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3D Visualization Tool Cookbook

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1 List of acronyms

CASA	Common Astronomy Software Applications
FITS	Flexible Image Transport System
IR	Infrared
NaN	Not a Number (IEEE floating-point standard representing an undefined or unrepresentable value)
WCS	World Coordinate System

2 Introduction

This document focusses specifically on the features of the CASA Viewer that are useful for optical/near-IR astronomers who wish to examine their data cubes. We do not attempt to describe the CASA Viewer in detail. Instead, here we provide four step-by-step examples that highlight particular functionality in an intuitive way: loading and displaying a spectrum with its associated errors (Section 4.1); displaying spectra from two spatially overlapping cubes (Section 4.2); 1D Gaussian spectral fitting (Section 4.3); and collapsing a cube over a specified wavelength range (Section 4.5).

For more detailed information on the viewer, we refer the reader to the 3D Visualization Tool Manual (needs updating) (VLT-MAN-ESO-19500-5651) or to Chapter 7 of the CASA User Reference & Cookbook). The detailed FITS format description used for 3D cubes is given in VLT-SPE-ESO-19500-5667 ("FITS Format Description for Pipeline Products with Data, Error and Data Quality Information").

3 Data cubes used in this cookbook

The examples detailed in this cookbook make use of three simulated optical data cubes that can be downloaded from `https://svn.cv.nrao.edu/svn/casa-data/trunk/regression/viewertest/`

- `small_meas3D.fits`: a simulated example cube with both a data and error extension
  - 50×50×50 pixels, with spatial scale 1 arcsec pix^{-1}. The spectral dispersion is 9 Å pix^{-1} with a starting wavelength 7568.0 Å. Its coordinates place it somewhere in the *Chandra* Deep Field South.
  - The science extension is made from a PNG image of the words "CASA Viewer" with added Poissonian noise.
  - The error extension contains the Poisson noise of the science extension for a certain exposure time and readout noise.
- `3DVisTestIDL.fits`: A simulated cube containing masked values (encoded as NaNs) in spaxel [13,13] between 5000–5050 and 5600–5605 Å.

  - $30\times30\times1300$ pixels, with spatial scale 1 arcsec pix^{-1}. The spectral dispersion is ~2.3 Å pix^{-1} with a starting wavelength 4000.0 Å. Its coordinates are arbitrary (RA=30°, DEC=30°)
  - The science extension comprises an intensity image of two 2D-Gaussians, each having its own spectrum which is a combination of Gaussian absorption and emission lines.
  - The error extension comprises a combination of Poisson and detector readout noise.

- `centGaussTest.fits`: A FITS image containing a number of increasingly elliptical 2D Gaussian profiles.
  - 256×256 pixels, with spatial scale 0.2 arcsec pix^{-1}. Its coordinates are arbitrary (RA=180°, DEC=−30°)
  - The science extension contains an image with 30 Gaussian objects with various shapes and intensities added over a constant background of 5 e/s. The image contains Poisson noise. The position angle of the elliptical Gaussian profiles vary between 0° and 150° in steps of 30°.

4 Step-by-step examples

This section contains four "hands-on", step-by-step examples showcasing some of the CASA Viewer's capabilities that have been designed for optical/near-IR datacubes. Each example details a number of steps that should be followed in order to guide the user to the various functionalities being covered in that example, and makes use of one of the three simulated datacubes described above. A number of labelled screen-shots are included to help familiarise the user with the graphical layout of the CASA viewer.

4.1 Loading and displaying a spectrum and errors

This example deals with the basics of loading a cube and displaying a spectrum with its associated errors. Errors are read from the error extension of the FITS file, and can be associated with every point in the 3D cube. We will explore options relating to how the spectrum is displayed, and how it can be saved in ASCII or FITS format. Fig. 4.1 shows the CASA Viewer main window with the most important panels and buttons labelled. Fig. 4.2 shows the spectral profile window and its main features.

1. Begin the CASA Viewer as a standalone application by typing `casaviewer &` on the command line. The "Load Data – Viewer" window will appear automatically.

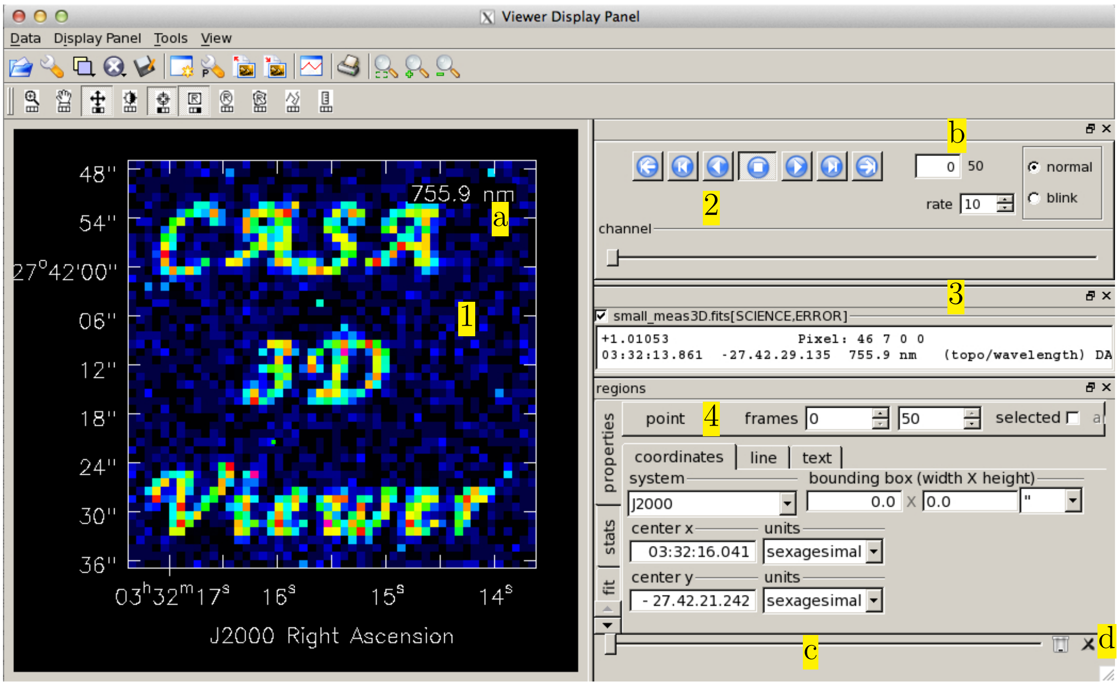

Figure 4.1: CASA Viewer main window showing the `small_meas3D.fits` example cube. (1) Main image viewer; (2) animator panel; (3) position tracker panel; (4) regions panel (note: this will only appear once a region is selected); (a) wavelength channel/slice label; (b) channel/slice box; (c) region selector slider; (d) region delete button.

2. Load the `small_meas3D.fits` test cube (which includes a SCIENCE and ERROR extension) as a raster image. To do this, click on the expand arrow and load the 1^{st} entry [SCIENCE,ERROR]. In this way the signal and error information is read in together and the viewer treats them as combined dataset. The main viewer window will look something like what is shown in Fig. 4.1.

3. In the animator panel use the sliding bar to move through the slices of the cube. The wavelength of each slice is indicated in the top right [default] of the main viewer panel (Fig. 4.1a).

4. Change the channel [slice] label units by opening the `Data Display Options` (spanner icon), and under the `axis label properties` sub-panel change `spectral unit` to `Wavelength [Angstrom]`, `[mm]`, `frequency [GHz]`, `MHz`, etc.

5. Display the error extension by selecting the `hidden axes` drop-down tab in the `Data Display Options` panel, and switch the quality slider to `1`. You will need to adjust the cut values in the `basic settings` tab to be able to see the error image in the main window. Note: the `hidden axes` tab is only present when there are more than three axes in the image (data-error is fourth axis) and not all data can be displayed along the x-y-movie axes of the viewer.

6. Open the "spectral viewer" window (graph icon or drop-down menu Tools → Spectral Profile). You can define regions from which the [sum/average] spectrum is displayed on the image using the `point`, `rectangle`, `ellipse`, or `polygon` tools. Try one of these now. In the regions panel in the main window you can see and manually adjust the properties (e.g. line color or width) of each region you define. You can select regions by either moving your mouse over one, or by using the slider at the bottom of the regions panel. Regions can be deleted using the cross icon.

7. Inspect the `mean`, `median` and `sum` spectrum in the spectral profile window (see Fig. 4.2 label c). For point regions there will be no difference between these options. Display the `rmse` and `propagated` errors using the drop-down menu to the right of the window. Note: rmse errors, which are derived from the signal itself, can be displayed for `mean` and `median` options only.

8. Change the x-axis units of the spectrum to `Angstrom`, `um`, `mm`, `GHz` etc. by using the drop-down menu.

9. Save the displayed spectrum as an ASCII file using the `export profile to file` button (disk icon) in the spectral profile window and selecting `txt` (not FITS) format. Errors will also be saved if selected. Note: a spectrum saved in ASCII format will be in its 'native' units, NOT the ones it was changed to in the profiler.

10. Save the spectrum as a FITS file using the `export profile to file` button (disk icon) and selecting FITS format. Note: a spectrum saved in FITS format will be in its 'native' units, NOT the ones it was changed to in the profiler.

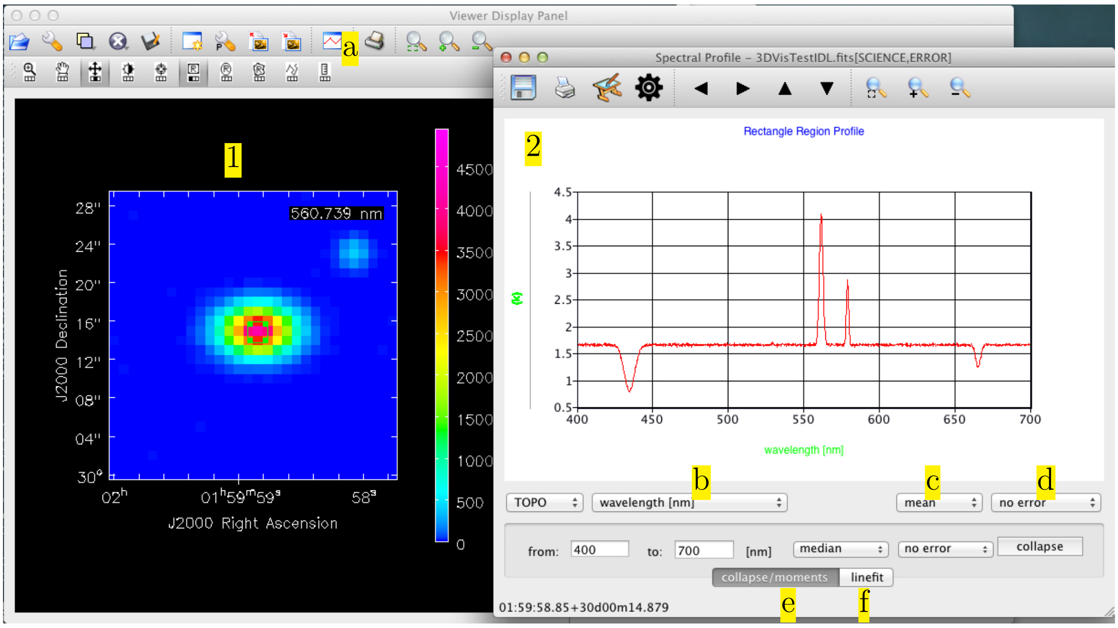

Figure 4.2: Spectral profiler window showing the mean spectrum from the rectangular region covering the brightest spaxels in the `3DVisTestIDL.fits` example cube. (1) Main viewer window; (2) spectral profiler window; (a) spectral profiler button; (b) spectrum unit drop-down box; (c) spectrum combination drop-down option box; (d) spectrum errors drop-down box; (e) collapse/moments tab; (f) line fitting tab.

4.2 Displaying two spectra from two spatially overlapping cubes, export to ASCII

This example deals with displaying spectra from two spatially overlapping cubes. Cubes can only be displayed simultaneously if they share coordinate space as determined by their WCS keywords.

1. Load `small_meas3Dsci.fits` test cube as a raster image
2. Load `small_meas3Derr.fits` test cube as a raster image. (Note, this is the associated error image.)
3. In the animator tool box in the main window, select `blink` then press play. The viewer will blink between the two cubes. The blinking rate can be adjusted with the "rate" parameter in the animator box. Note: this will only work on cubes with spatially overlapping world coordinate systems (WCS).
4. Open the `spectral viewer` window (graph icon) and define a region on the image using the rectangle or ellipse tools (make sure it is larger than 1×1 pixel). The spectrum of the 1^{st} loaded cube (`small_mean3Dsci`) should be shown in red, and the 2^{nd} (`small_mean3Derr`) in blue.
5. Open the spectral profiler window preferences (black cog icon) and de-select the `Overlay` option. Only the red spectrum will now be displayed.
6. Display `rmse` errors using the drop-down box. Error bars will appear on the red (primary) spectrum only.
7. In the main viewer display window, unregister (layers icon) the `small_mean3Dsci` cube, then re-register it. This will bring this cube to the top in the viewer window, and swap around the blue and red spectra in the spectral profile window (don't forget to switch on the `Overlay` option again). Displaying `rmse` errors will now add error bars to the `small_mean3Derr` spectrum.
8. If you save the displayed spectra as an `ASCII plot file`, both spectra will be saved one after the other in the text file, with errors for the first and none for the second.

4.3 Spectral fitting

Displayed spectra can be fit with a simple Gaussian+continuum function. This example demonstrates how this can be achieved using an example cube containing spectra with emission and absorption lines. Fig. 4.3 shows the main buttons and options needed for the spectral fitting.

1. Load `3DVisTestIDL.fits` cube as a raster image. Open the `spectral viewer` window and use the rectangle select tool to select a region.

2. In the spectral viewer window, zoom into the central region of the spectrum with the brightest emission line (draw a zoom box with left mouse button).

3. Use the shift key together with the left mouse to select this brightest line including some continuum either side. Select the `linefit` tab and fit the default `gauss+poly1` line (single Gaussian + polynomial of order 1 [i.e. sloped line]). The results are printed in the status bar of the viewer and to the terminal (command line). Note: if the spectral profile has associated errors, these errors are used in the fitting as weights. The buttons and options needed for fitting are labelled in Fig. 4.3.

4. Display `rmse` errors and re-fit the line. Note: the values and errors of the results will change – if only very slightly. You can also change the x-axis units and re-fit to get the results in your preferred units.

5. Click `clean` to remove the fits from the plot.

6. Open `data display options` in main window (spanner symbol) and under the `axis label properties` sub-panel enter a rest wavelength of 660 nm and change the spectral unit to `optical velocity [km/s]`. The frame/channel value (axis unit) displayed in upper-right [by default] of the image in the main viewer window will change to km/s values relative to zero at 660 nm. The x-axis units of the spectrum in the spectral viewer will also change accordingly.

4.4 2D spatial fitting

Profiles within slice/channel images can be fit with a two-dimensional Gaussian function in the main viewer window by utilising a region. This example demonstrates how this can be achieved using an example image containing a variety of simulated elliptical Gaussian profiles. Fig. 4.4 shows the main buttons and options for the 2D spatial fitting.

1. Load the `centGaussTest.fits` image as a raster image.

2. Use the rectangle or ellipse tools to select a region covering one of the shapes in the image.

3. Select the “fit” tab in the regions panel (as shown in in Fig. 4.4).

4. Make sure “sky component” is selected and click “gaussfit” (Fig. 4.4b). The Viewer will fit a 2D Gaussian profile to the peak within the region you selected, together with a flat (i.e. single valued) background level. It will mark the centre of the profile with a point and indicate the major axis position angle with a straight line (Fig. 4.4c). The results (position, major and minor axis, position angle in Ra/Dec and pixels, and the flux of the Gaussian and the background) will be printed inside the “fit” tab and to the command line.

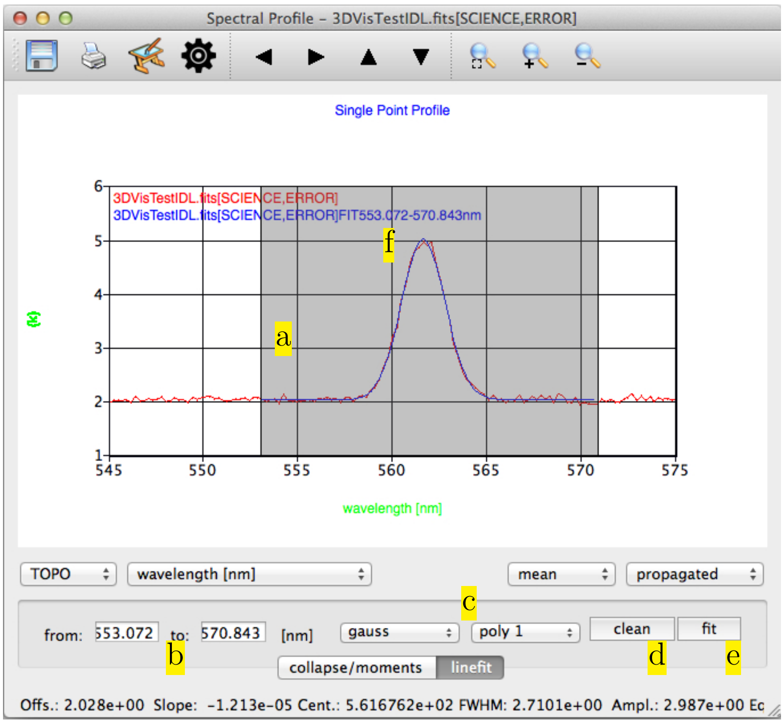

Figure 4.3: Fitting a spectral line. (a) fit limits defined by shift-click-dragging (grey shaded area); (b) numerical fit limits recorded from the shift-clicking (can be entered manually here also); (c) drop-down boxes for line and continuum options; (d) clear fits button; (e) perform fit button; (f) the fit result is displayed on the plot as a different colour, as indicated in the legend above. Numeric fit results are displayed at the bottom of the Spectral profiler window and also on the command line.

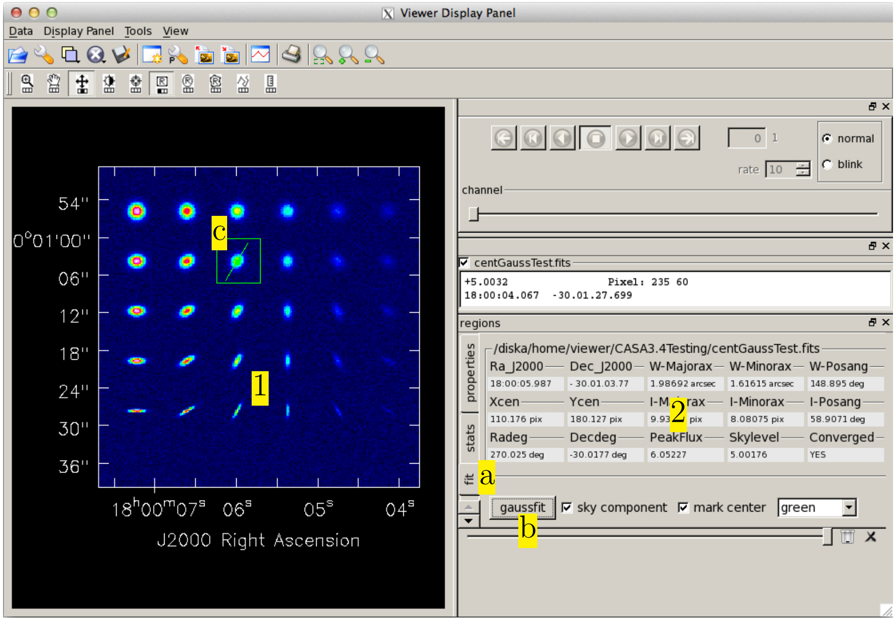

Figure 4.4: Two-dimensional Gaussian fitting. (1) `centGaussTest.fits` image; (2) 2D fitting tab within the regions panel (showing the results after performing a 2D fit); (a) 2D fitting tab; (b) perform fit button; (c) selected rectangular region, and the marked centre and major axis position angle of the fit.

4.5 Image collapse and export

In this example, the image collapse functionality will be demonstrated. You will see how cubes can be collapsed (summed or averaged) over a specific wavelength range in order to produce pseudo-narrow-band images and saved for further analysis.

1. Load `3DVisTestIDL.fits` test cube (which includes a SCIENCE and ERROR extension) as a raster image (click expand arrow and load the 1^{st} entry [SCIENCE,ERROR]). This image contains masked values (encoded as NaNs) in spaxel [13,13] between 5000–5050 Å and 5600–5605 Å (channels 433–454 and 693–694, respectively), which in the Spectral Profiler window will be displayed as zeros (see Fig. 4.5 and denoted as "masked" in the position tracker panel (see Fig. 4.1). You may need to change the image cut range to e.g. [−1,1] to see this masked region.

2. Open the `spectral viewer` window and use an area select tool (e.g. rectangle) to select a region.

3. Press and hold the ctrl key. This will display a grey vertical line on the spectrum at the location of the mouse. Clicking the mouse will display the corresponding channel [slice] in the main window as an image.

4. In the spectral viewer window, mark a spectral range (shift key + left mouse button).

Figure 4.5: A section of the spectrum between 480–570 nm from spaxel [13,13] of `3DVisTestIDL.fits`, showing the masked regions (NaN; displayed in the Spectral Profile window as zeros).

Select the `collapse/moments` tab and collapse the image over this wavelength range. Besides collapsing using the `mean` option, the collapse can also be calculated as a `sum` or `median`, and the associated errors can also be calculated and attached. The resulting collapsed image will be displayed in the main viewer. By using the blink option in the animator panel (select "blink" and press "play") one can conveniently compare the collapsed image with a given cube channel.

5. Save the collapsed image using the `save as` (disk icon) button (main viewer window). This will save the image in FITS format. If errors were also calculated in the collapse, these will be saved as a second extension in the FITS file.