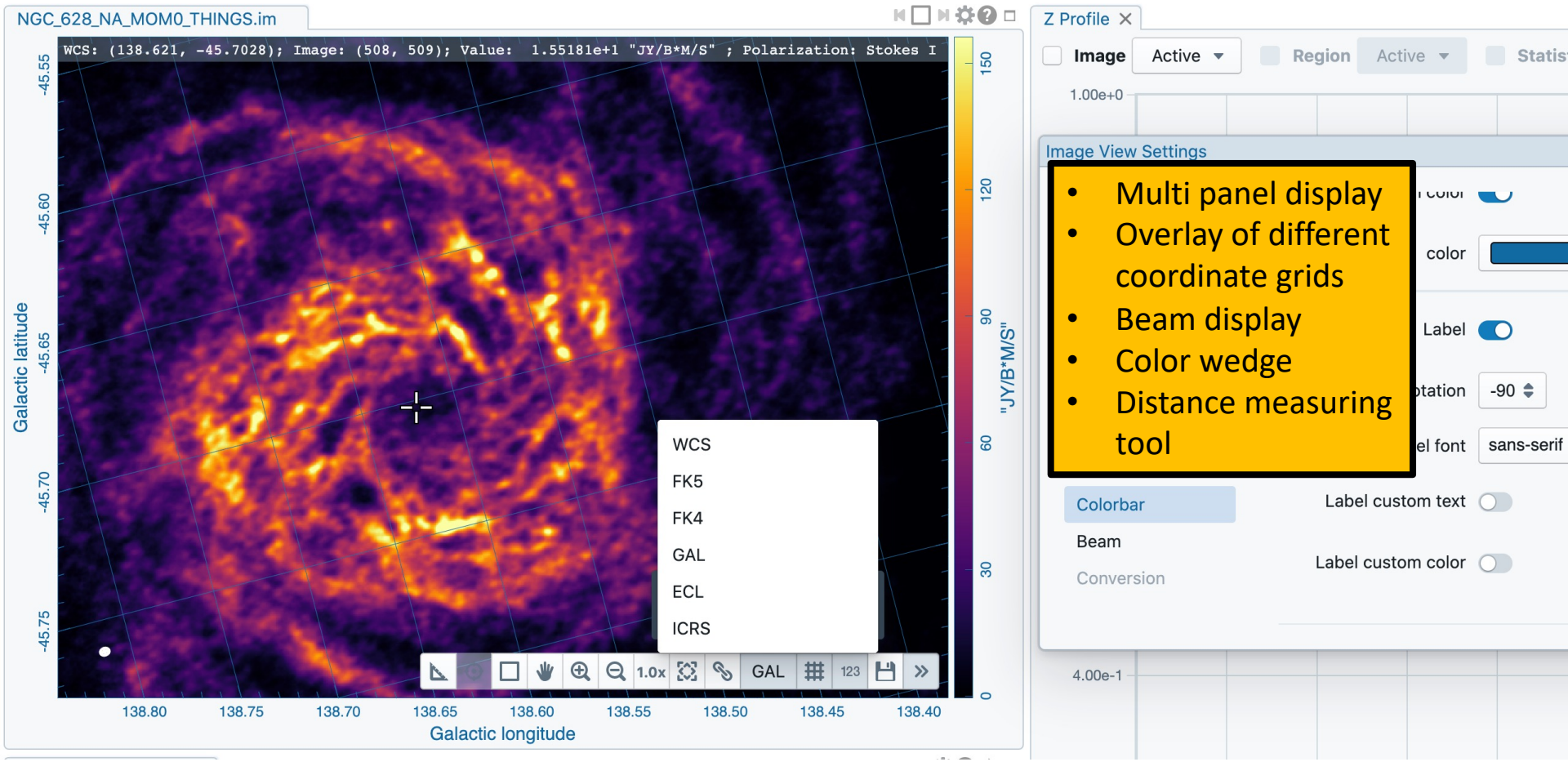


Image display widget



- Multi panel display
- Overlay of different coordinate grids
- Beam display
- Color wedge
- Distance measuring tool

Distance Measurement

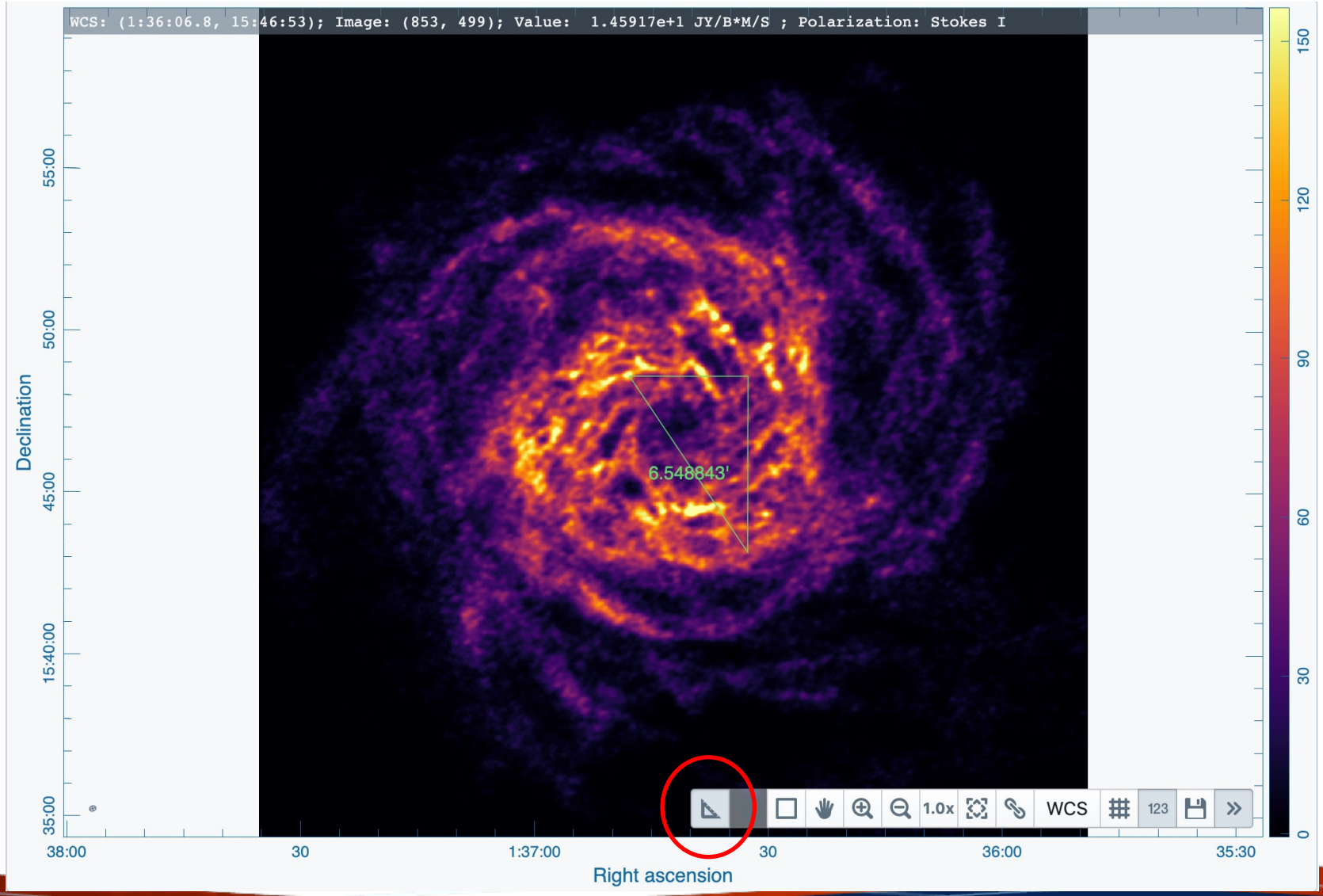


Image display widget - multipanel

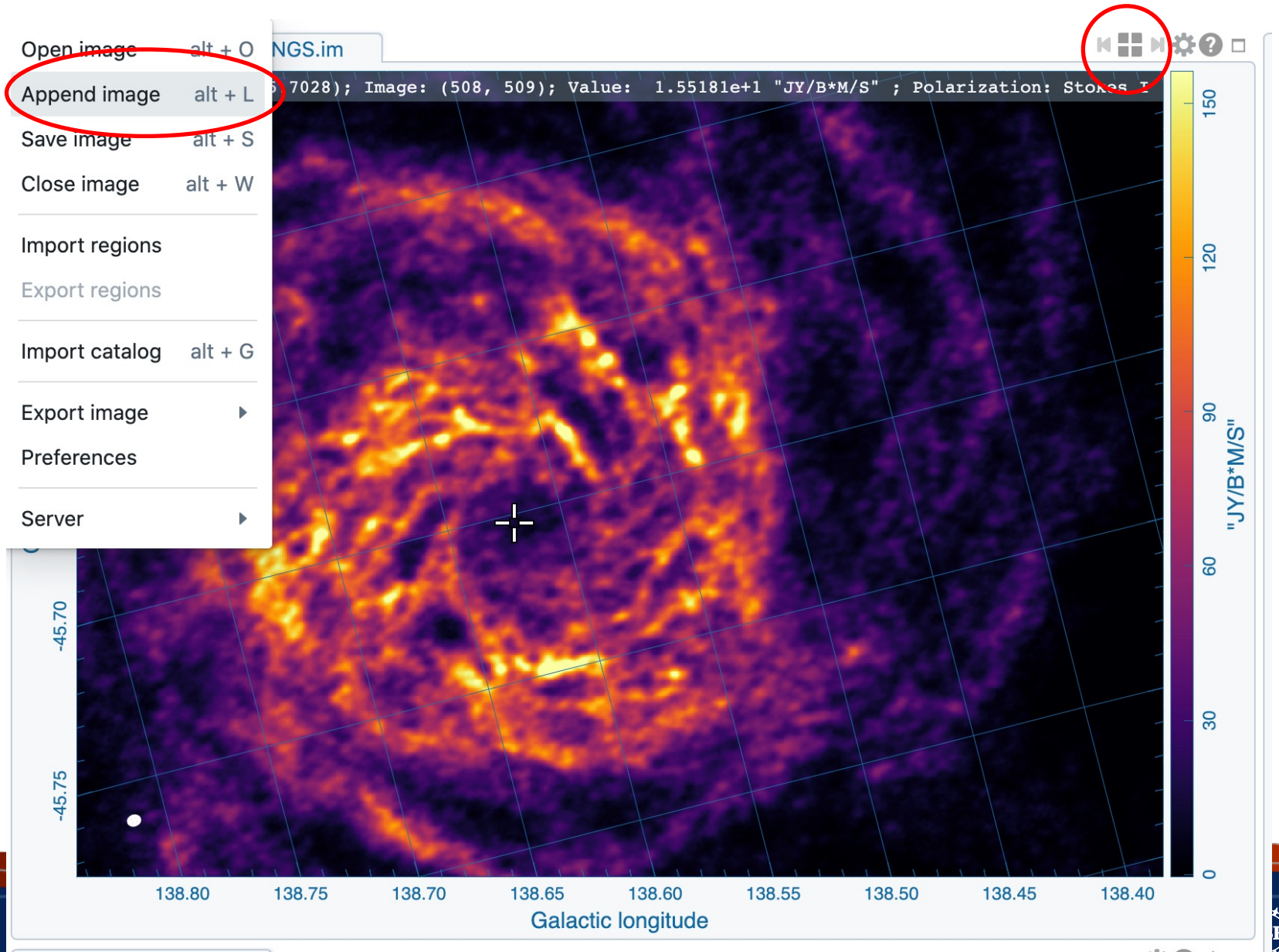


Image display widget - multipanel

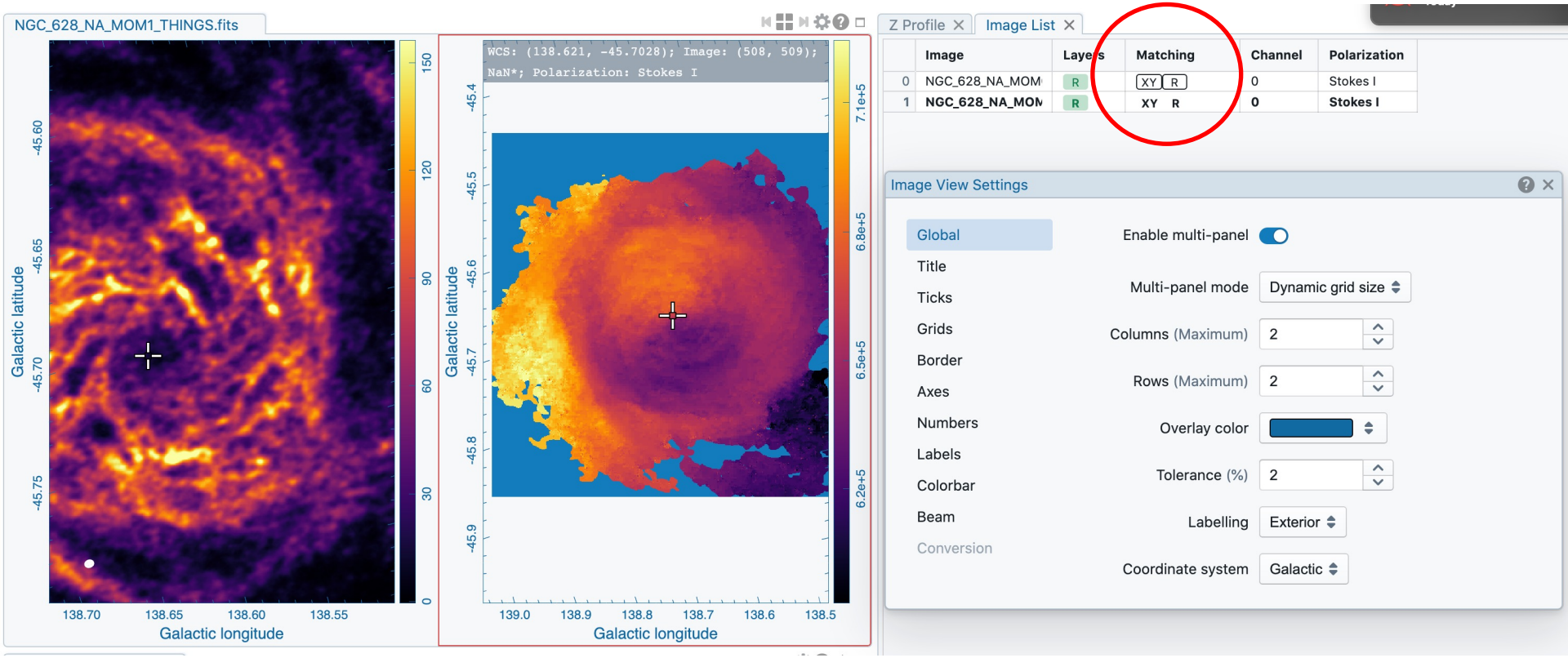
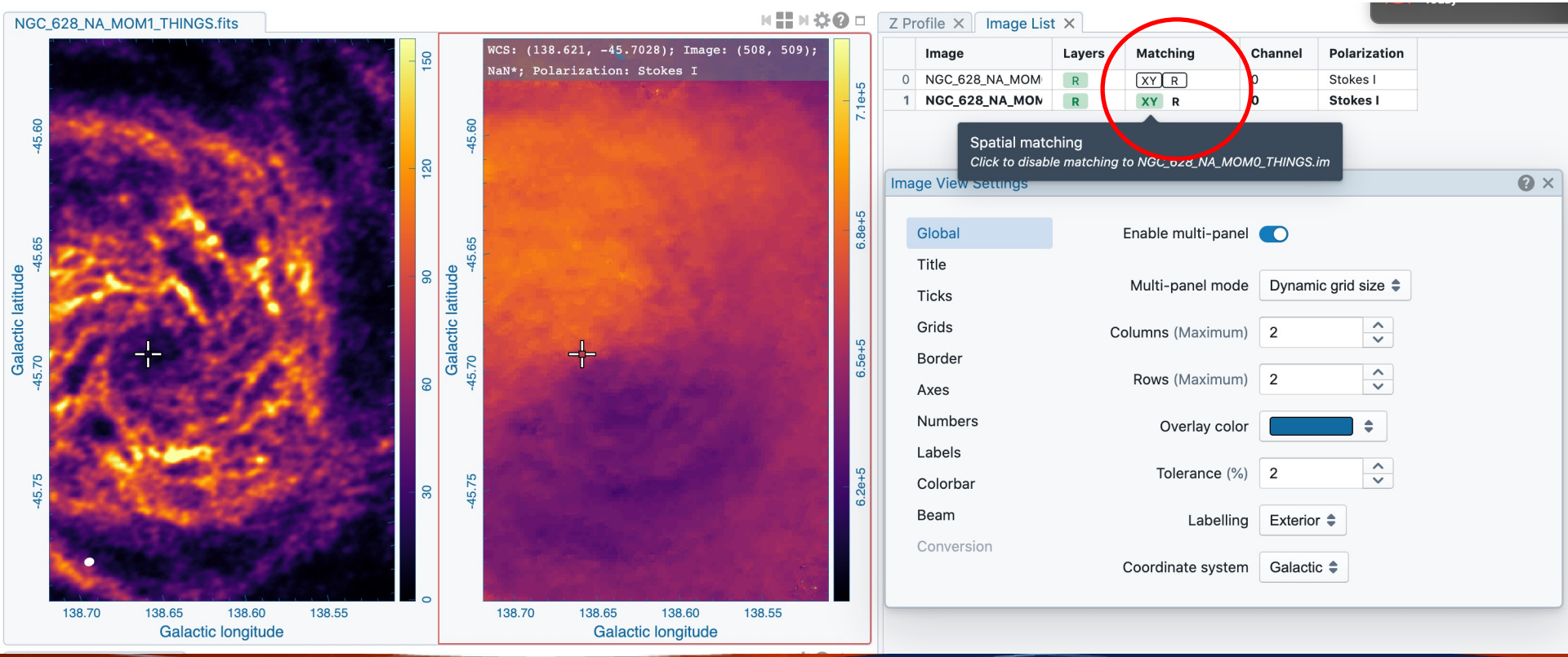


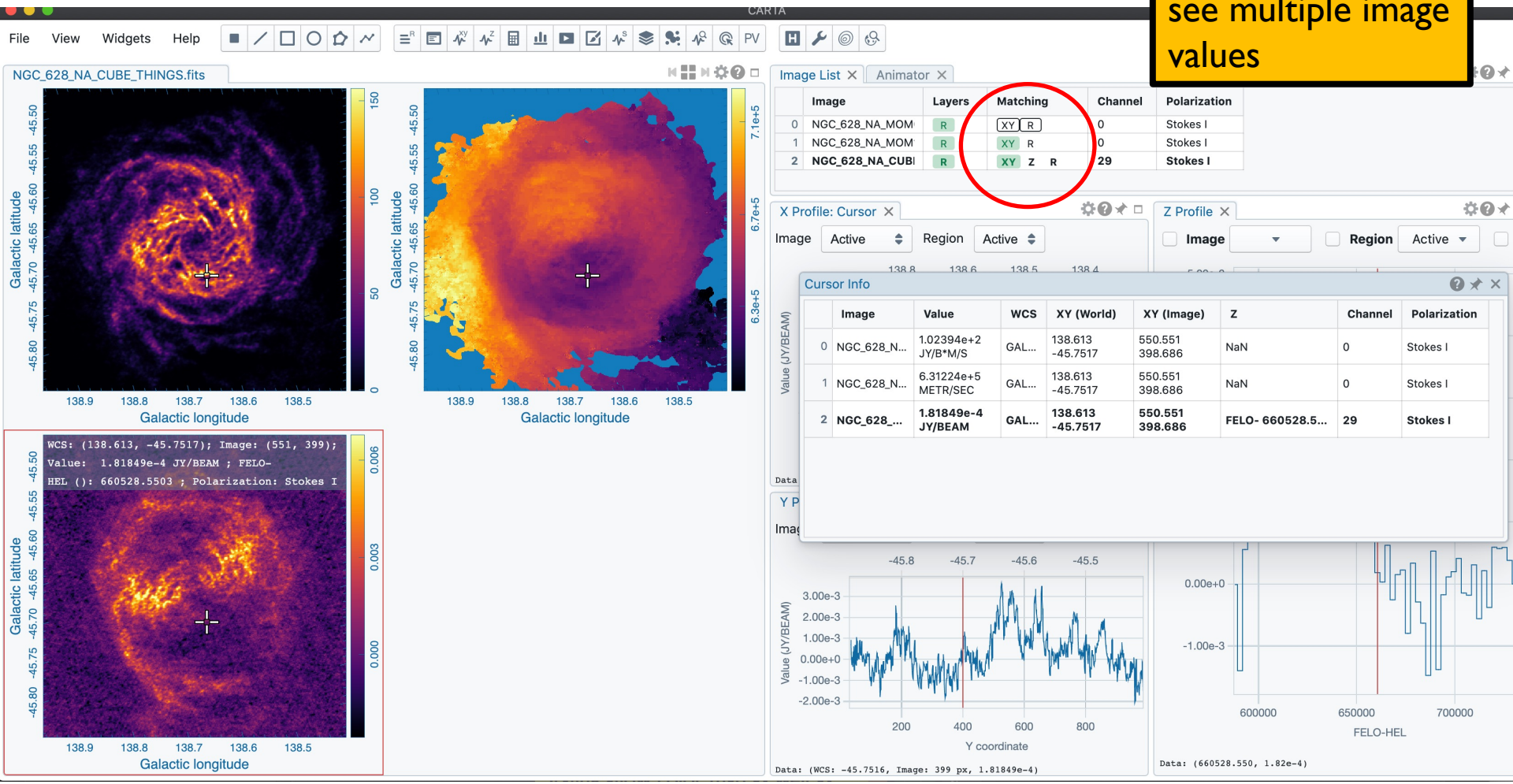
Image display widget - multipanel

WCS image registration will align coordinates of different images
Master is outlined; aligned images in green
Alignment in XY (spatial) and/or Z (spectral), and or R (color scale)



Cursor Widget

Align WCS first to see multiple image values



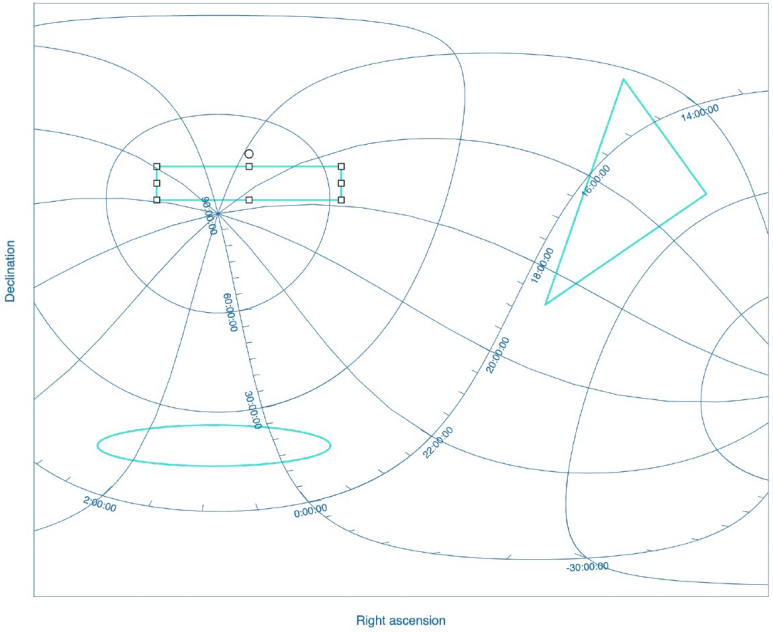
CARTA

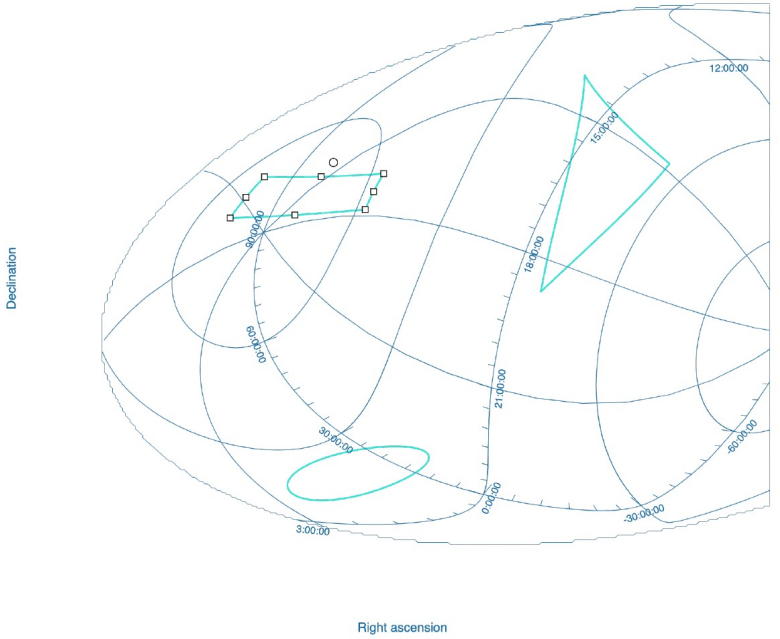
Projection handling:

To avoid regridding, WCS matching shifts and rotates the image to the master image
This produces a small error for large fields, only visible in blinking
But images are projected correctly when overlaid as contours

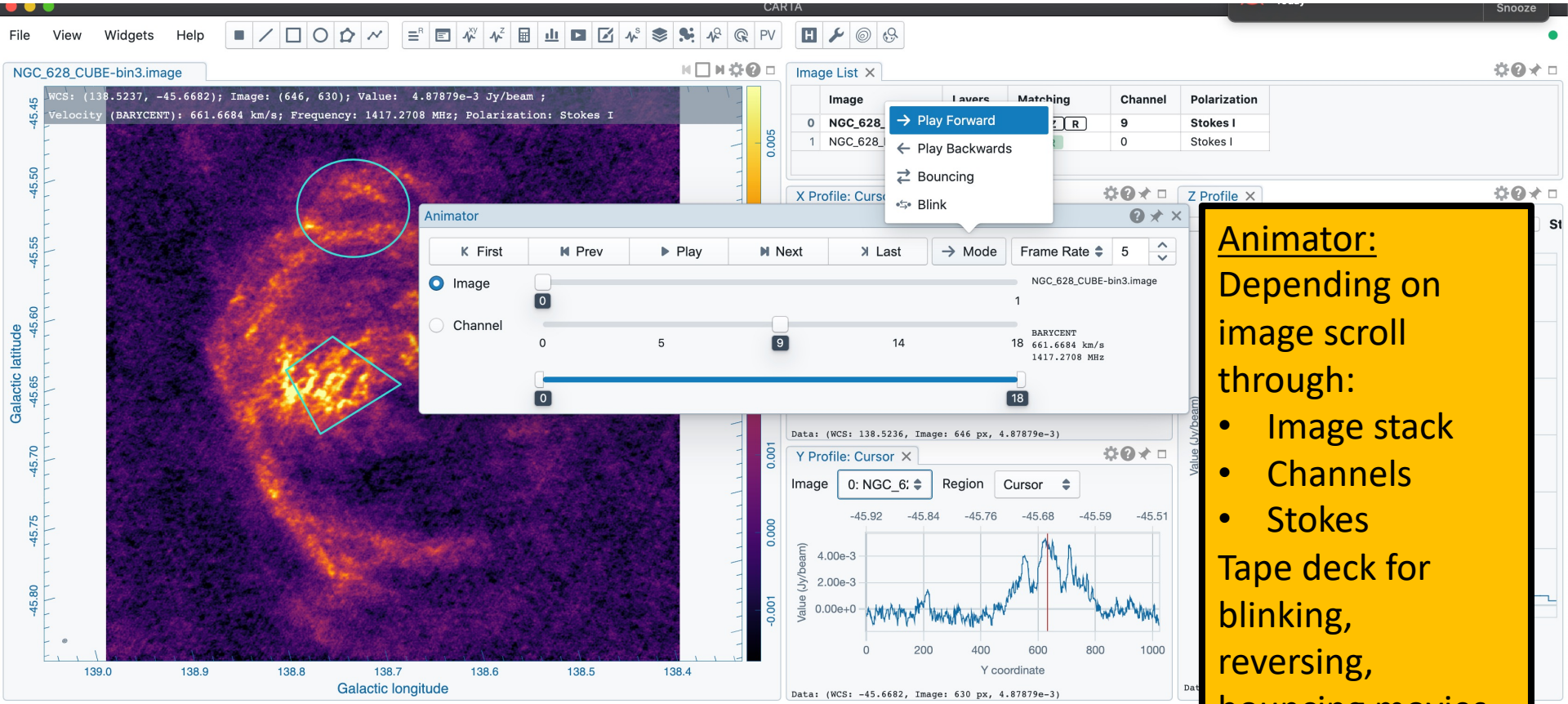
Spectral matching: Nearest interpolation

Regions: They project correctly when moving across the sky in different coordinate systems





Animator



Animator:
Depending on image scroll through:

- Image stack
- Channels
- Stokes

Tape deck for blinking, reversing, bouncing movies

Rendering

Selection of
- Color maps
- Scaling/transfer function (shown as overlay)
- Per plane or per cube scaling
- Global scaling through the image list widge
- Bias/Contrast

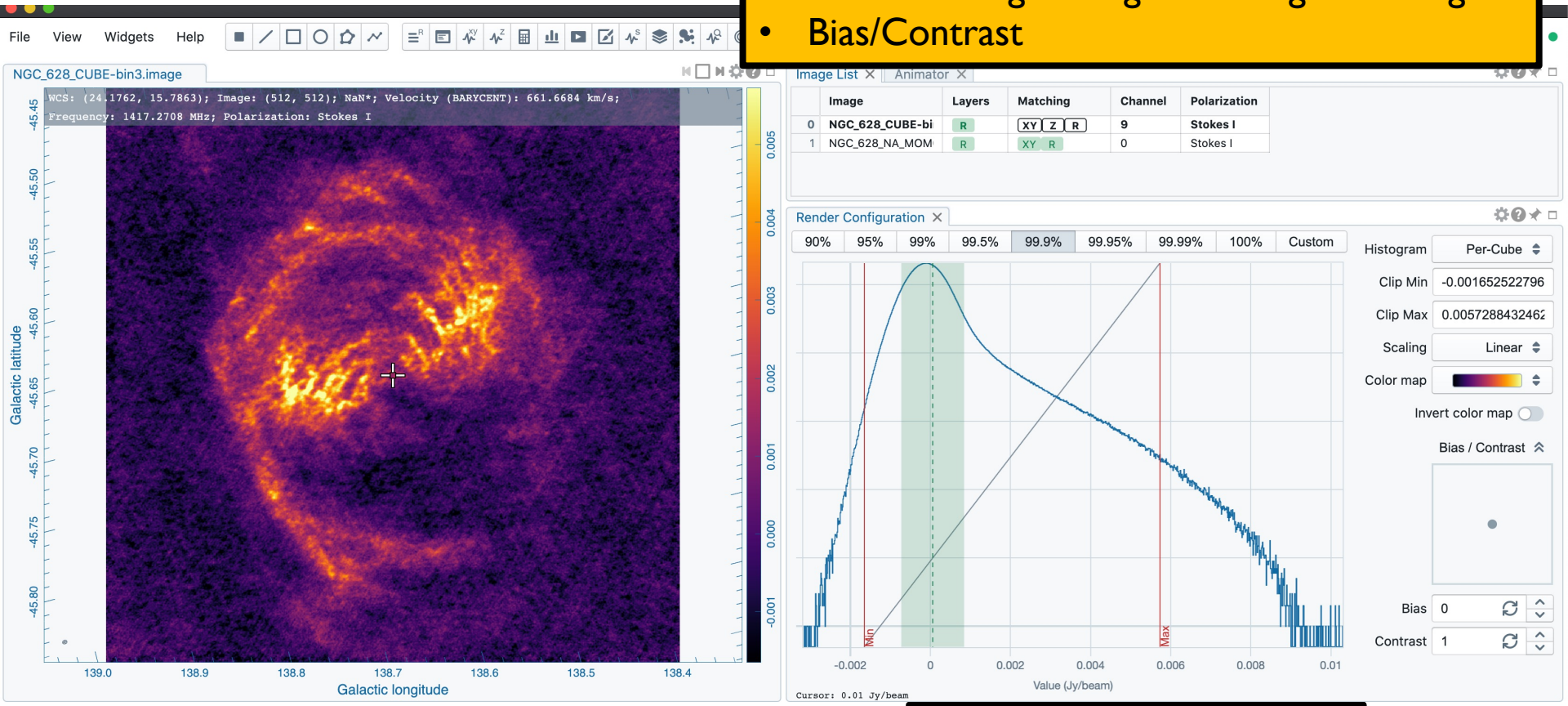


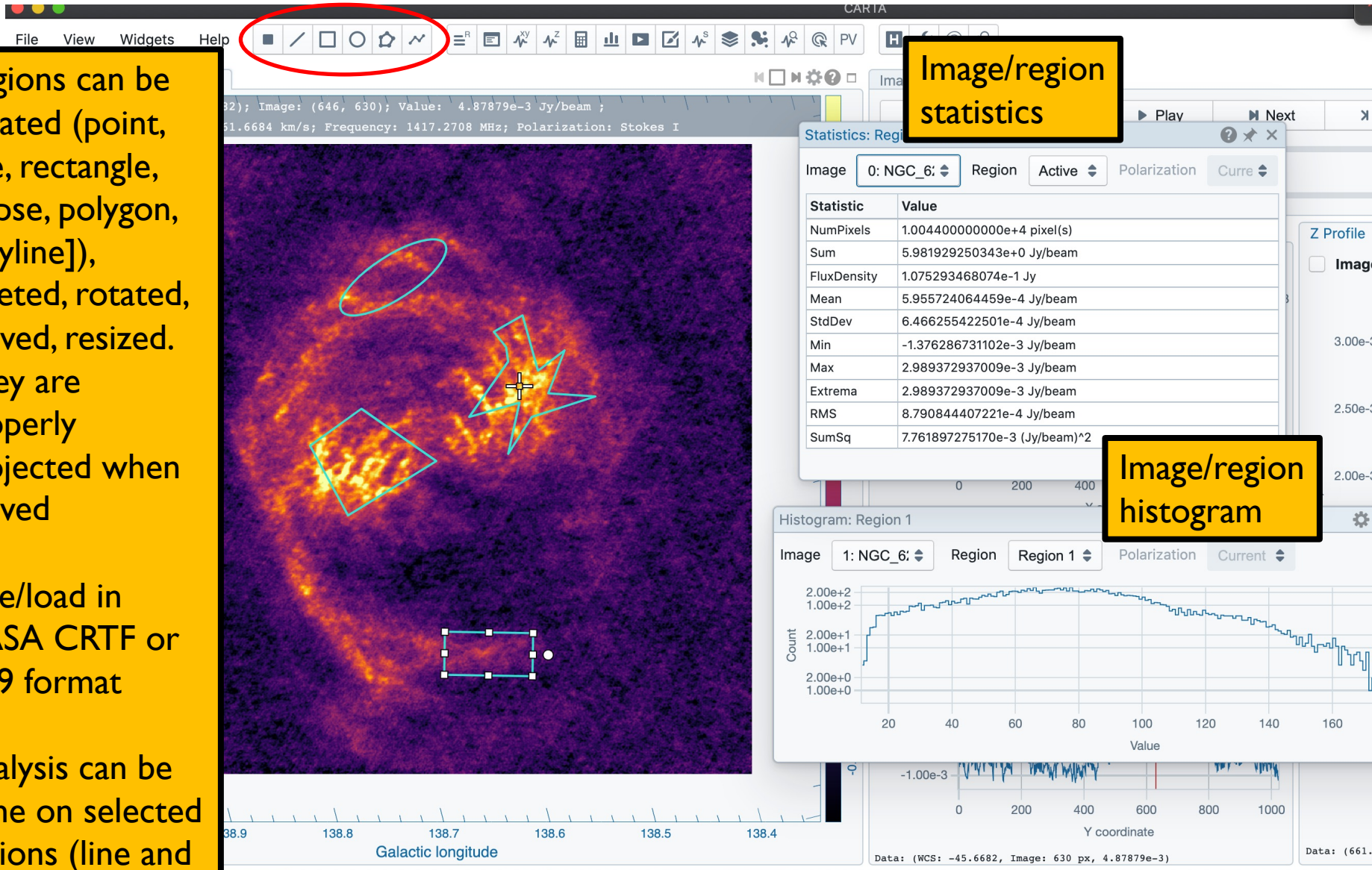
Image statistics, setting the cuts manually or by percentage or by values

Regions

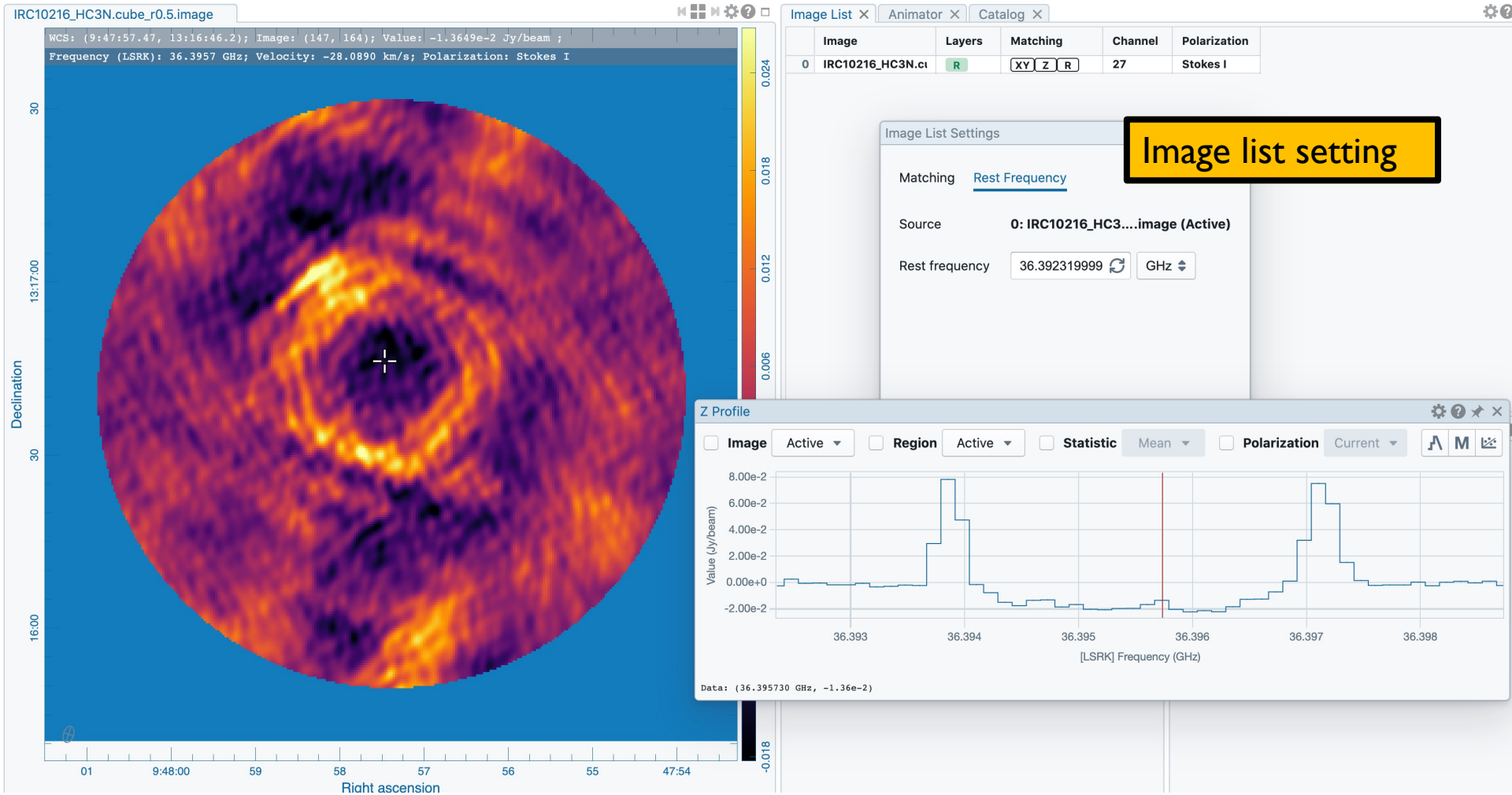
Regions can be created (point, line, rectangle, ellipse, polygon, polyline]), deleted, rotated, moved, resized. They are properly projected when moved

Save/load in CASA CRTF or DS9 format

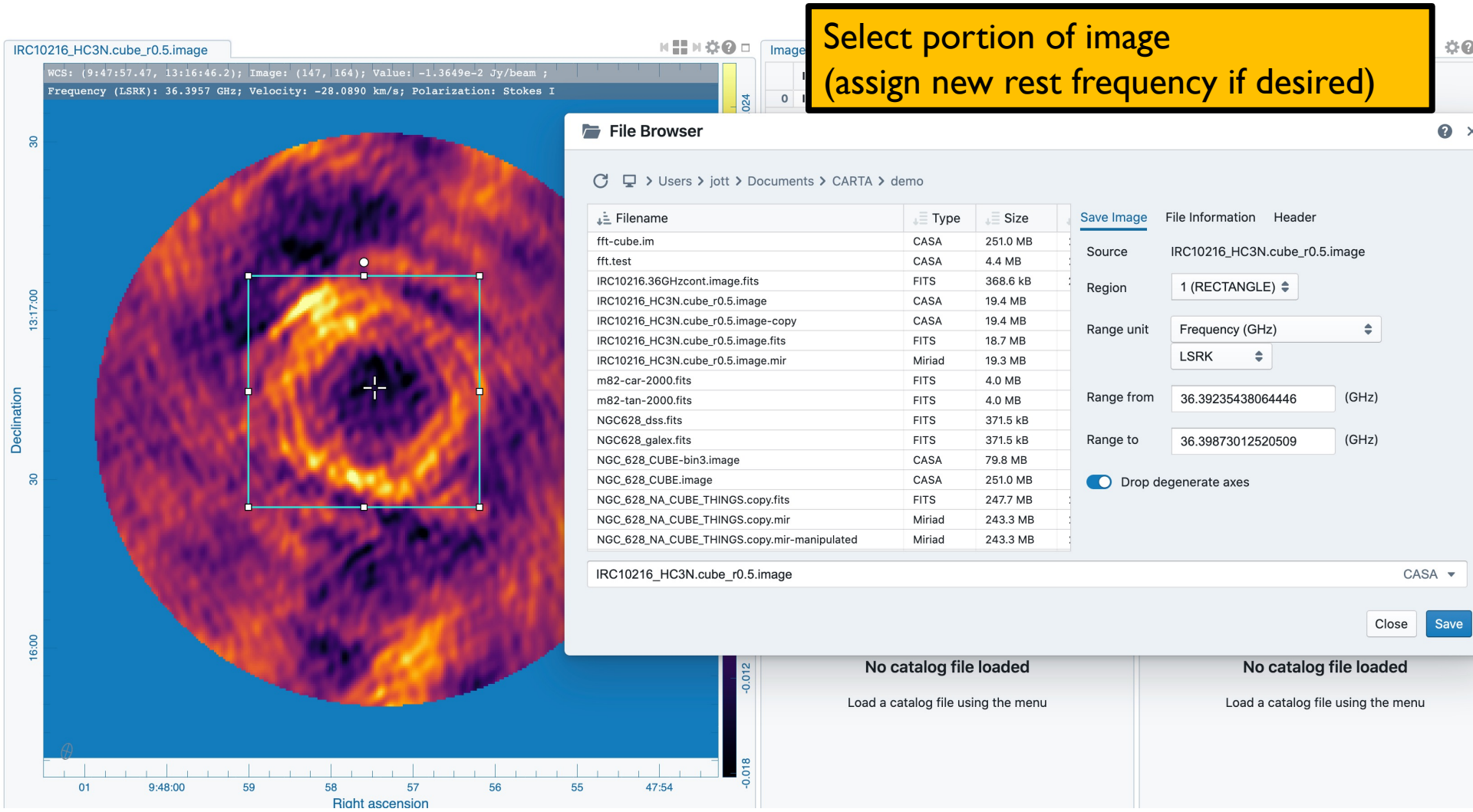
Analysis can be done on selected regions (line and polyline for profiles, pV)



Set new rest frequency

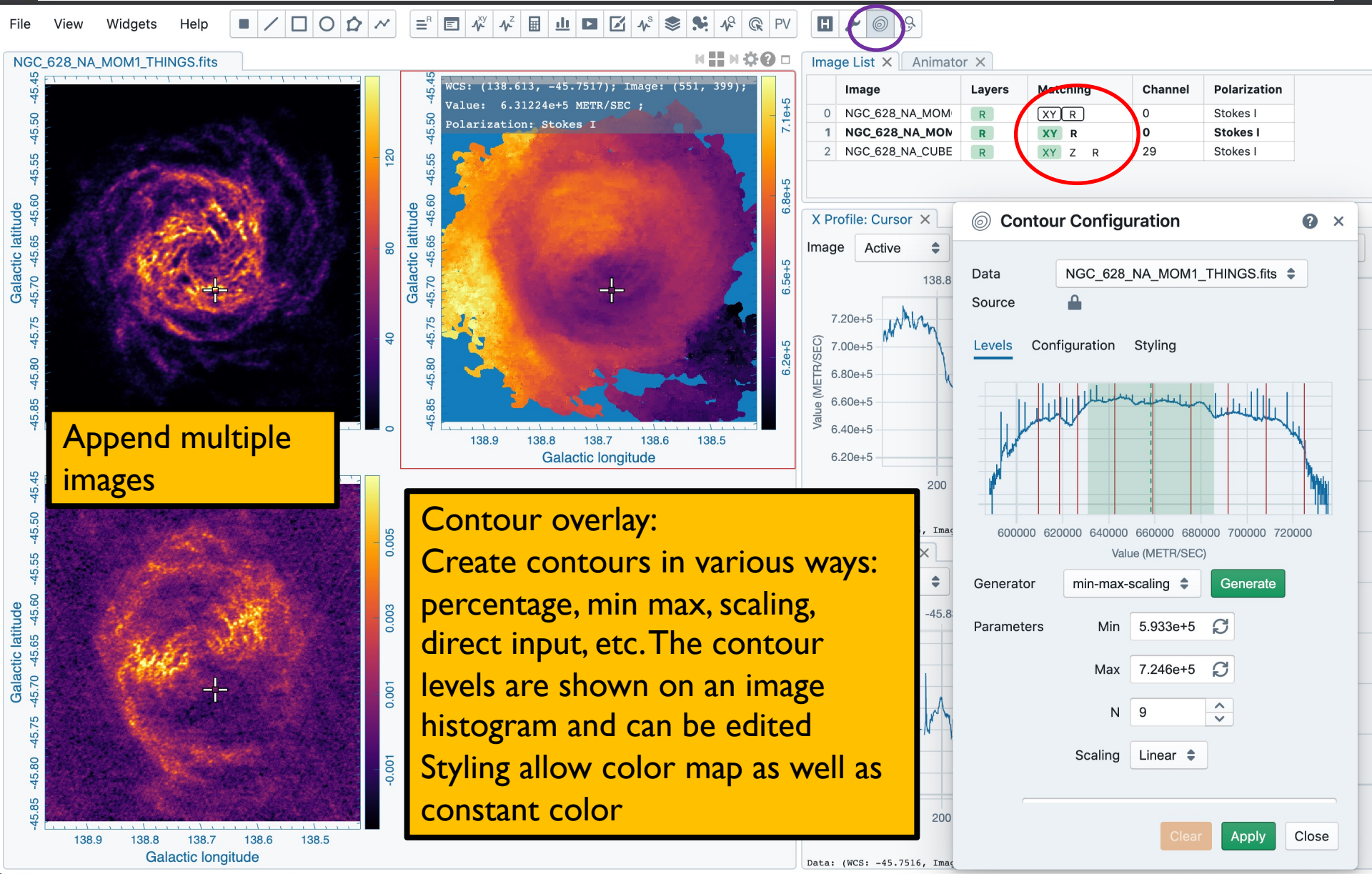


Saving subimages



Contours

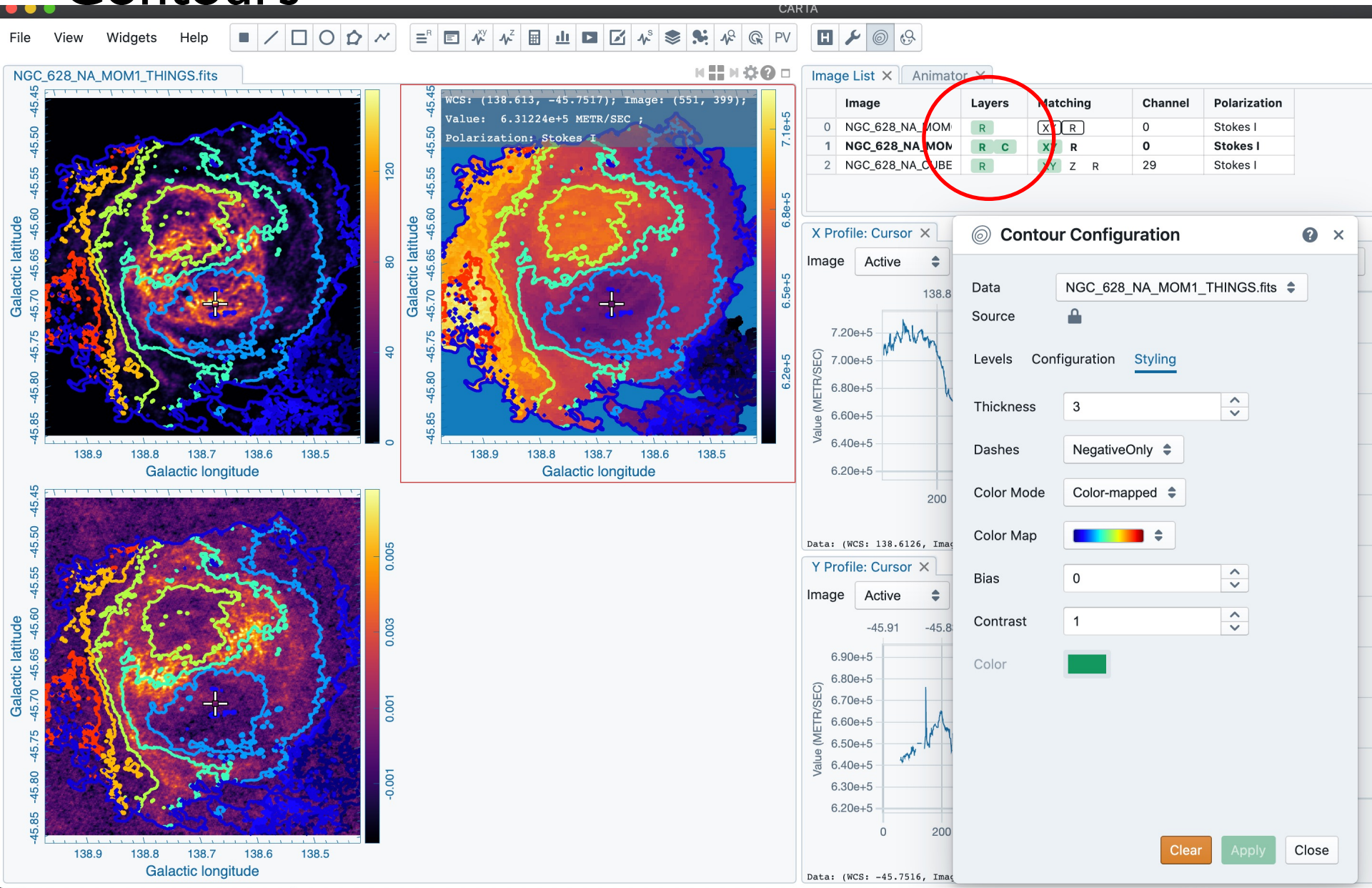
- Match the coordinates for multiple images



Append multiple images

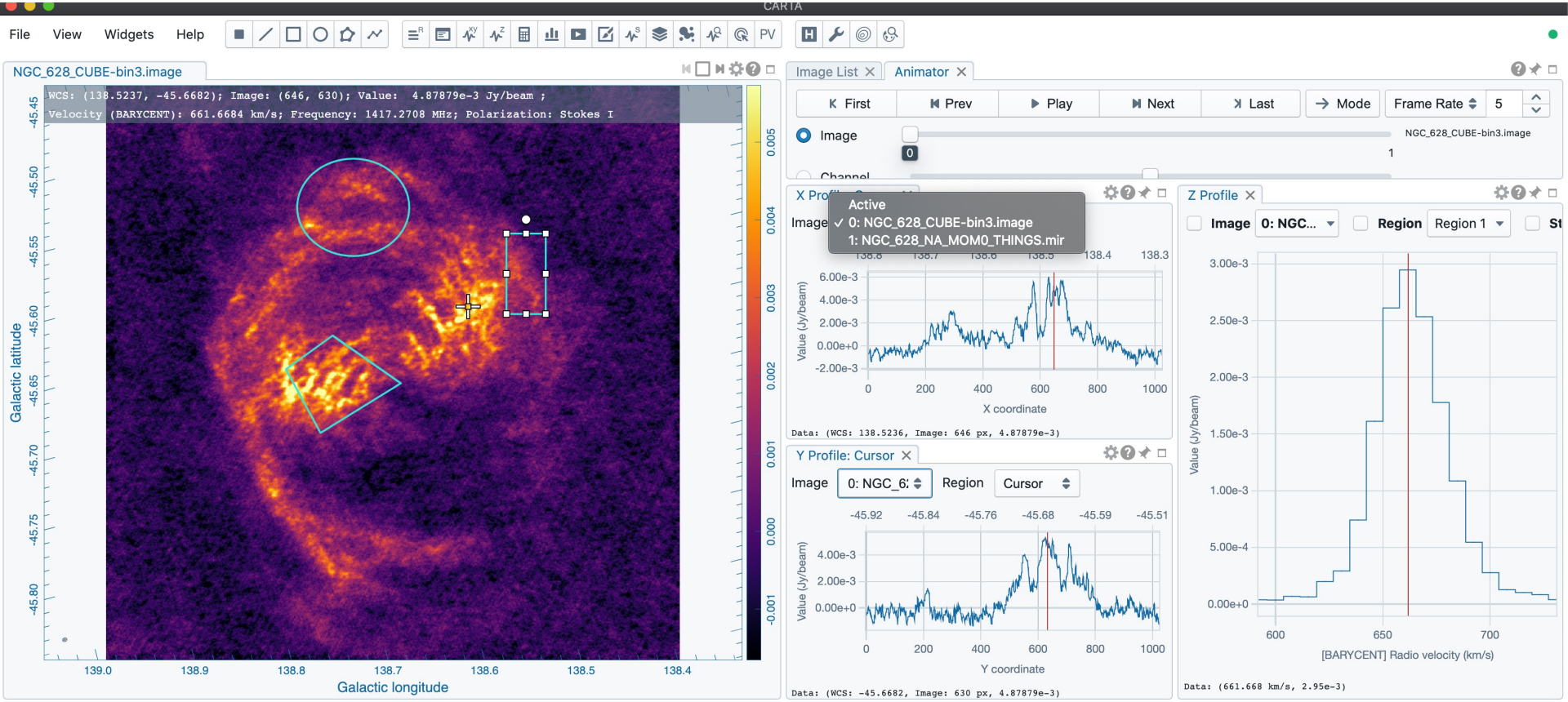
Contour overlay:
Create contours in various ways: percentage, min max, scaling, direct input, etc. The contour levels are shown on an image histogram and can be edited
Styling allow color map as well as constant color

Contours

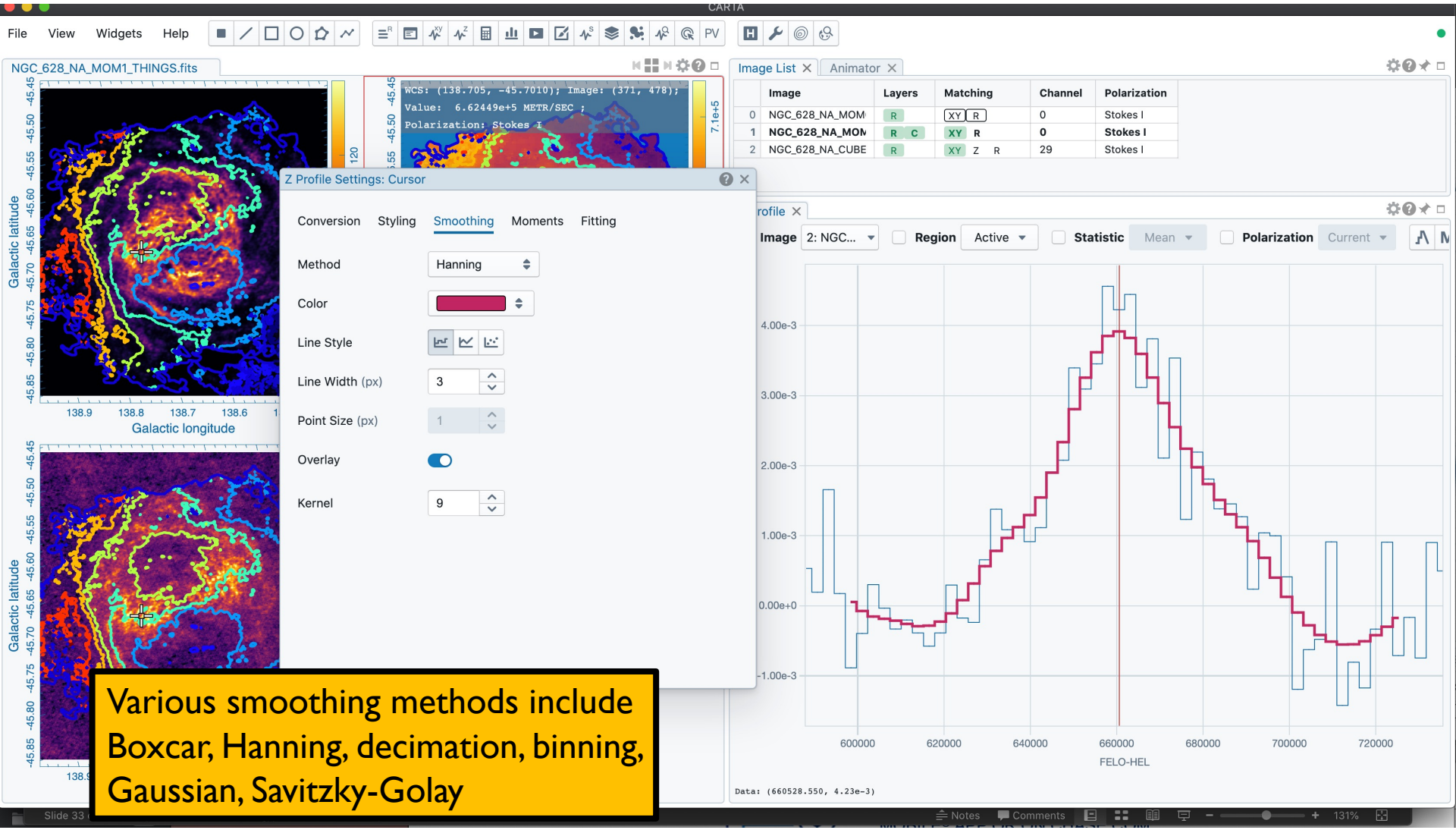

CARTA
File
View
Widgets
Help
NGC_628_NA_MOM1_THINGS.fits
WCS: (138.613, -45.7517); Image: (551, 399);
Value: 6.31224e+5 METR/SEC ;
Polarization: Stokes I
Galactic latitude
Galactic longitude
Image List
Animator
Image
Layers
Matching
Channel
Polarization
0 NGC_628_NA_MOM R 0 Stokes I
1 NGC_628_NA_MOM R C R 0 Stokes I
2 NGC_628_NA_CUBE R Z R 29 Stokes I
X Profile: Cursor
Y Profile: Cursor
Value (METR/SEC)
Contour Configuration
Data
NGC_628_NA_MOM1_THINGS.fits
Source
Levels
Configuration
Styling
Thickness
3
Dashes
NegativeOnly
Color Mode
Color-mapped
Color Map
Bias
0
Contrast
1
Color
Clear
Apply
Close
Slide 30 of 45
English (United States)
Accessibility: Investigate
Notes
Comments

Profiles

- Spatial/Spectral profile: Line shape can be changed (color, steps/connect/points), spectral smoothing; data can be saved as ascii
- Marker is the position of the cursor/animator (freeze with 'f')
- Selection of region and image in each widget
- For spectral profile, regions can be selected, as well as statistics, axis labels (velocity, frequency, channel, wavelength, ..)
- 3D Position is marked by a red vertical line

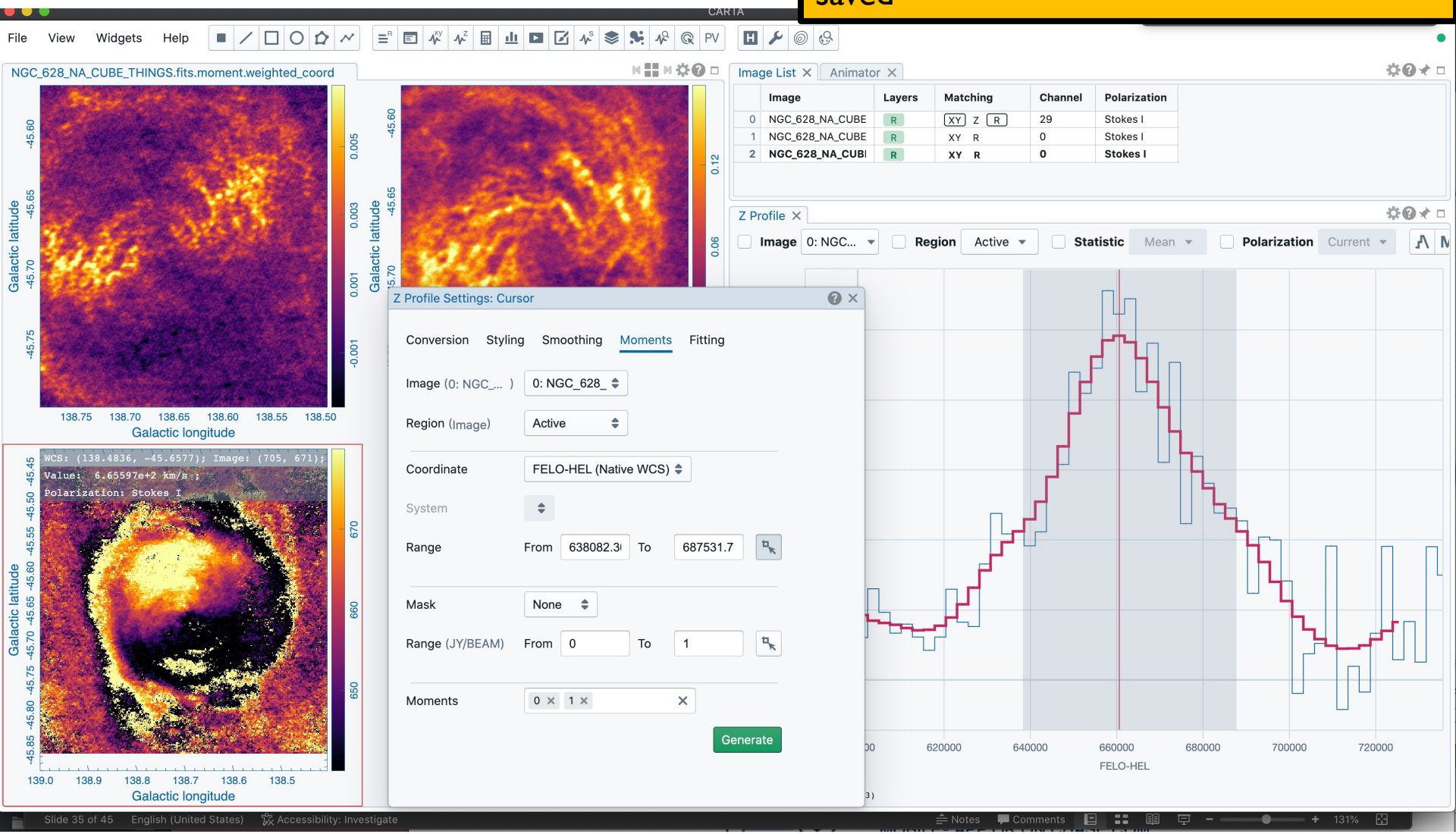


Spectral smoothing



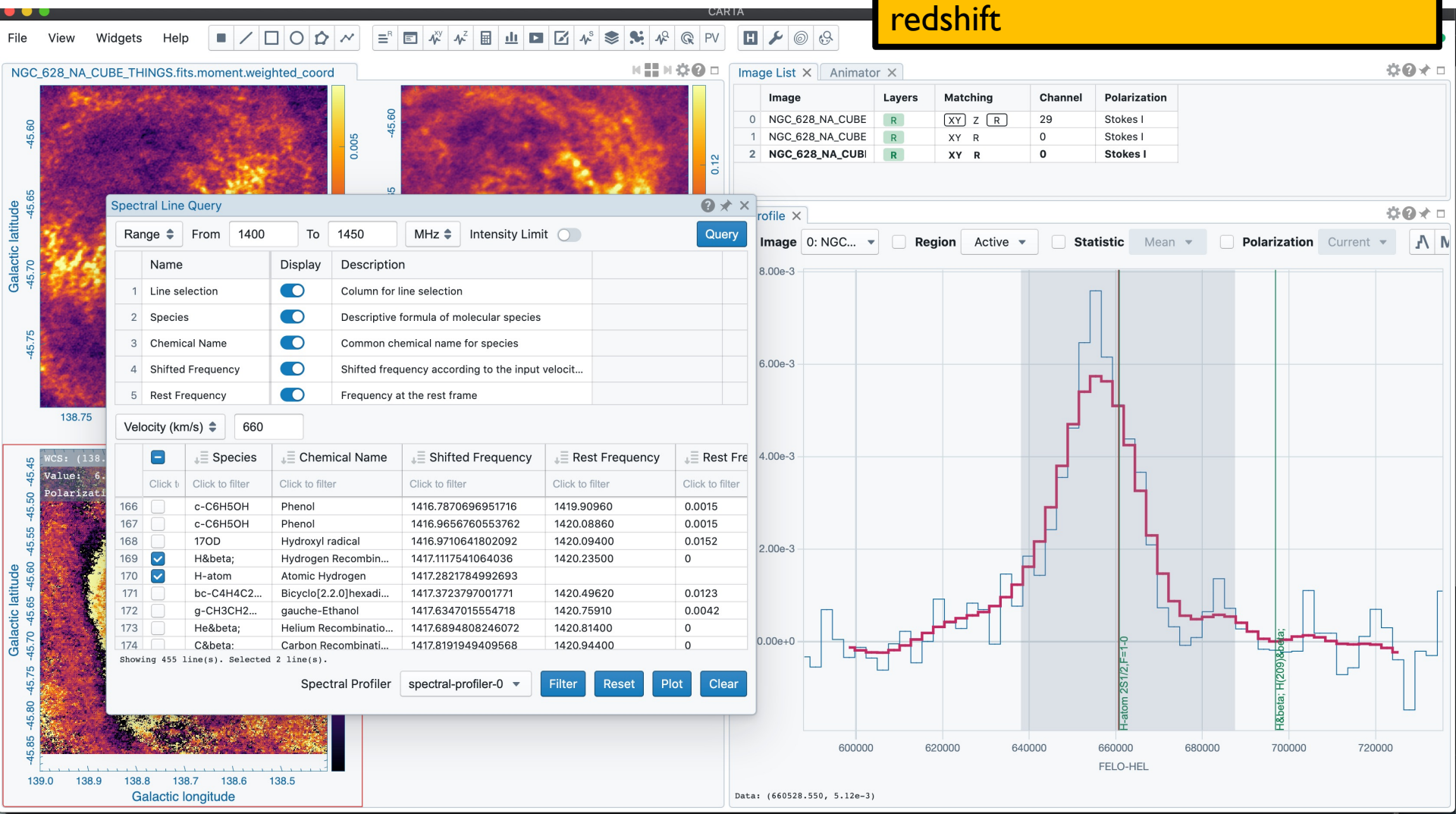
Moment maps

Spectral selection can be done interactively, including clip. Images can be saved



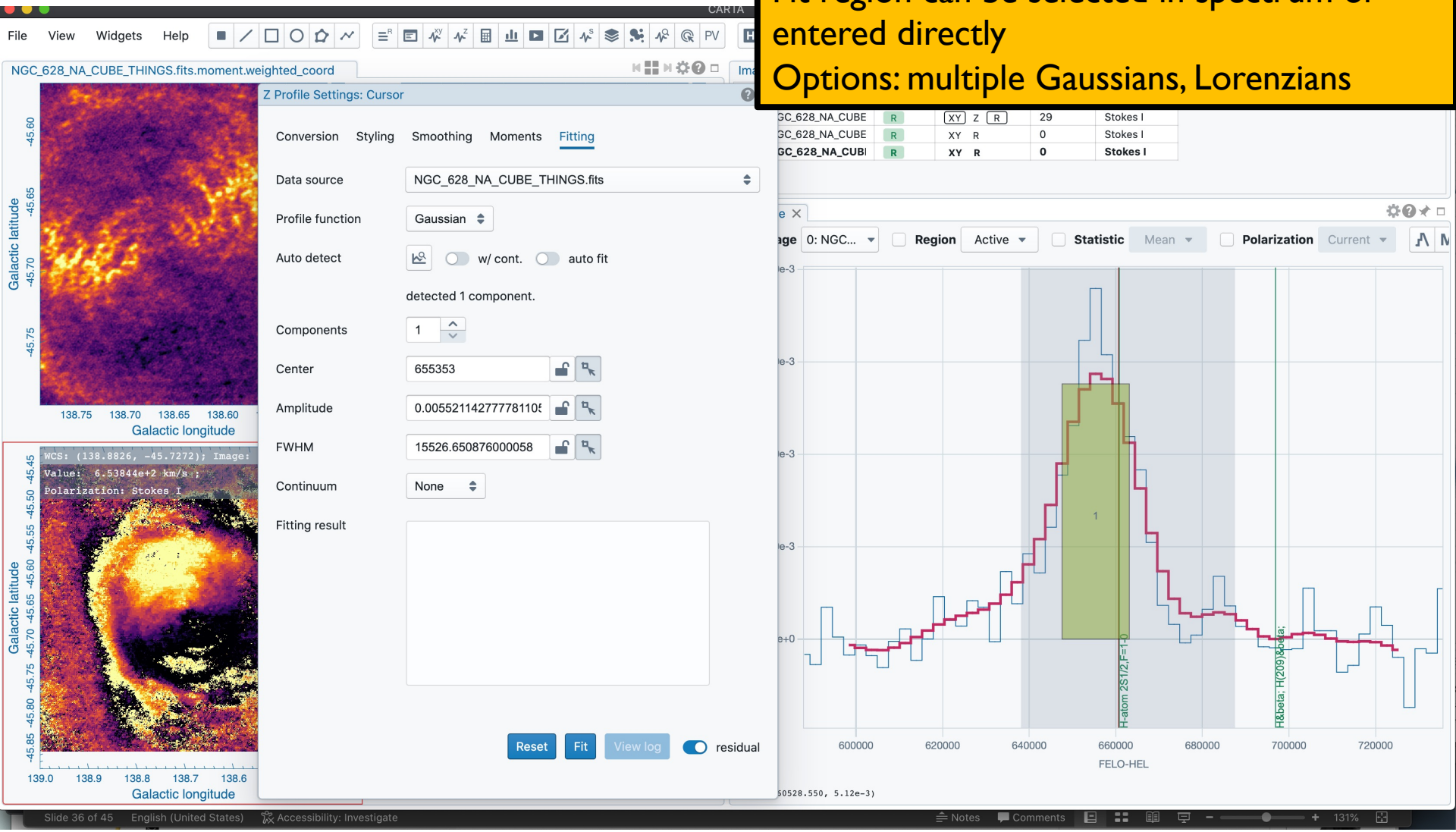
Spectral line labeling

Based on splatalogue, select line strength, frequency range and redshift



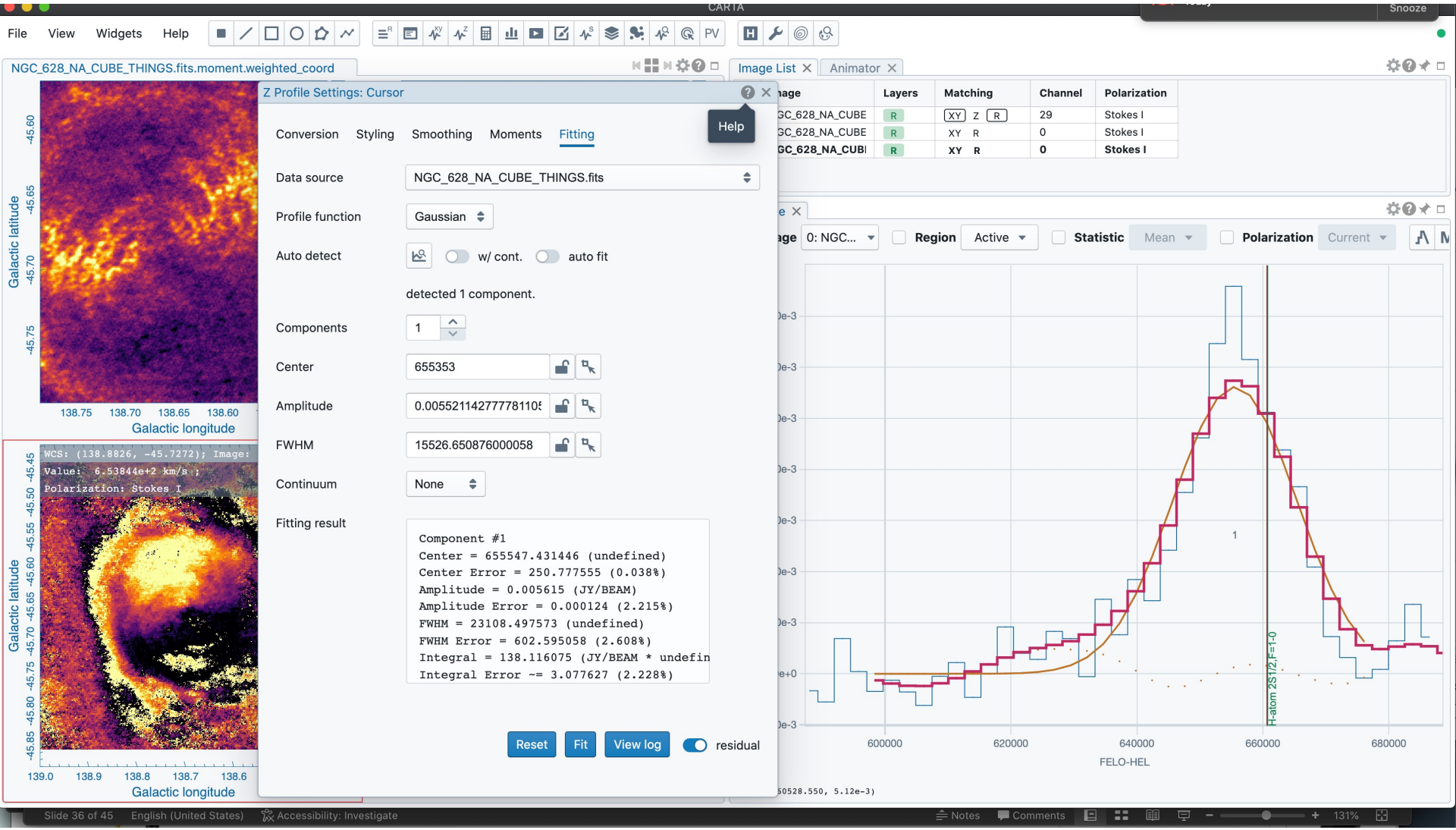
Spectral Line Fitting

Autodetection of line for initial fitting parameters (can also be set manually).
Fit region can be selected in spectrum or entered directly
Options: multiple Gaussians, Lorenzians



Spectral Line Fitting

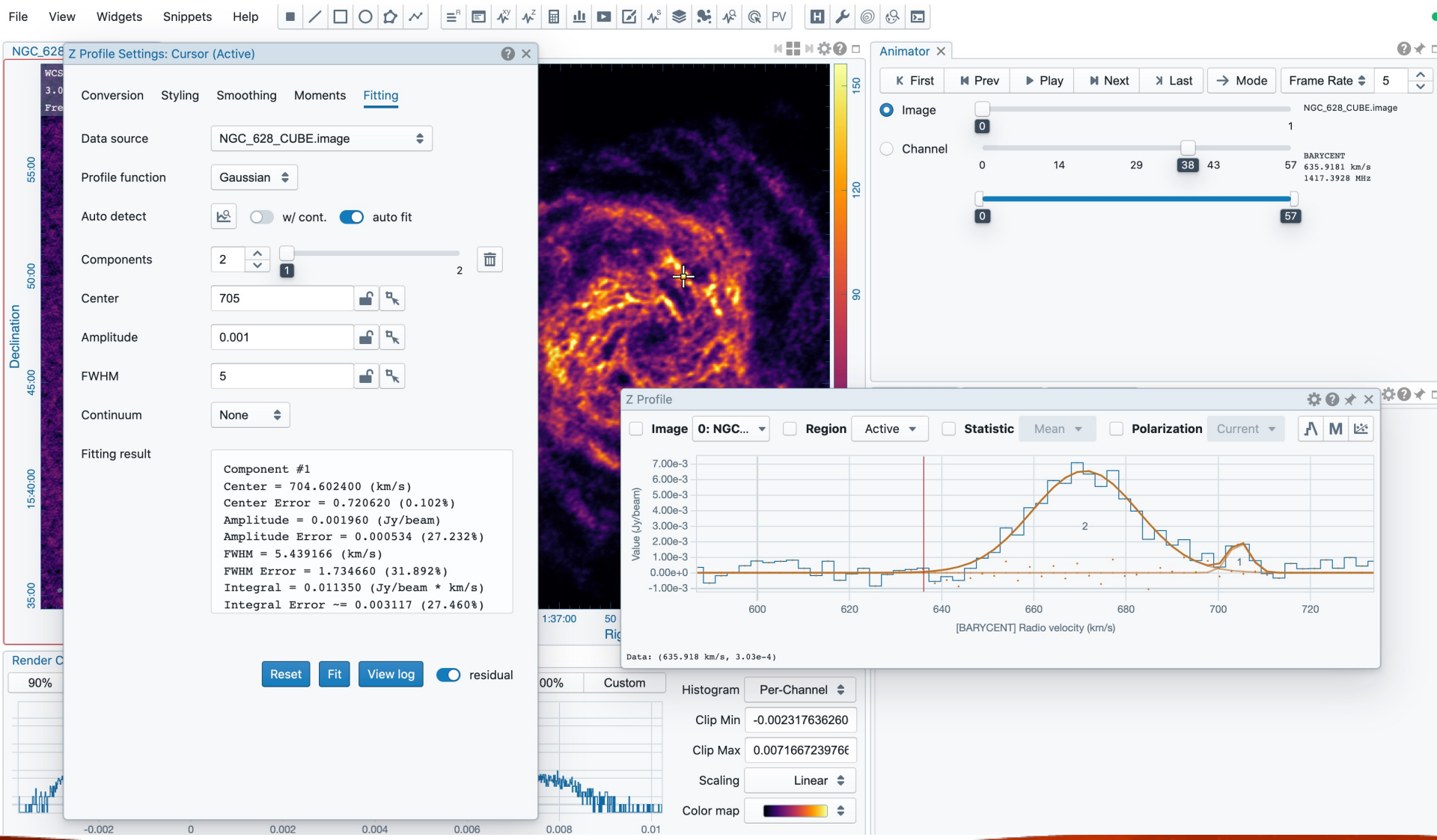
Fit results can be copied/pasted



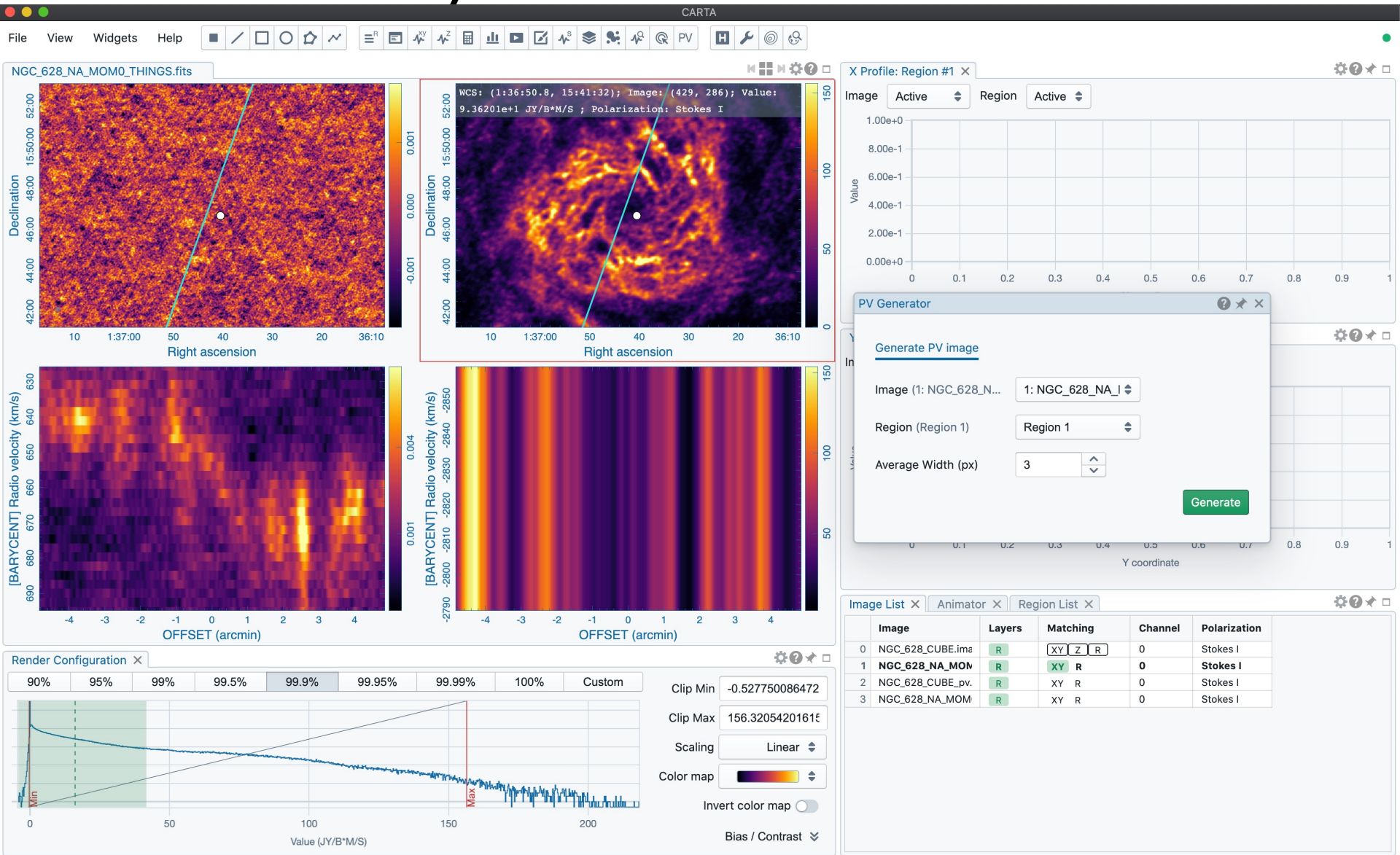
CARTA v3 (2022)

Spectral Line Fitting

Multiple Gaussians

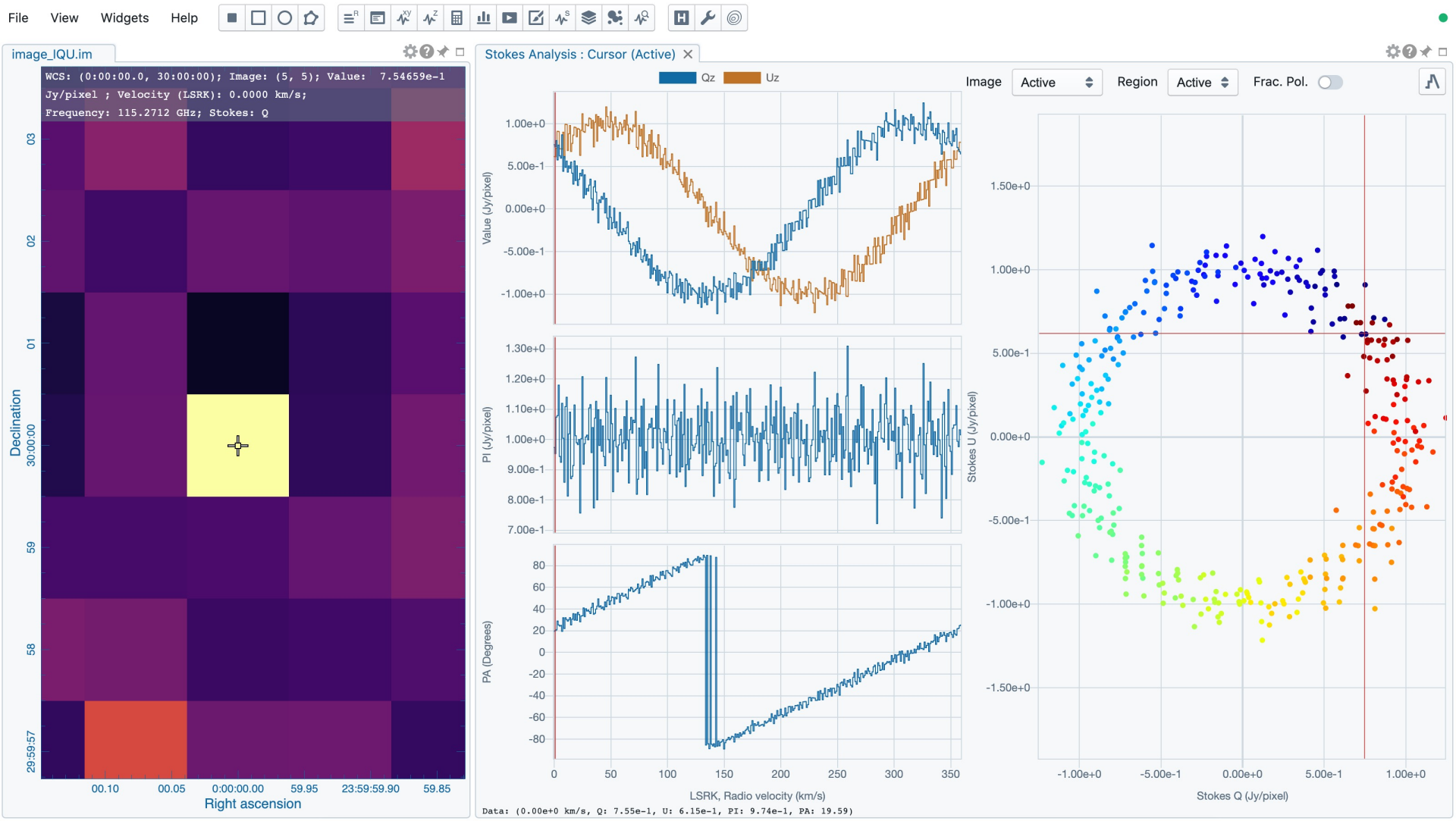


Position-Velocity

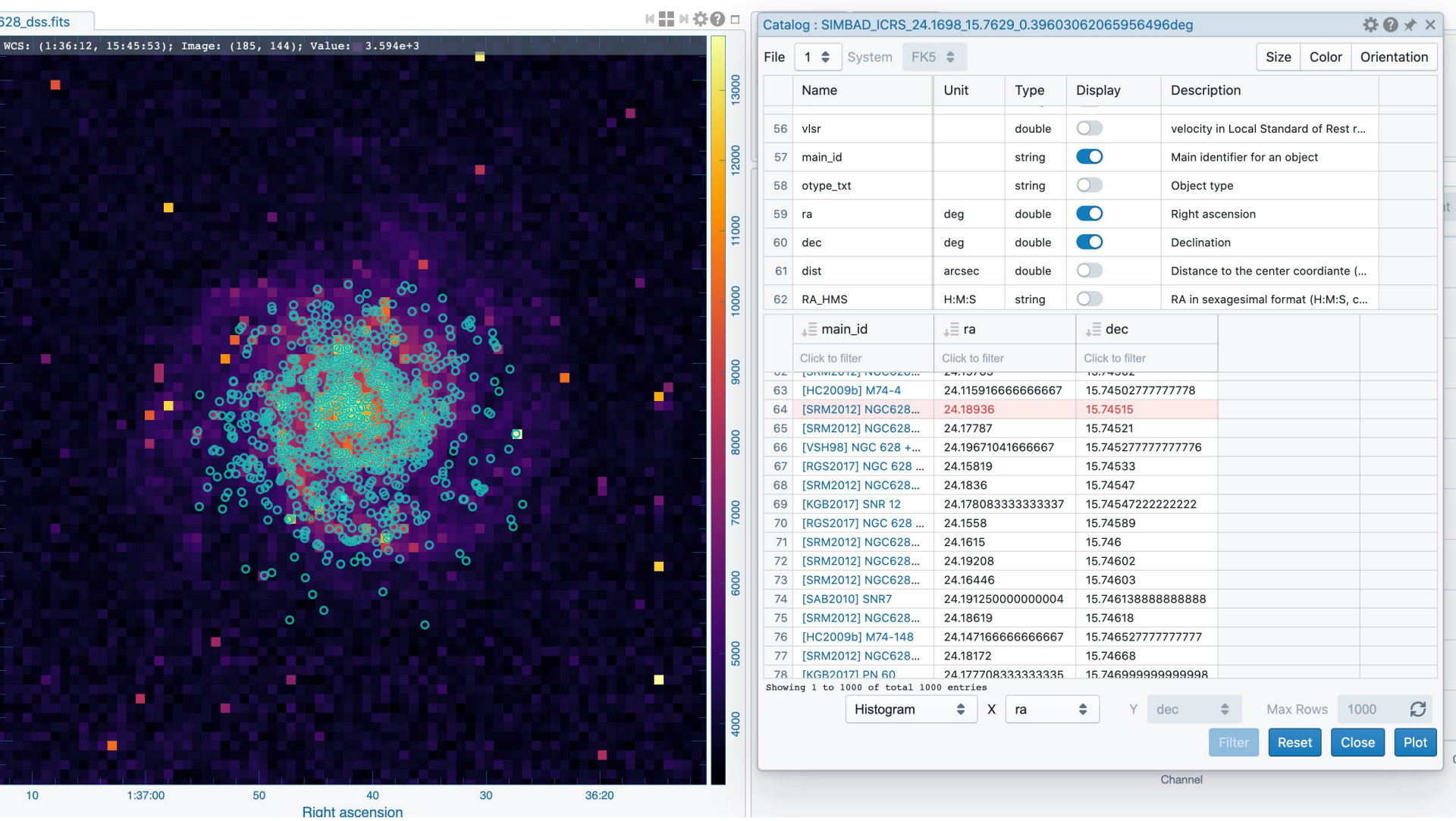


CARTA v3 (2022)

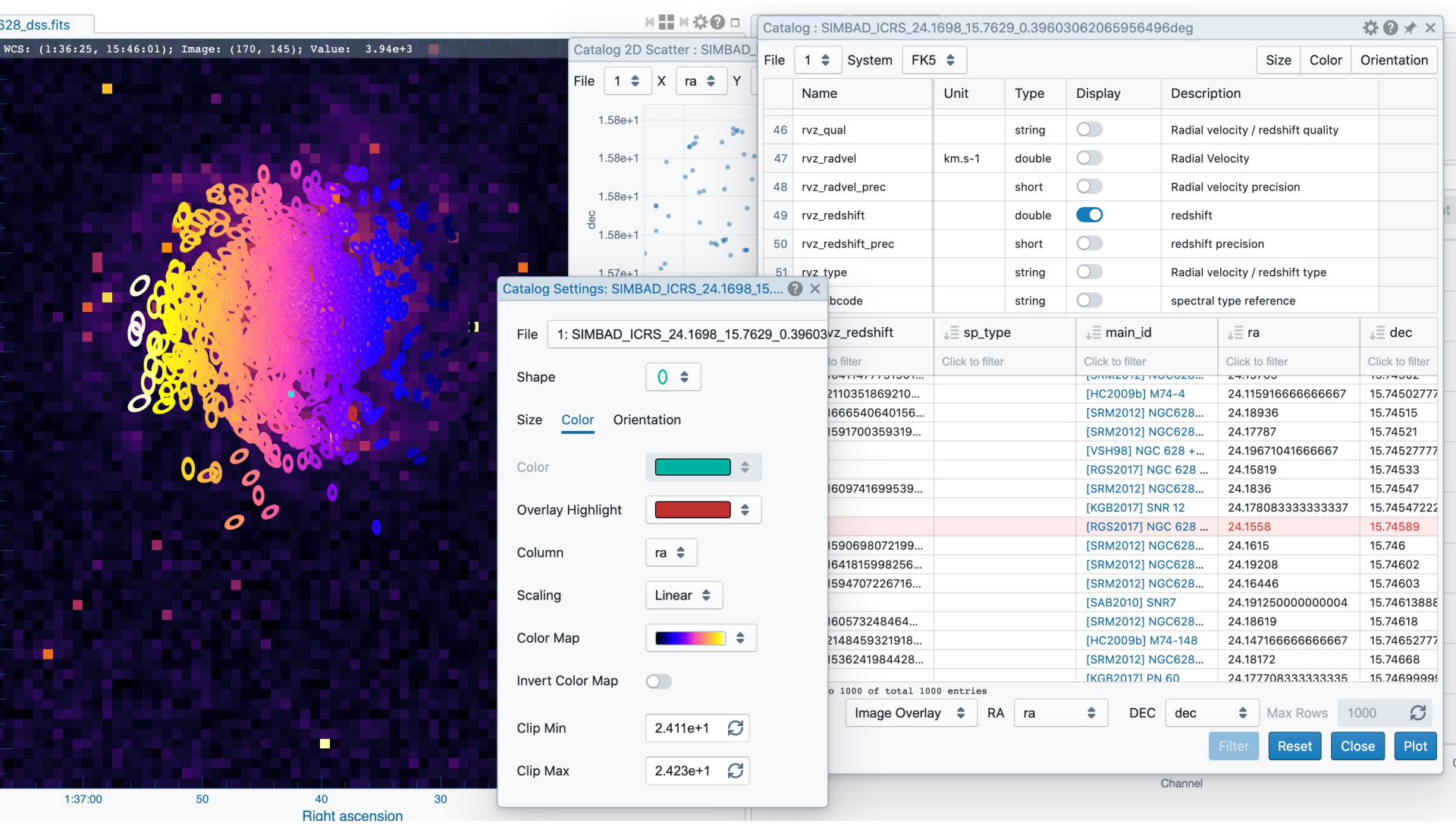
CARTA – Stokes Analysis Widget



CARTA – Catalog tool

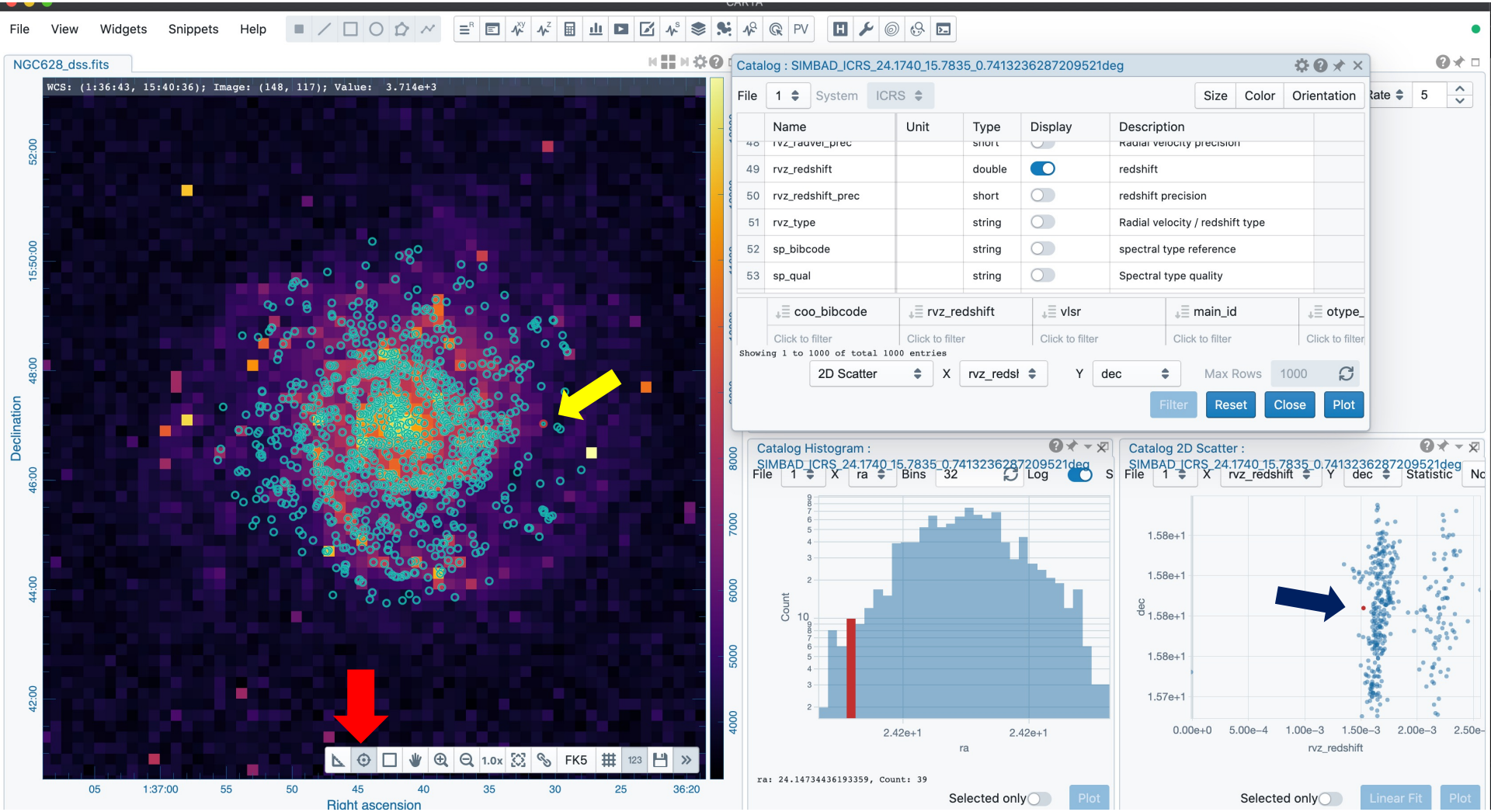


CARTA – Catalog tool

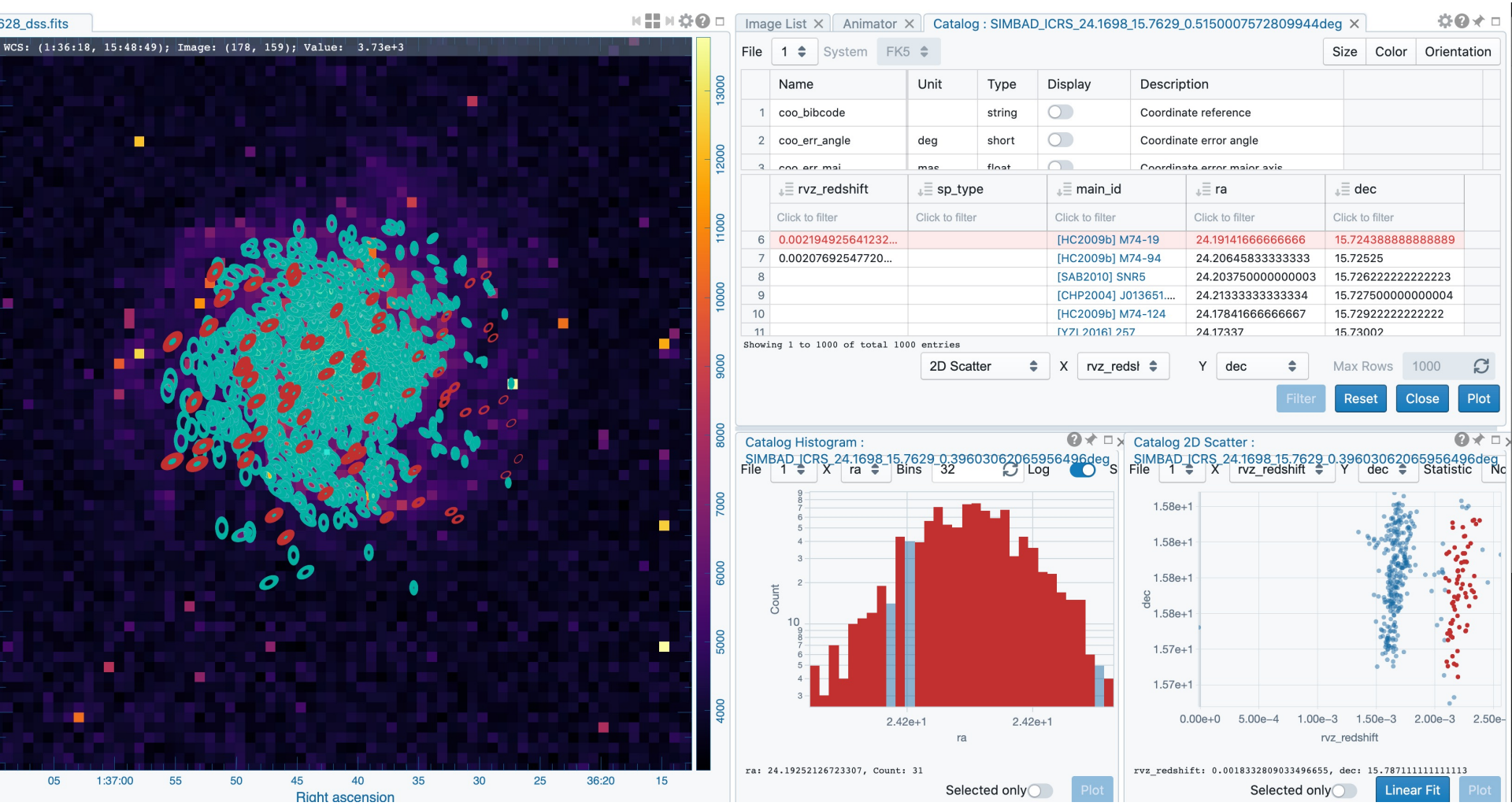


CARTA v3 (2022)

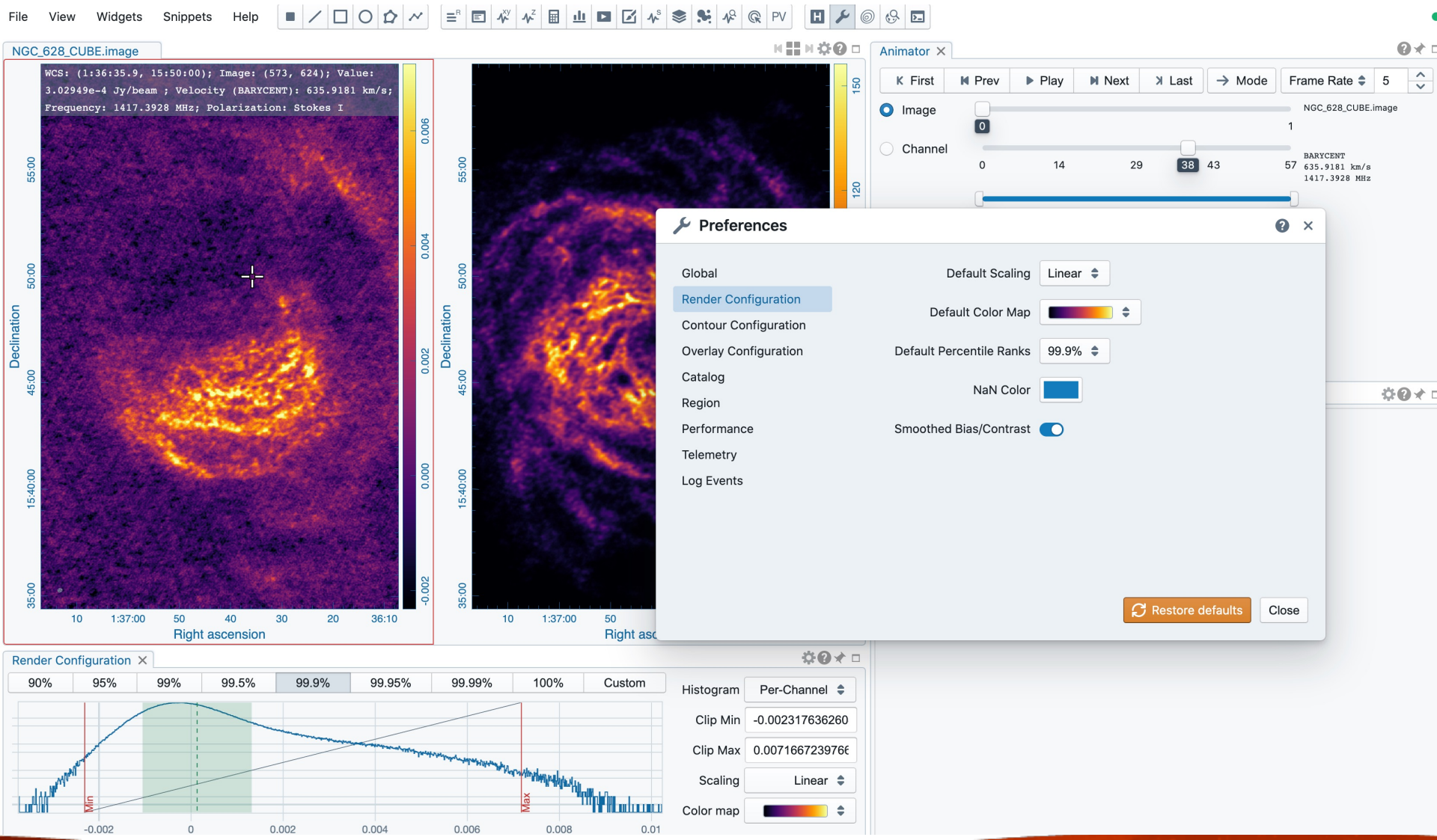
CARTA – Catalog tool



CARTA – Catalog tool

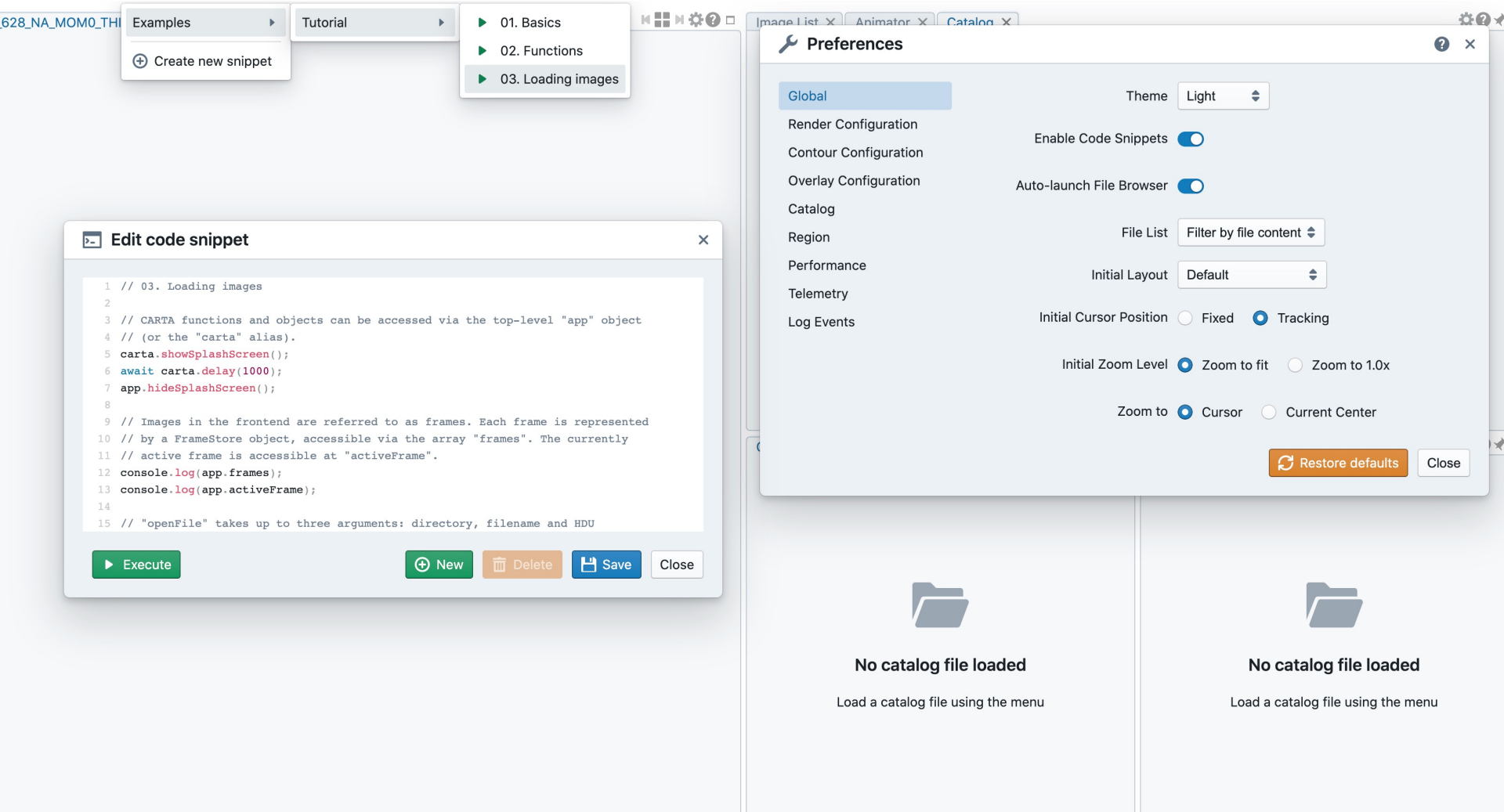


Preferences

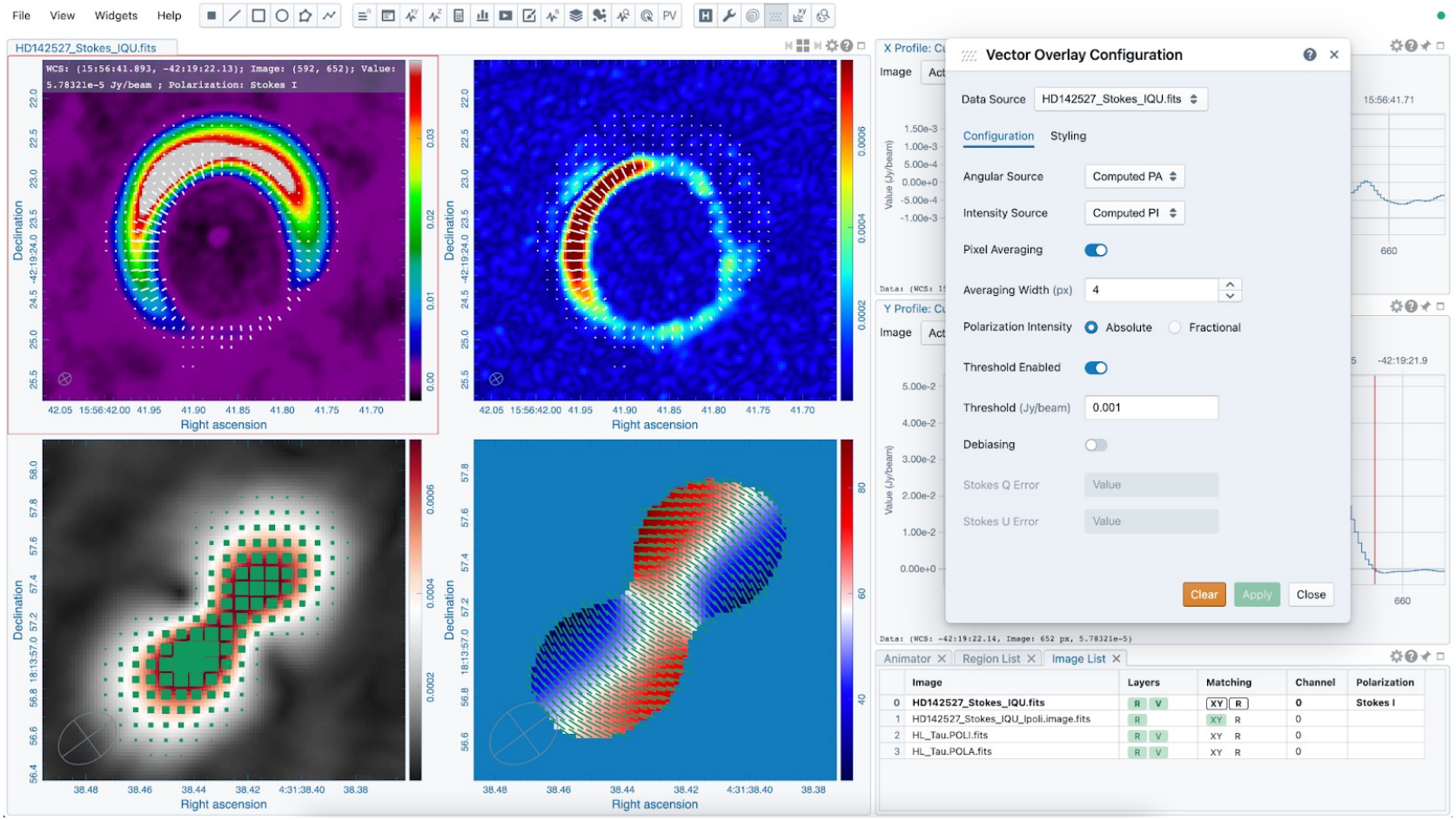


CARTA v3 (2022)

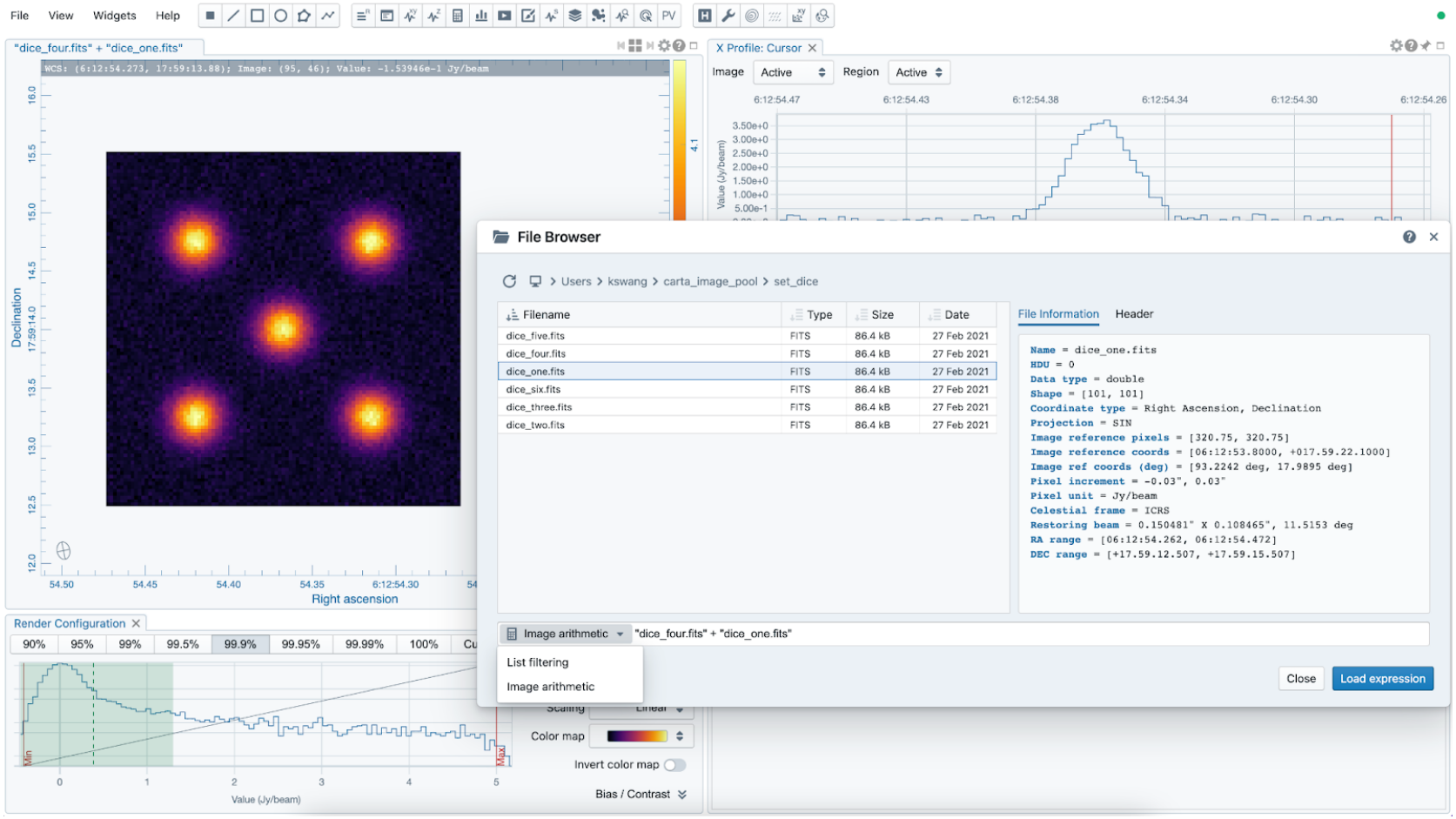
Python scripting in progress/Code snippet



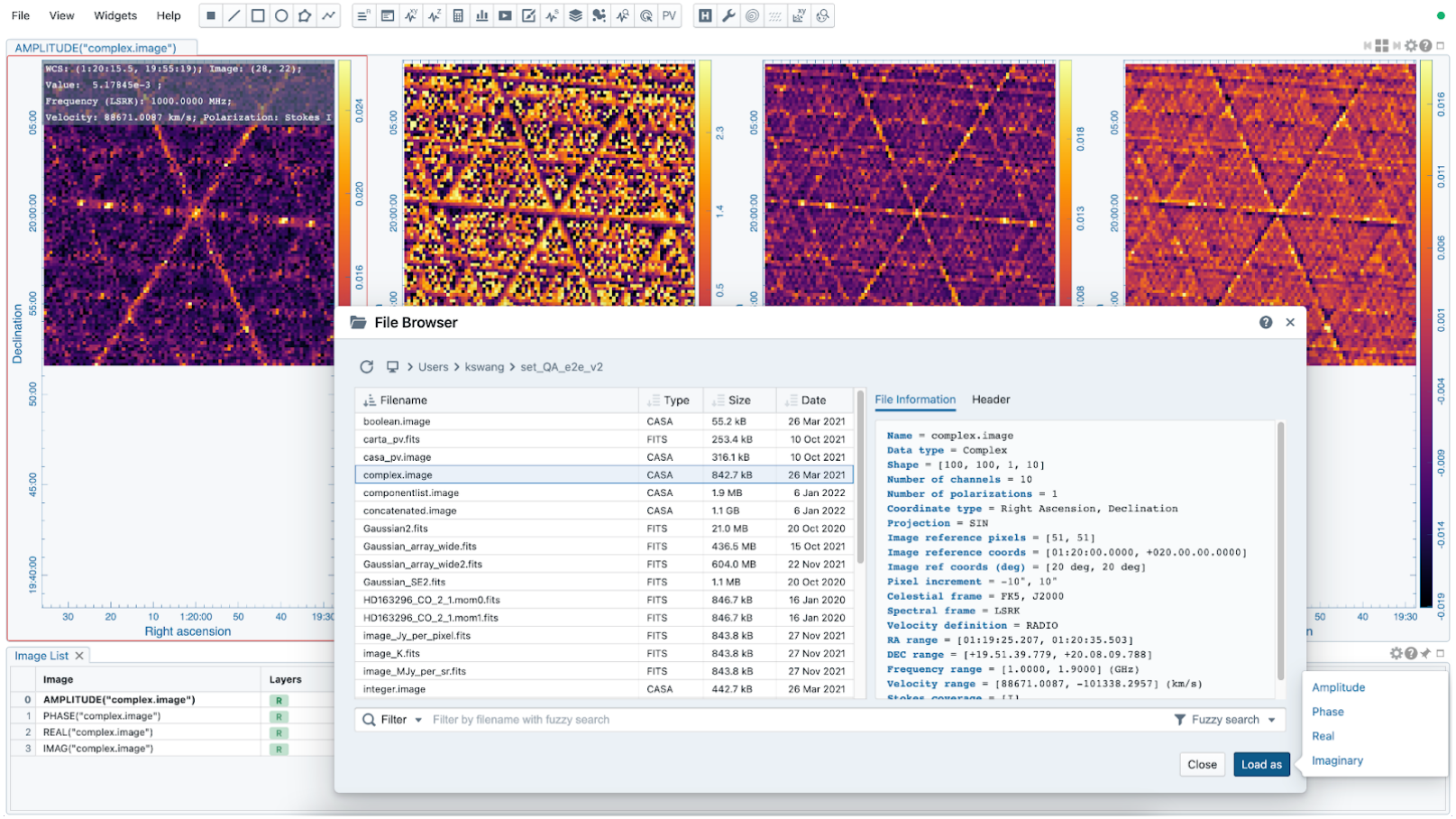
Vector field rendering



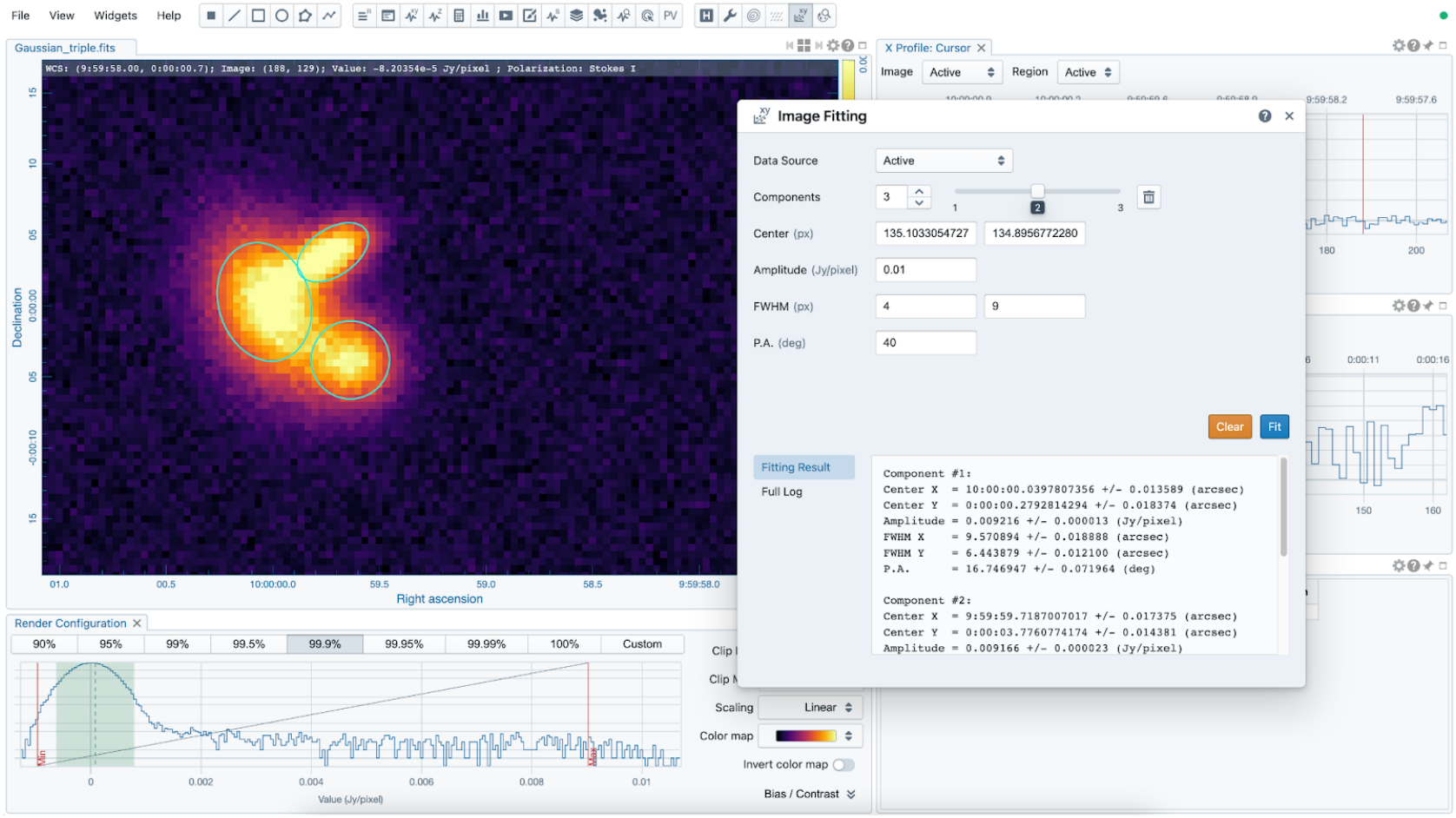
LEL image loading (mathematical expressions)



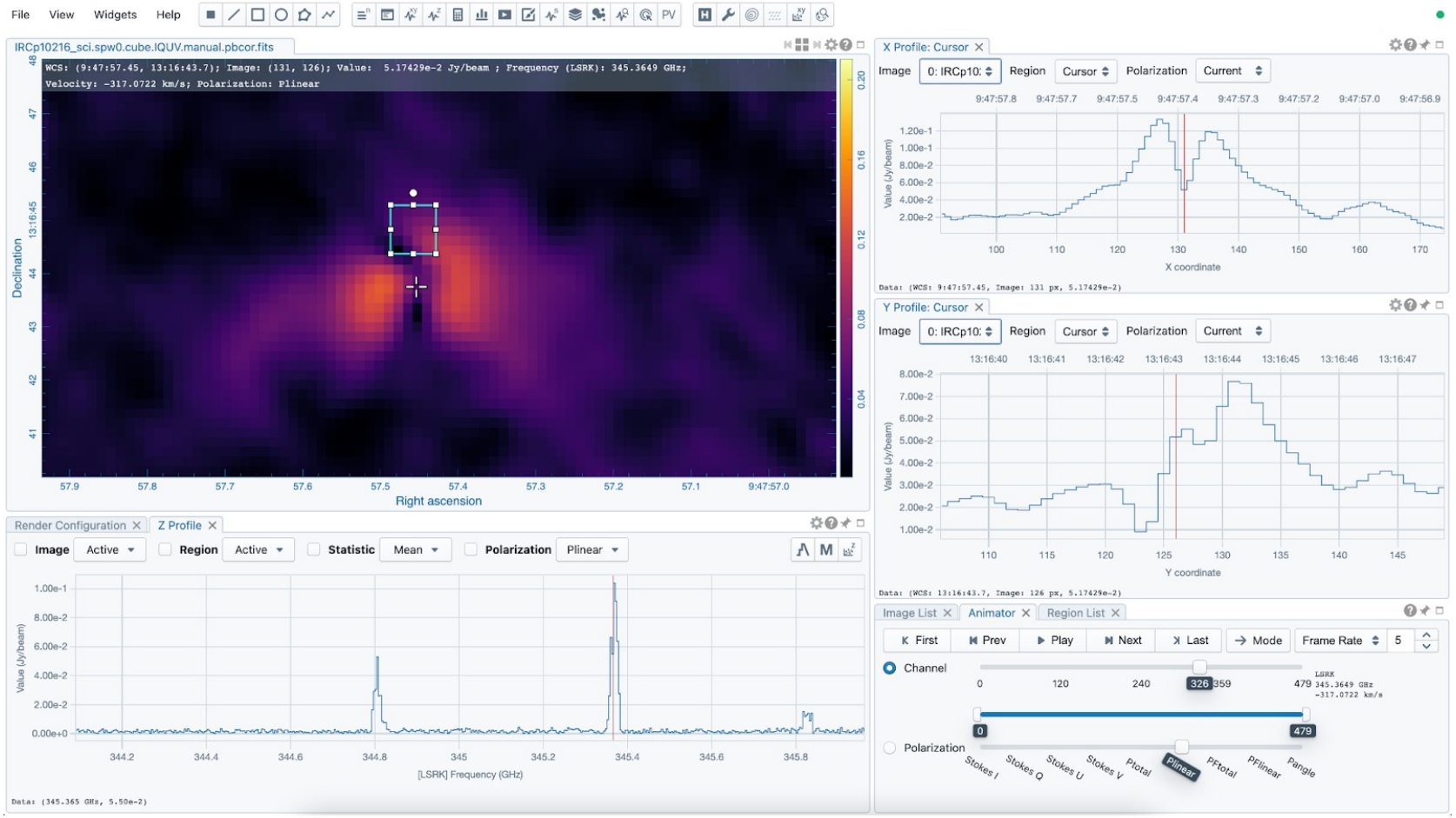
Complex-valued images



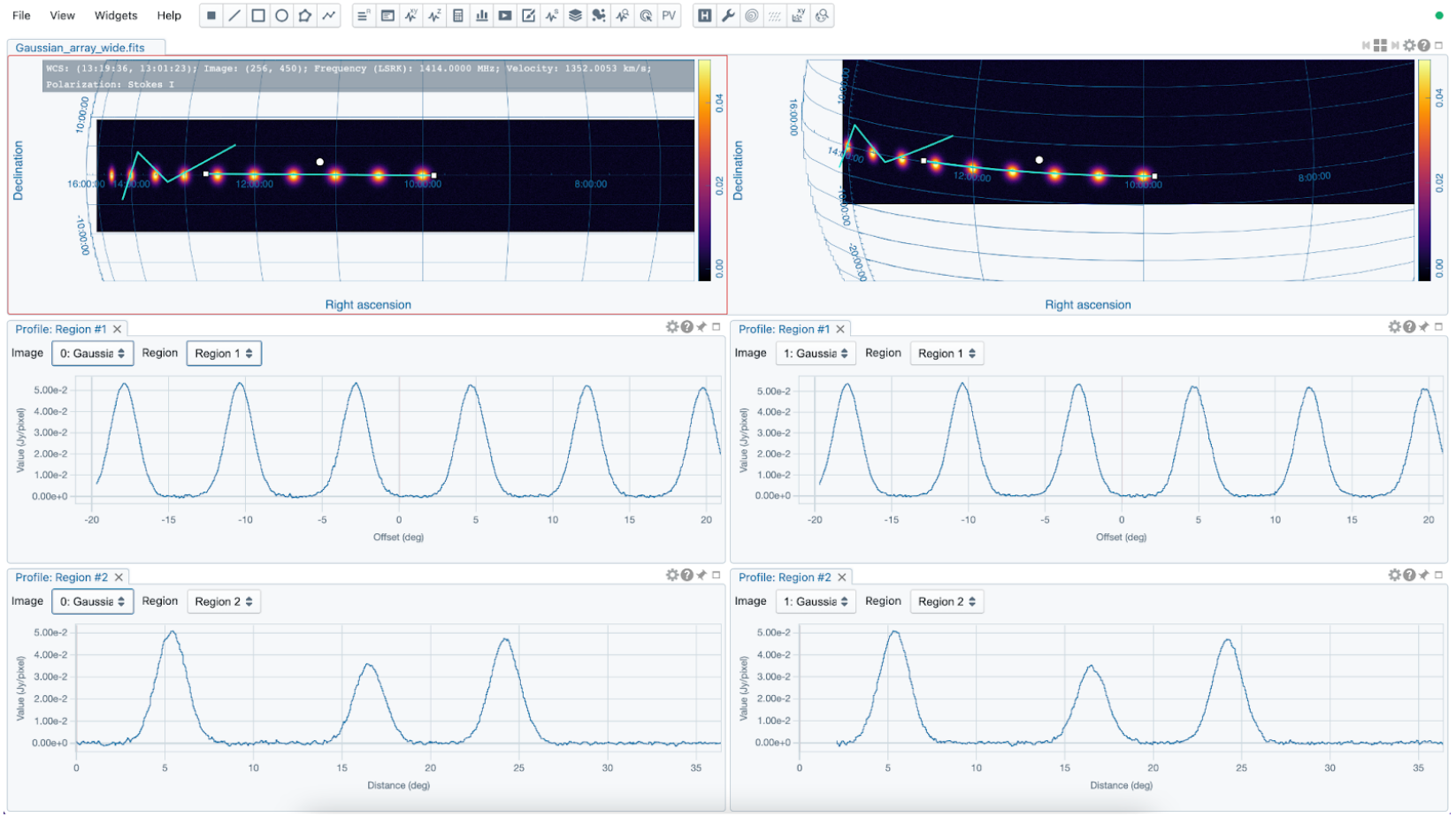
2D Gaussian Fitting



Calculation of polarization quantities (like linear polarization intensity, polarization angle) from Stokes IQUV cube

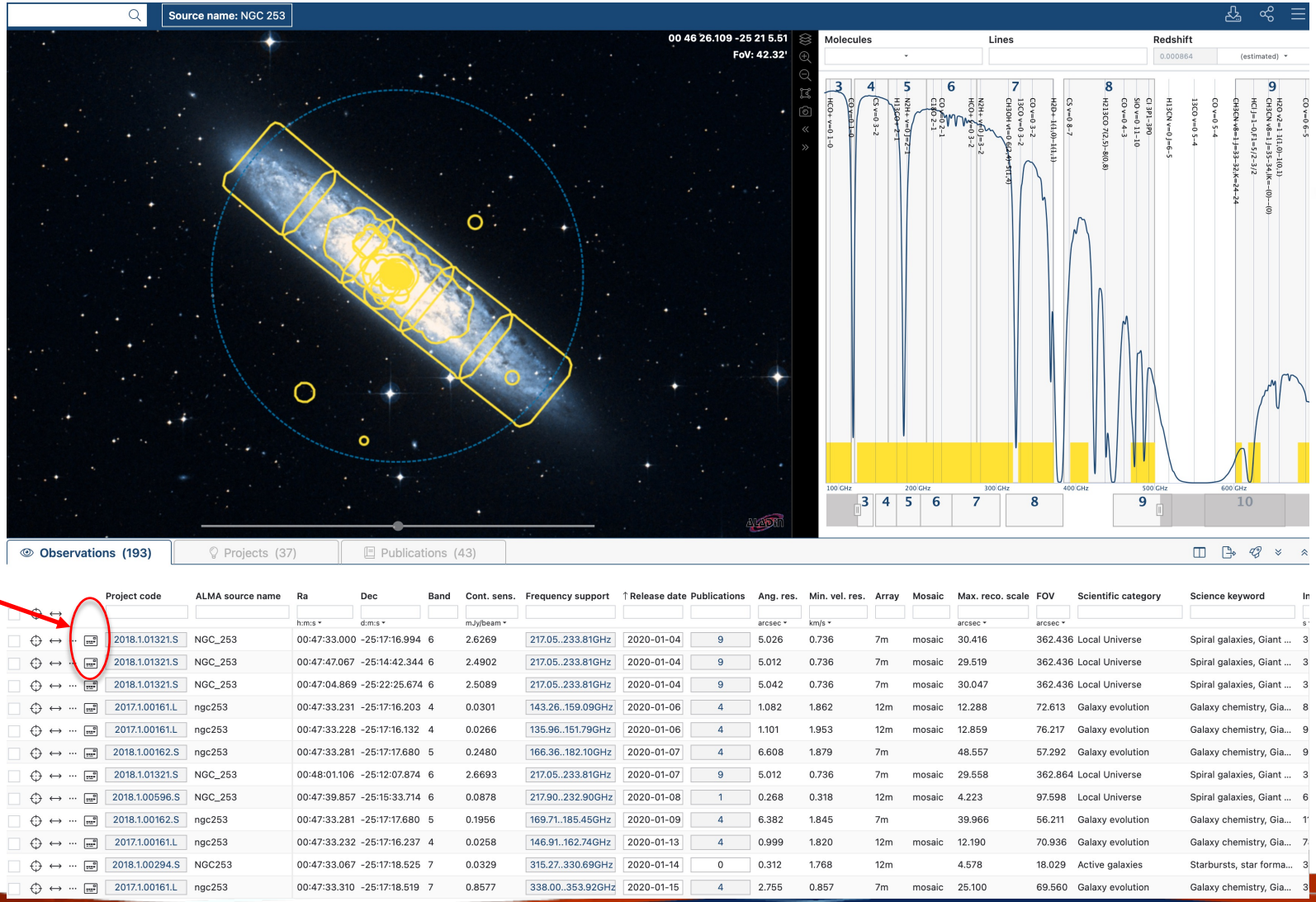


Line and Polyline spatial profiles



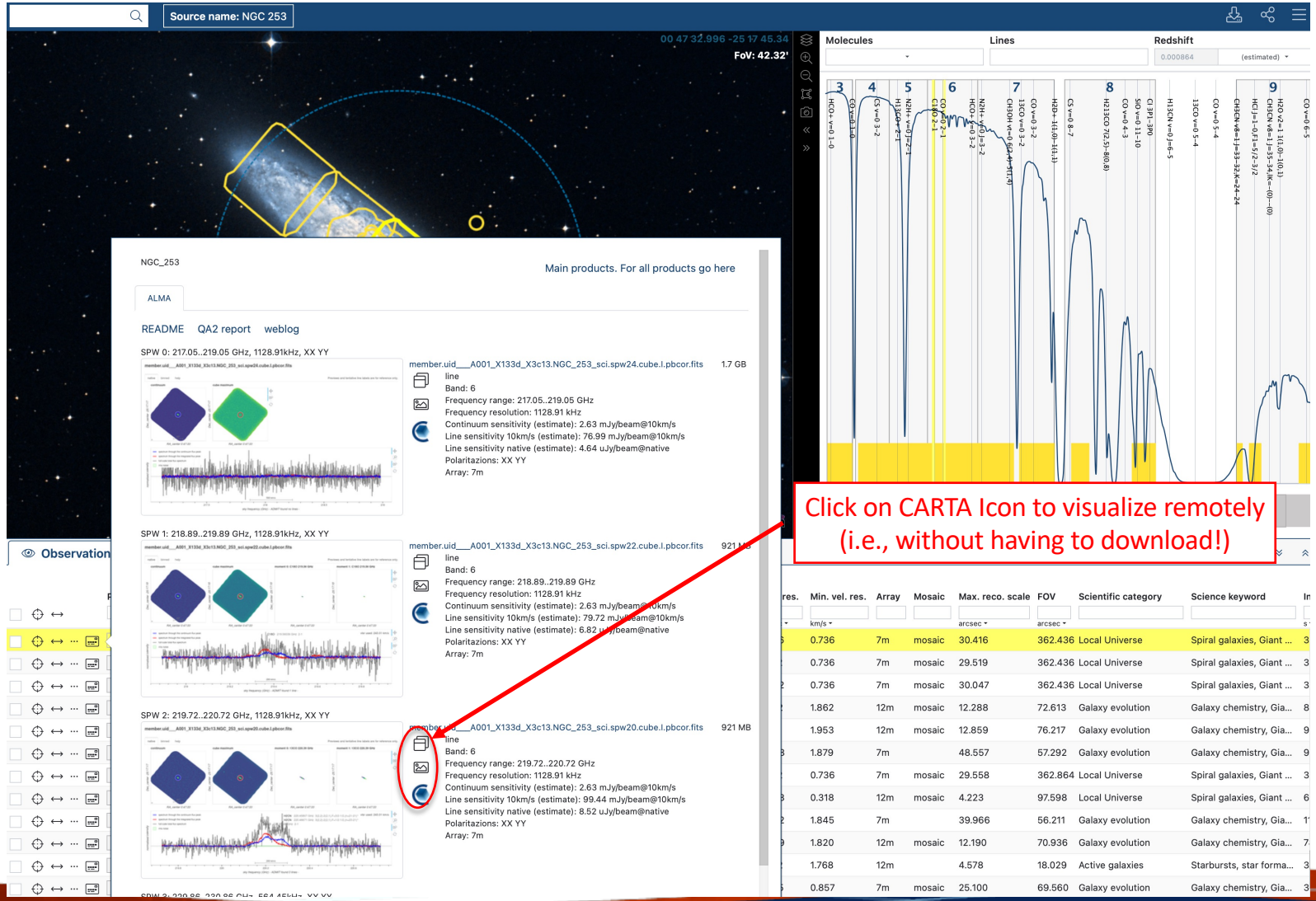
Remote Visualization of products in the ALMA Science Archive using CARTA

Click on “preview” icon



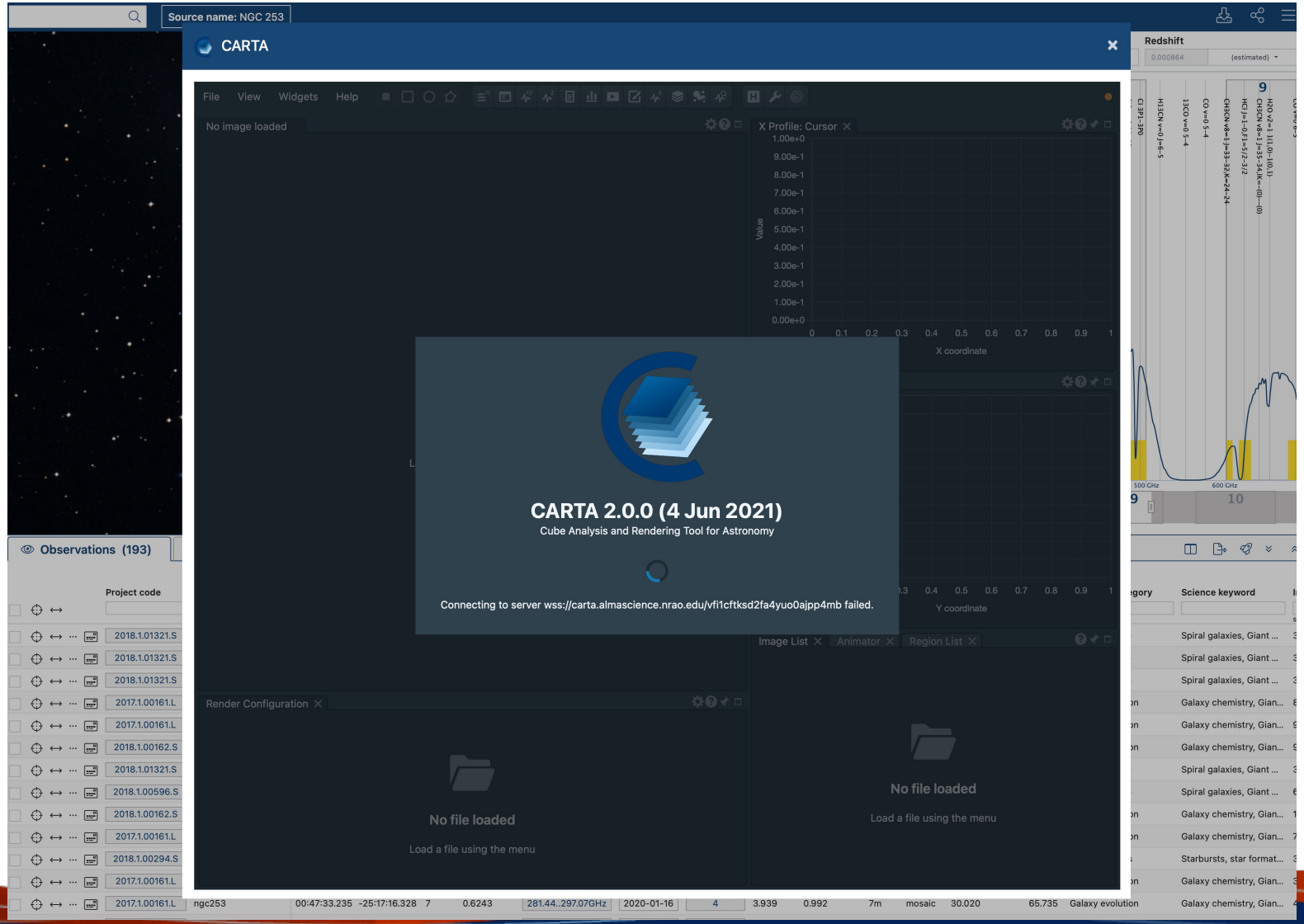
Project code	ALMA source name	Ra	Dec	Band	Cont. sens.	Frequency support	↑ Release date	Publications	Ang. res.	Min. vel. res.	Array	Mosaic	Max. reco. scale	FOV	Scientific category	Science keyword	In
		h:m:s	d:m:s		mJy/beam				arcsec	km/s			arcsec	arcsec			s
2018.1.01321.S	NGC_253	00:47:33.000	-25:17:16.994	6	2.6269	217.05..233.81GHz	2020-01-04	9	5.026	0.736	7m	mosaic	30.416	362.436	Local Universe	Spiral galaxies, Giant ...	3
2018.1.01321.S	NGC_253	00:47:47.067	-25:14:42.344	6	2.4902	217.05..233.81GHz	2020-01-04	9	5.012	0.736	7m	mosaic	29.519	362.436	Local Universe	Spiral galaxies, Giant ...	3
2018.1.01321.S	NGC_253	00:47:04.869	-25:22:25.674	6	2.5089	217.05..233.81GHz	2020-01-04	9	5.042	0.736	7m	mosaic	30.047	362.436	Local Universe	Spiral galaxies, Giant ...	3
2017.1.00161.L	ngc253	00:47:33.231	-25:17:16.203	4	0.0301	143.26..159.09GHz	2020-01-06	4	1.082	1.862	12m	mosaic	12.288	72.613	Galaxy evolution	Galaxy chemistry, Gia...	8
2017.1.00161.L	ngc253	00:47:33.228	-25:17:16.132	4	0.0266	135.96..151.79GHz	2020-01-06	4	1.101	1.953	12m	mosaic	12.859	76.217	Galaxy evolution	Galaxy chemistry, Gia...	9
2018.1.00162.S	ngc253	00:47:33.281	-25:17:17.680	5	0.2480	166.36..182.10GHz	2020-01-07	4	6.608	1.879	7m		48.557	57.292	Galaxy evolution	Galaxy chemistry, Gia...	9
2018.1.01321.S	NGC_253	00:48:01.106	-25:12:07.874	6	2.6693	217.05..233.81GHz	2020-01-07	9	5.012	0.736	7m	mosaic	29.558	362.864	Local Universe	Spiral galaxies, Giant ...	3
2018.1.00596.S	NGC_253	00:47:39.857	-25:15:33.714	6	0.0878	217.90..232.90GHz	2020-01-08	1	0.268	0.318	12m	mosaic	4.223	97.598	Local Universe	Spiral galaxies, Giant ...	6
2018.1.00162.S	ngc253	00:47:33.281	-25:17:17.680	5	0.1956	169.71..185.45GHz	2020-01-09	4	6.382	1.845	7m		39.966	56.211	Galaxy evolution	Galaxy chemistry, Gia...	1
2017.1.00161.L	ngc253	00:47:33.232	-25:17:16.237	4	0.0258	146.91..162.74GHz	2020-01-13	4	0.999	1.820	12m	mosaic	12.190	70.936	Galaxy evolution	Galaxy chemistry, Gia...	7
2018.1.00294.S	NGC253	00:47:33.067	-25:17:18.525	7	0.0329	315.27..330.69GHz	2020-01-14	0	0.312	1.768	12m		4.578	18.029	Active galaxies	Starbursts, star forma...	3
2017.1.00161.L	ngc253	00:47:33.310	-25:17:18.519	7	0.8577	338.00..353.92GHz	2020-01-15	4	2.755	0.857	7m	mosaic	25.100	69.560	Galaxy evolution	Galaxy chemistry, Gia...	3

Remote Visualization of products in the ALMA Science Archive using CARTA

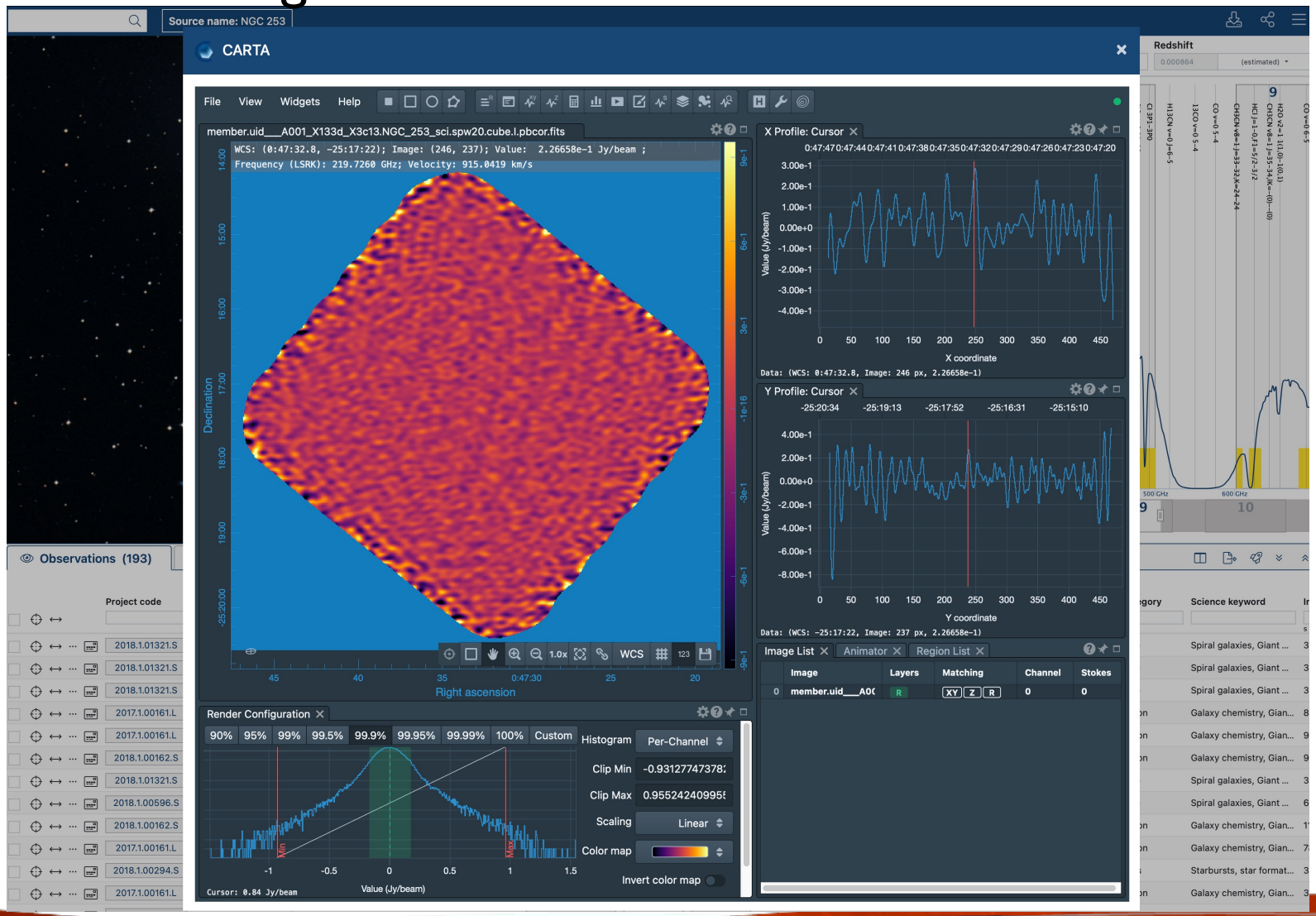


CARTA v3 (2022)

Remote Visualization of products in the ALMA Science Archive using CARTA

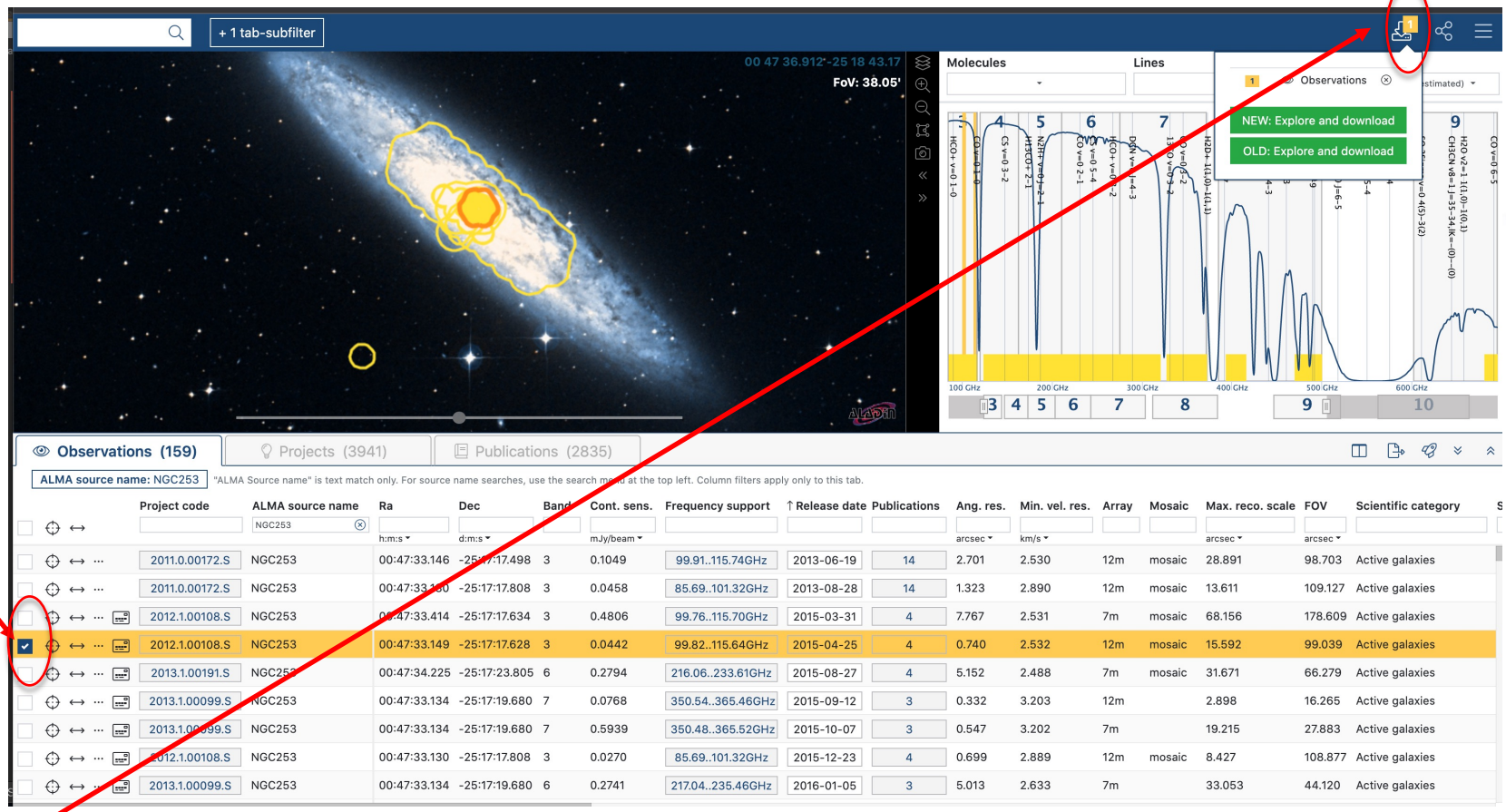


Remote Visualization of products in the ALMA Science Archive using CARTA



CARTA v3 (2022)

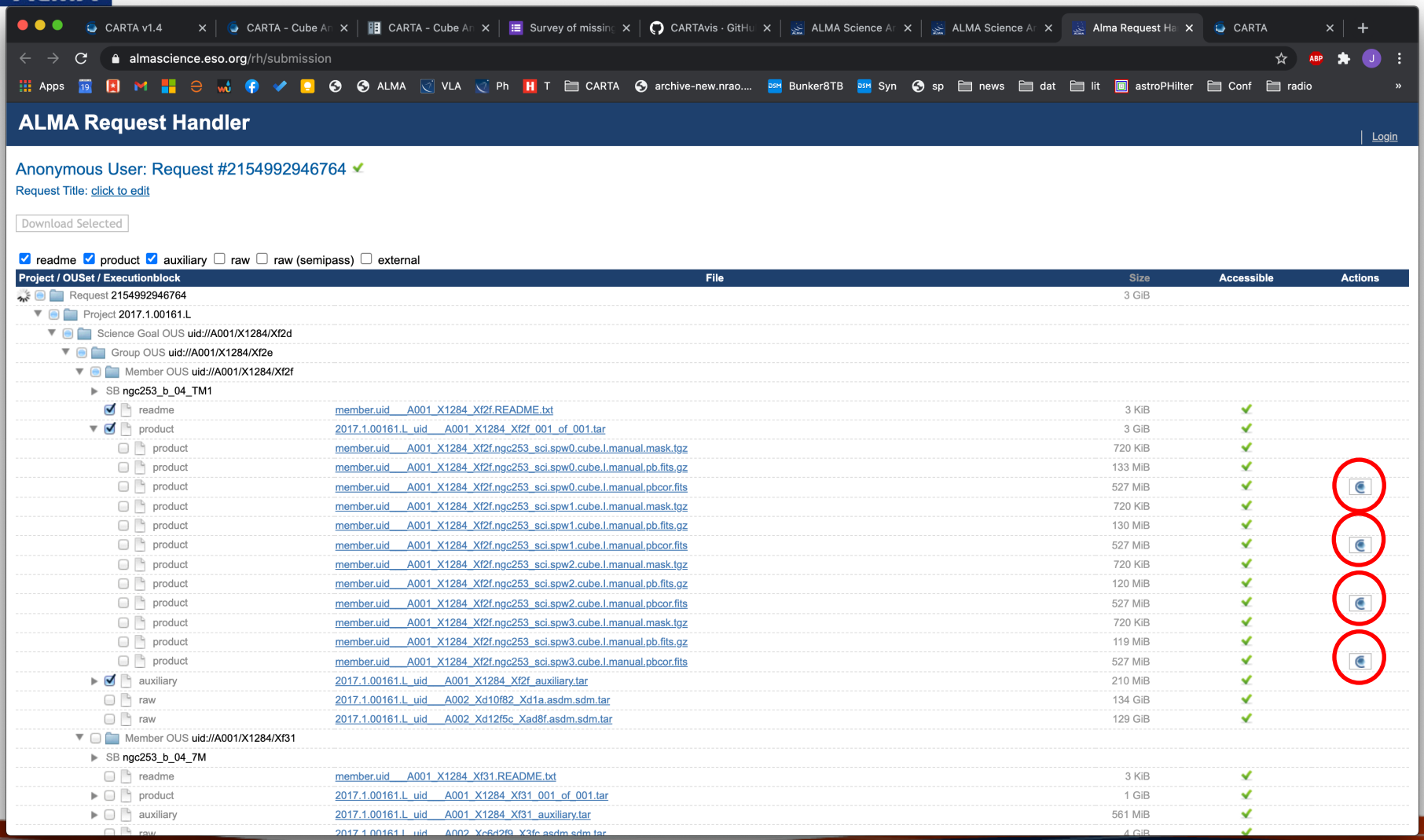
Remote Visualization of products in the ALMA Science Archive using CARTA



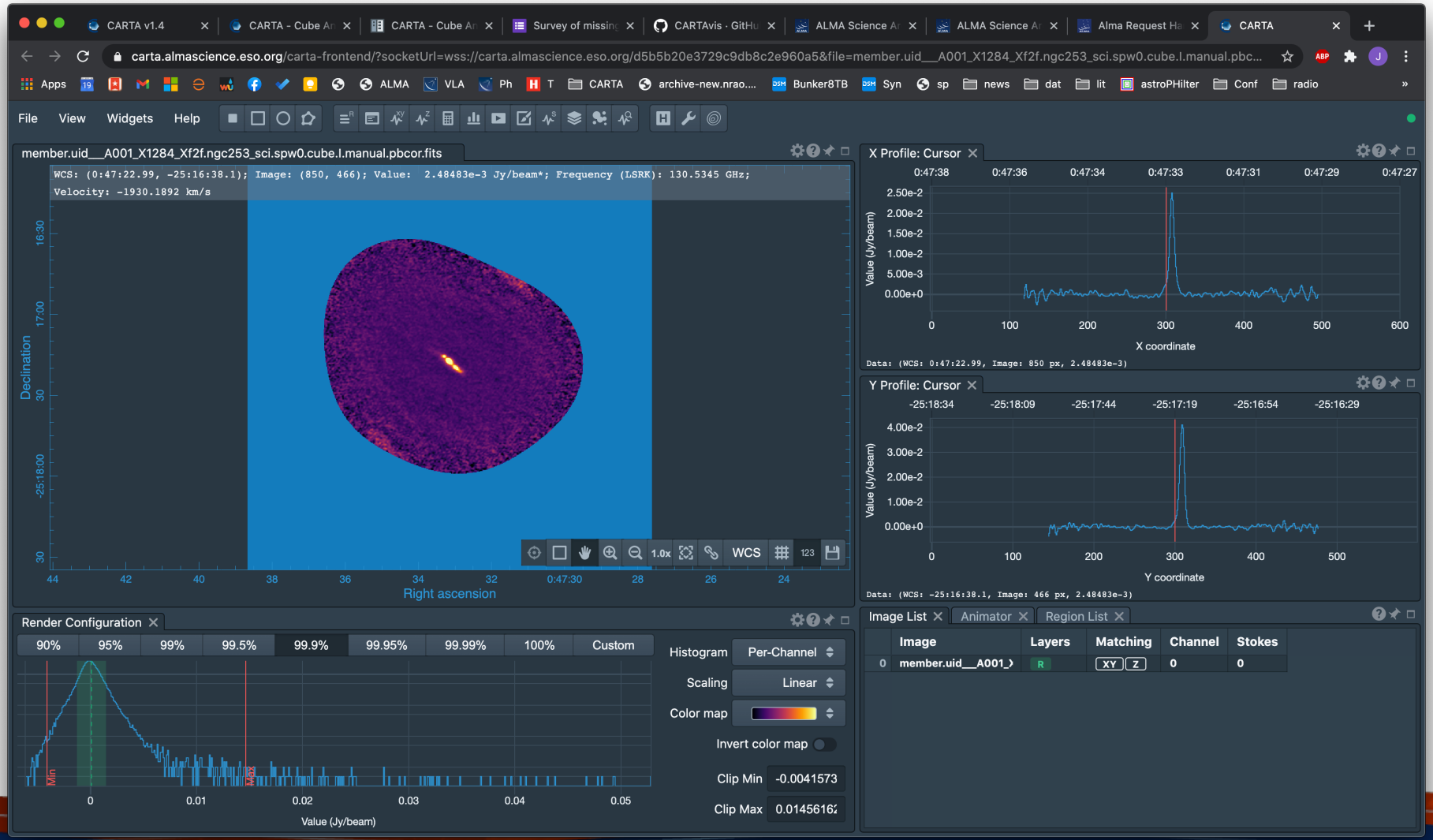
Select dataset

Then go on
"Explore and download"

Remote Visualization of products in the ALMA Science Archive using CARTA

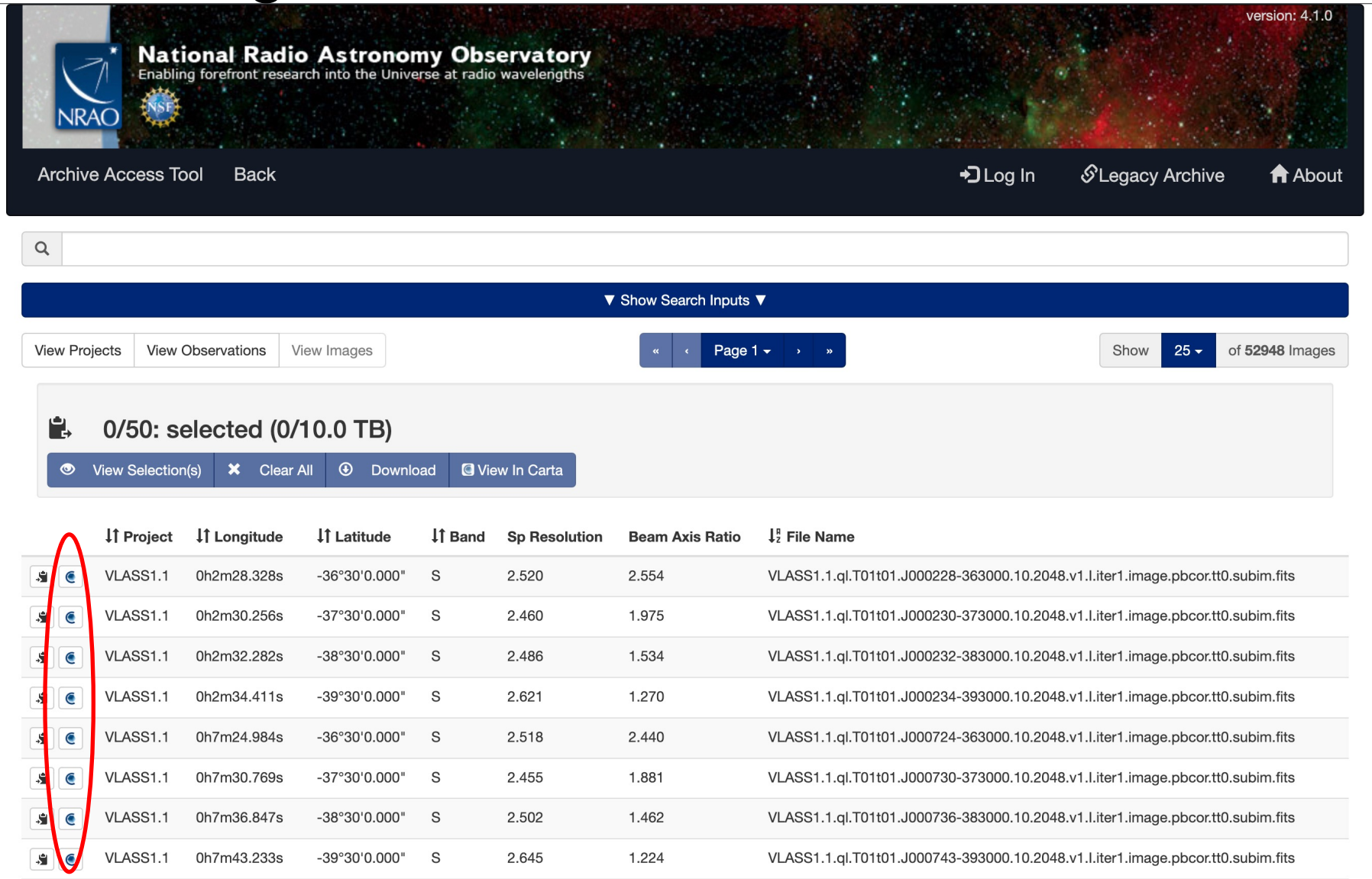


Remote Visualization of products in the ALMA Science Archive using CARTA



CARTA v3 (2022)

SRDP image archive



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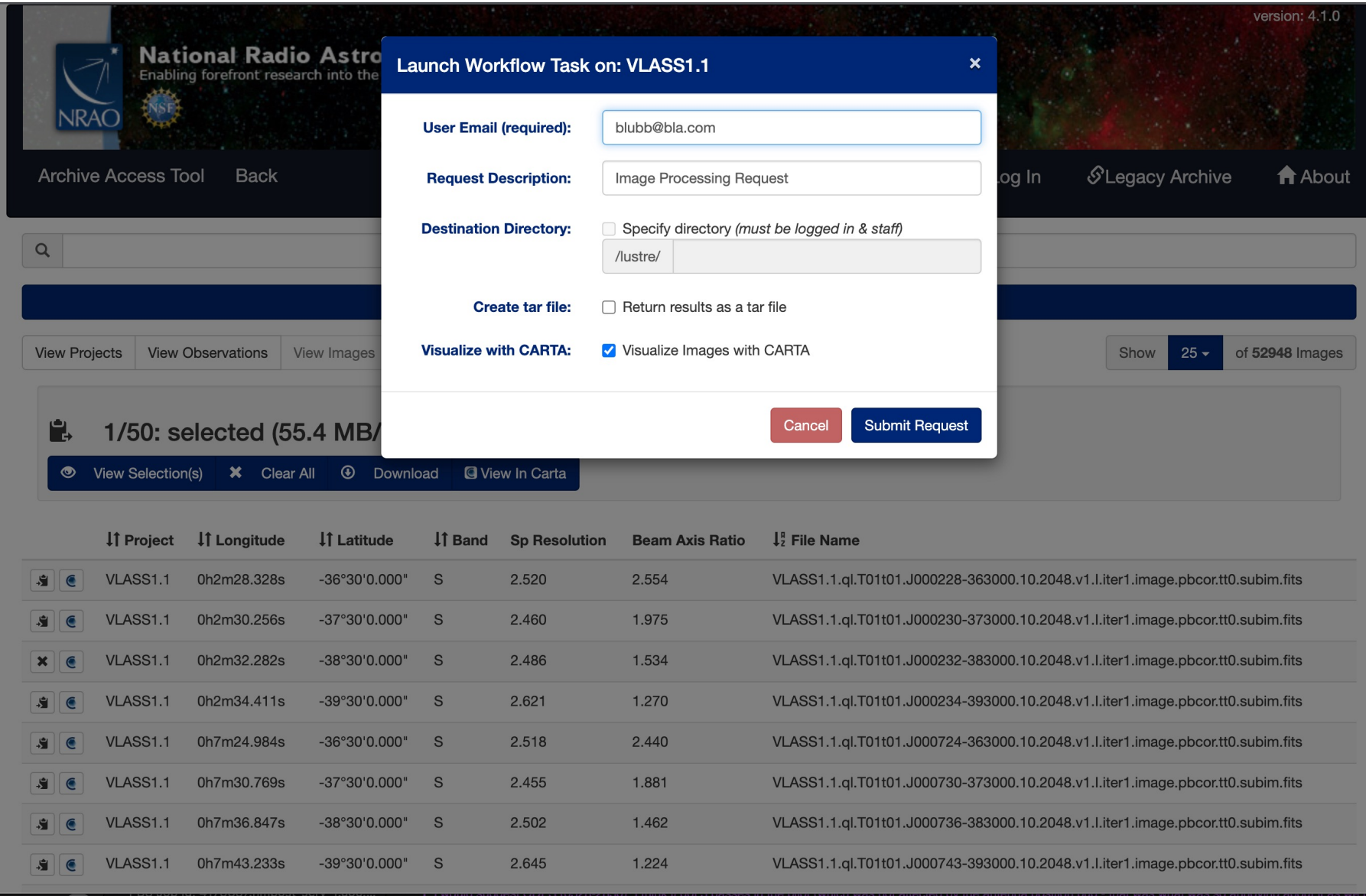
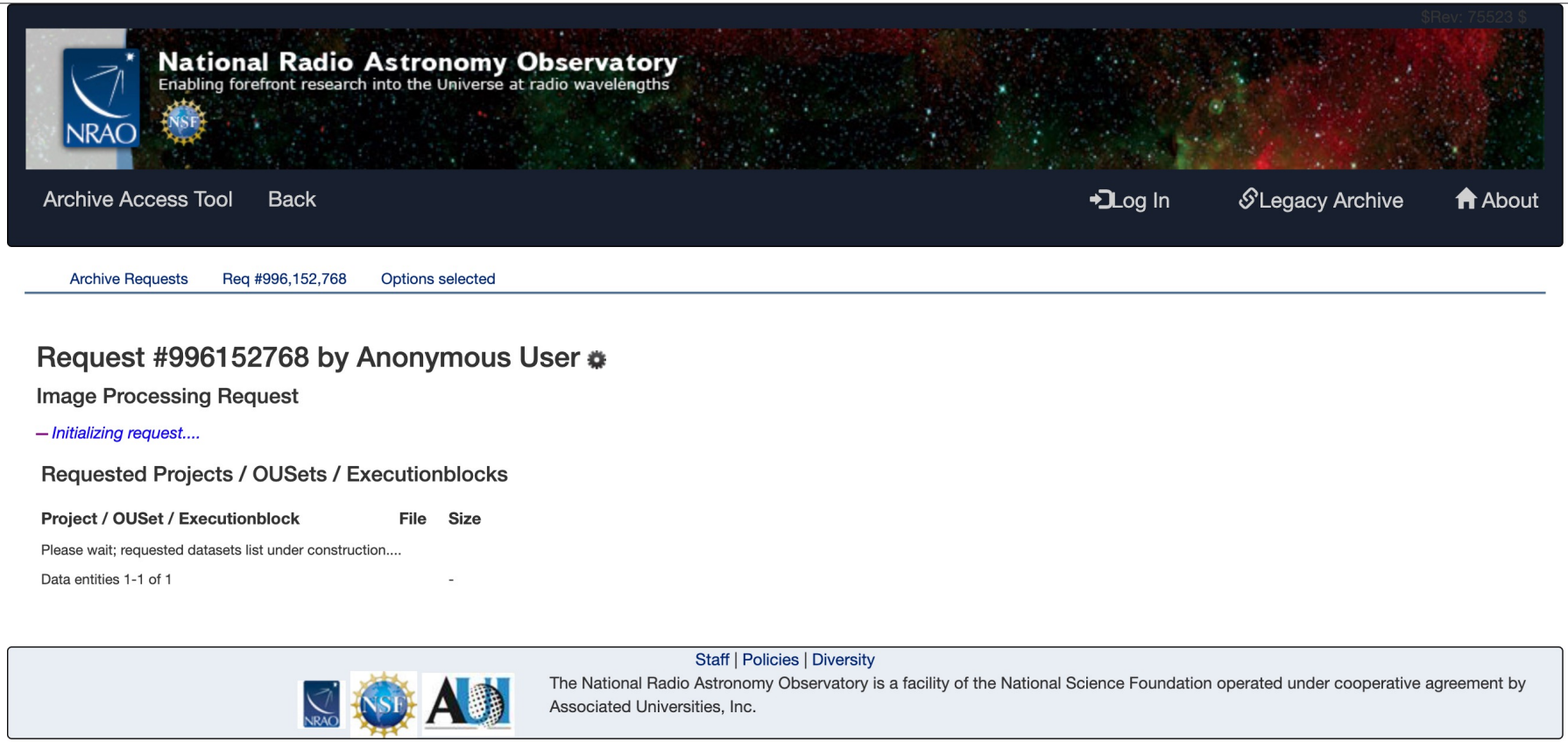
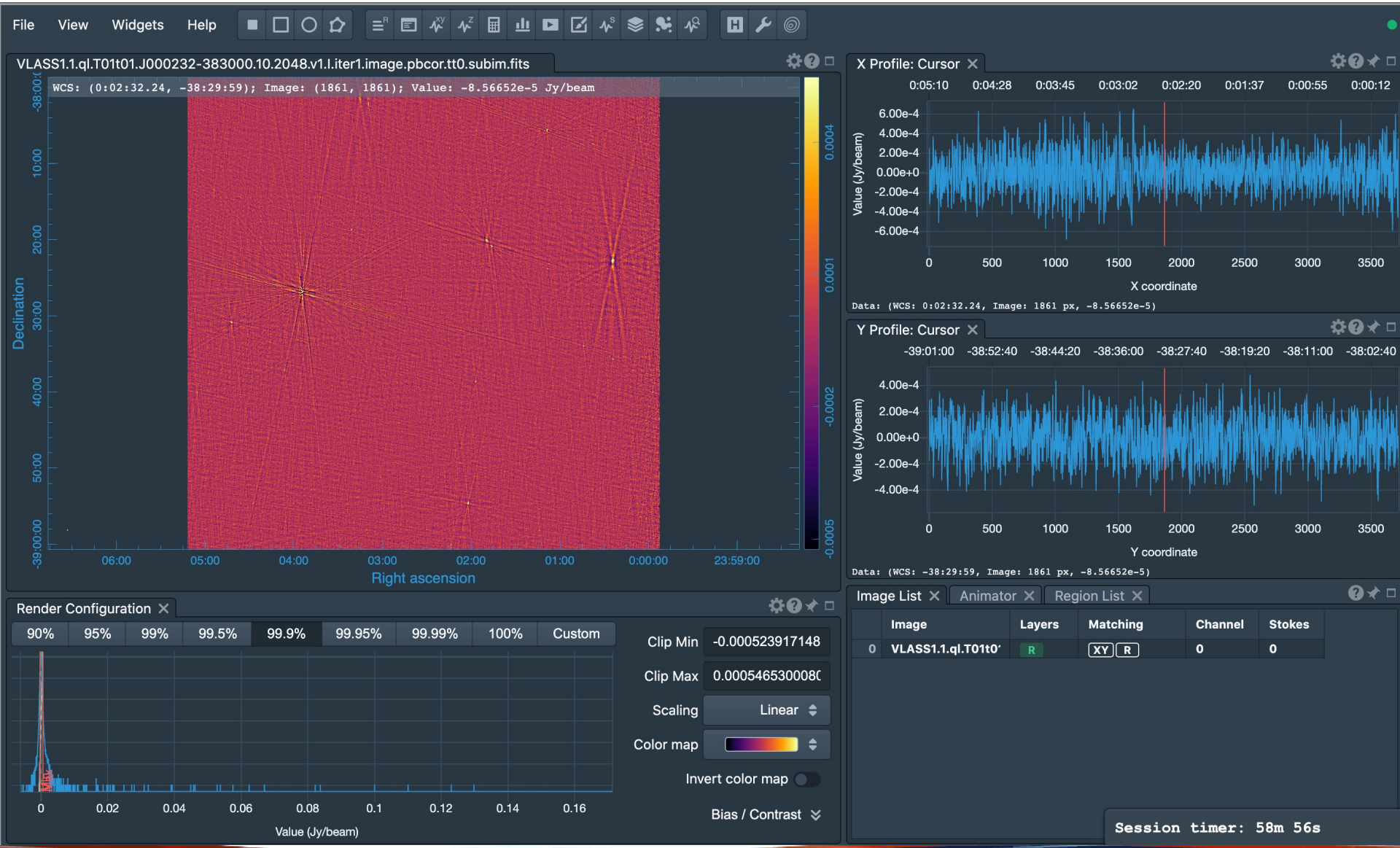
SRDP image archive



SRDP archive



SRDP archive



CARTA v3 (2022)

CARTA

Development for v4 (release in 2023, but beta versions with subset of features will be available sooner):

- Save, restore state
- Share states
- Interactive position-velocity plots
- 2D image fitting
- RGB image blender
- Spatial profile fitting
- Histogram improvements with custom parameters
- Image annotation
- Channel maps
- Scripting interface

Later:

- Volume (3D) rendering
- Improved Profile, histogram, and image fitting tools
- Source finder
- Transposed cubes
- Image smoothing
- VR integration (IDaVie)

CARTA

- CARTA is the new visualization tool, actively developed for radio image formats (but can be used for any fits image [cube]). It replaces the CASAviewer that is not supported anymore.
- Performance and architecture of CARTA are ideal for displaying large images hosted locally (VLA, ALMA, …) or remotely (SKA, ngVLA, VLASS, …)
- Almost all CASAviewer functionality is now available in CARTA v3, it is now a good time to switch over
- CARTA is integrated in the ALMA and NRAO/SRDP archives
- Python scripting is under active development

- For questions, comments, suggestions, please contact the CARTA helpdesk support@carta.freshdesk.com
- CARTA homepage: cartavis.org

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science.nrao.edu
public.nrao.edu

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