CARTA: **Cube Analysis and Rendering** Tool for Astronomy Introduction and tutorials

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Kuo-Song Wang (ASIAA) and the CARTA development team CASA VLBI workshop 2023 (June 5-9)











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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



CARTA basics

CARTA **Cube Analysis and Rendering Tool for Astronomy**

- A new generation image visualization and analysis tool designed for
 - ALMA, VLA, and SKA pathfinders (MeerKAT and ASKAP)
 - future telescopes such as ngVLA and SKA.
- Support *terabyte*-scale image cubes
- Provide easy-to-use, efficient, and feature-rich user interfaces (GUI and CLI)
 - Observing/grant proposal preparation
 - General image analysis
 - Science presentation and publication
- To support collaborative tools over internet

Overview CARTA development team

- Membership of the CARTA development project
 - ASIAA Academia Sinica, Institute of Astronomy and Astrophysics
 - IDIA Inter-University Institute for Data Intensive Astronomy
 - NRAO
 National Radio Astronomy Observatory
 - Dept. of Physics, University of Alberta
- Team scale: ~20 people including dev, science, and management teams currently



Overview **CARTA** releases

- Project reboot: March 2018
- CARTA v1.0 release: December 2018
- Targeting one beta release and one stable release every 9-month development cycle
- Upcoming:
 - v4.0-stable (~ August 2023)
- Obtain CARTA via <u>https://cartavis.org</u>

Latest stable release

Latest beta release

V3.0

v4.0-beta



Overview **CARTA architecture: Client-Server**





Data stream with just sufficient accuracy for visualization (Latency hiding techniques)

WebSocket

Your (really) BIG DATA here





See <u>https://cartavis.org</u> for a list of adopted libraries See https://github.com/CARTAvis for the CARTA codebase See <u>https://carta-controller.readthedocs.io/en/latest/</u> for server deployment





Overview **CARTA deployment modes**

User Deployment Mode (UDM)

Ideal for a single user with a local computer or a remote server



[2022-02-15 10:57:50.230] [CARTA] [info] CARTA is accessible at http:// localhost:3002/?token=10E3735B-3E42-43C1-A1E5-3B324885B0F6



Check the controller user manual https://carta-controller.readthedocs.io/en/latest/ Or contact support@carta.freshdesk.com for help

Site Deployment Mode (SDM)

Ideal for institute-wide deployment to support multiple users with a shared file system and *collaborative work*







Overview ALMA Science Archive Deployment

- ALMA news on March 24, 2021 https://almascience.nrao.edu/ news/alma-science-archiveremote-visualization-with-carta
- v3.0 is online now







Overview **CARTA** info

- Homepage https://cartavis.org
- User manual lacksquarehttps://carta.readthedocs.io/en/latest
- Controller user manual (for site deployment) https://carta-controller.readthedocs.io/en/ latest/
- Helpdesk Email to support@carta.freshdesk.com
- Codebase https://github.com/CARTAvis



INSTALLATION TEAM ABOUT HOME FEATURES GALLERY ROADMAP



Cube Analysis and Rendering Tool for Astronomy; is a next generation image visualization and analysis too designed for ALMA, VLA, and SKA pathfinders

Installation	User Manual	Helpdesk	
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CARTA v3.0 release is now availabl





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Unzipped size ~ 500 MB



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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4 256 x 256 **Downsample factor = 4**



16 256 x 256 **Downsample factor = 2**

Layer 3



64 256 x 256 No downsampling

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 \bullet
- Reference image v.s. secondary \bullet images







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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

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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



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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



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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





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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

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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



New in v4-beta

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

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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

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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



Data: (345.377 GHz, 9.72e-3)

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 Bfield)
- 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

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- Stokes analysis widget
- Spectral profiler widget
- Vector field rendering dialog

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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 columnmapped markers
 - Size mapping
 - Color mapping
 - Orientation mapping





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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-topan)
 - 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**



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HL_Tau_band6_Stokes_IQUV.fits
HL_Tau_band6.POLA.fits
HL_Tau_band6.POLI.fits
HLTau_band7_cont.fits
IRCp10216_line_pol
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Thank you~ We hope CARTA can make your life easier 😃

https://cartavis.org

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Cite CARTA! This project needs your support!





Please contact <u>support@carta.freshdesk.com</u> for any questions/comments

