

# The ESO 3D Visualisation Tool

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The ESO 3D visualisation tool provides the capability for visualisation and basic scientific exploitation of 3D spectroscopic datasets obtained with VLT integral field unit instrumentation, including MUSE. The tool was implemented as part of the ALMA CASA software viewer and as such provides the opportunity to view ALMA data as well as VLT 3D data within the same tool. Recently, the first version of the visualisation tool, featuring optical and near-infrared spectroscopic capabilities, has been completed and we describe the released software which is available for Mac OS X and Linux systems.

## Introduction

The majority of present and future ESO facilities — the Very Large Telescope (VLT), the Atacama Large Millimeter/sub-millimeter Array (ALMA), and of course the European Extremely Large Telescope (E-ELT) — feature (presently or in their plans) instruments which produce datacubes (i.e., data with two spatial axes plus one wavelength/frequency axis). In this context, the need for an ESO-based visualisation tool capable of handling datacubes was raised and discussed. A project was set up to deliver a 3D visualisation tool to be used by the ESO community for the visualisation and basic scientific exploitation of (large) 3D datasets.

The development of the tool was focused on the requirements for the Multi Unit Spectroscopic Explorer (MUSE), a VLT second generation instrument (see Bacon et al., 2006, 2012), but it includes the capability of visualising data from other, single-field integral field units (IFUs) operated at the VLT. In many respects, MUSE datacubes provide a challenge to the viewer, not least because of their sheer size (2.9 Gigabytes ~ 300 × 300 × 3600 pixels) both for science and error data.

Given the limited manpower and time-frame available to the project, it was decided that extending the capabilities of one of the already existing visualisation software platforms was the most practical solution. Several possibilities were explored and the viewer of the ALMA CASA software package was selected. The major motivations for this choice were the potential for developing synergies between ALMA and VLT and the long-term maintenance aspects.

The resulting ESO 3D visualisation tool aims at providing the typical astronomer in the ESO community and also ESO operations staff with the means for visualising and performing *basic* scientific analysis of fully calibrated and reduced VLT datacubes of single fields. The tool allows the novice IFU user to obtain a first evaluation of his/her data, as well as the more experienced IFU user to assess data quality in more detail.

## Input data

With the exception of the second generation VLT instrument SPHERE (Beuzit et al., 2006; Kasper et al., 2012), all currently operational and almost completed VLT 3D instruments record spatial and wavelength information in a way that can be conveniently re-sampled into a linear 3D grid (i.e., a datacube with uniform  $dx$ ,  $dy$  and  $dz$ ). As such, the viewer requires cubes to be linearly sampled in all three axes and the data to be properly described according to the FITS standard (Calabretta & Greisen, 2002; Greisen et al., 2006). The main difference with SPHERE is that it records spatial information via hexagonal lenslets projected onto the sky and maintains the wavelength as recorded on the detector (to avoid re-sampling). The SPHERE data reduction pipeline, however, will also produce a linearly re-sampled cube for visualisation.

Starting with the second generation VLT instruments, error arrays are commonly provided by the data reduction pipelines. Owing to the lack of a pre-existing FITS standard describing the format of error extensions, ESO has defined a new, internal FITS format (ESO, 2012). This format describes how science data, errors and data quality information should be stored

in separate extensions of the same FITS file, and how the relationship between them is handled via FITS header keywords. The ESO 3D visualisation tool not only has the capability of displaying the errors, but also the facilities to use them in internal calculations or analysis procedures. This functionality sets the tool apart from similar software available elsewhere. The existence of error and quality information is desirable but not mandatory; the viewer can therefore also be used with 3D data without error information.

As part of the ESO 3D visualisation tool project, all ESO data reduction pipelines for instruments with 3D capabilities were upgraded to produce output files compliant with this new format.

## The viewer display panel

The prime purpose of any 3D viewer is to visualise a datacube in a convenient and user controlled, interactive manner. The CASA viewer application consists of a number of graphical user interface (GUI) windows that respond to mouse and keyboard input. In the standard configuration, the viewer display panel (see Figure 1) shows one slice (or channel) of a given datacube in the main image viewer (Figure 1, (a)) and allows the user to move through the slices with the animation panel (Figure 1, (b)). Crucial information on the mouse position in world coordinates as well as pixel-based systems is provided in the position tracker panel (Figure 1, (c)).

In the main image viewer one can define regions (point, rectangle, ellipse or polygon) from which the mean, median or summed spectrum is displayed in the spectral profiler window (see Figure 2). Information on the selected region is given in the regions panel (Figure 1, (d)). The viewer display panel is highly configurable, giving access to all important display options such as colour tables, data display ranges and scalings, and the axis labels. It also allows the user to select any two of the three axes of the datacube to be displayed (e.g., right ascension versus wavelength). Visualisation of non-orthogonal projections is not incorporated, but more specialised tools are available in the public domain (e.g., Campbell, Kjær & Amico, 2012). High quality images of

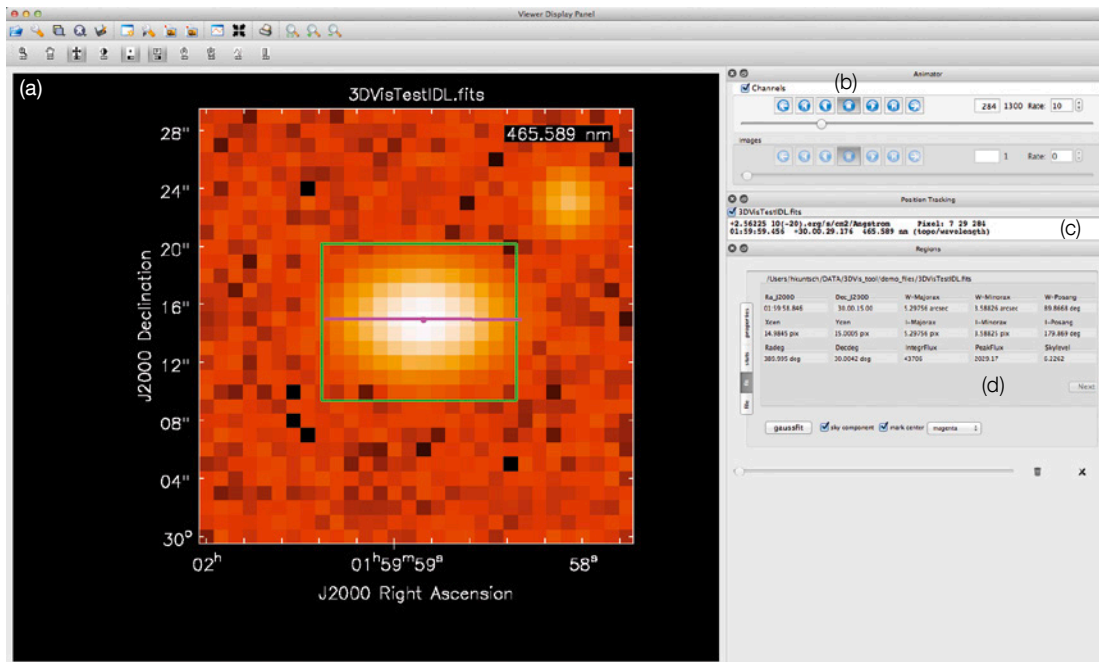


Figure 1. Screenshot of the main viewer panel showing one channel or slice (#284) of a simulated test datacube at 465.589 nm. The locations of the main image viewer (a), the animator panel (b) and the position tracker panel (c) are indicated on the screenshot. The spectrum within the green rectangular region marked in the image viewer panel (a) is displayed in the spectral profiler (see Figure 2). The position tracker panel provides crucial information on the current cursor position such as data value, coordinates in pixels and world coordinate system (WCS) format. In this example, a two-dimensional Gaussian fit to the highlighted emission region has been made. The centre and position angle is given by the magenta line and cross, respectively, and the numeric fit values are shown in the regions sub-panel (d).

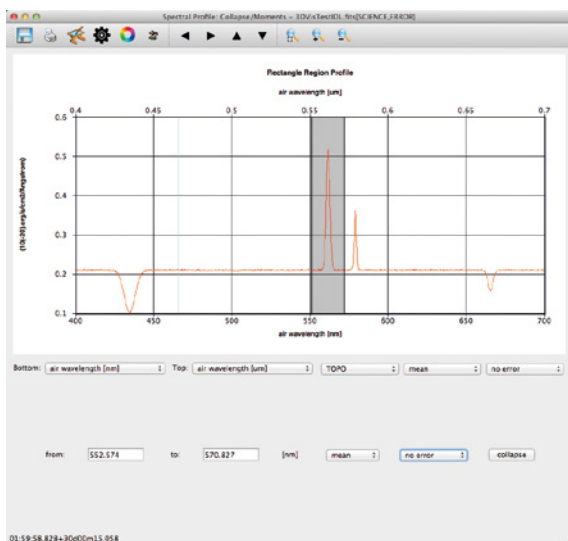


Figure 2. Screenshot of the spectral profiler showing the mean spectrum of the rectangular region (green) marked in Figure 1. A blue line indicates the wavelength of the slice shown in the main viewer panel. In this example a spectral range (grey shaded area) is marked by cursor interaction, which can then be used to collapse the cube and reconstruct an image over this wavelength range (in this case 552.574–570.827 nm).

region showing a distinct emission feature was chosen. After image reconstruction (a choice between mean, median and sum algorithms is available) the image is displayed in the image viewer (not shown in Figure 1) and can be, e.g., “blinked” with other slices of the cube. Error estimates, derived from the data themselves, can be optionally calculated and stored together with the reconstructed image.

An often-requested application for imaging data is the ability to fit a simple 2D Gaussian to an object in the field of view in order to obtain estimates on the object position, extent and orientation. The viewer provides this capability as part of the *regions* functionality. In Figure 1 we show an example: a rectangular region around a bright emission knot is marked and a 2D Gaussian fit made. The peak is automatically found, and the fit results are shown graphically (magenta line and cross) and numerically (in the regions panel in both pixel and world coordinate systems; see Figure 1).

1D Gaussian fits can also be performed on the spectrum in order to determine, for example, the central wavelength for an emission/absorption line. We show an example of this application in Figure 3. For the fit, a wavelength region is selected

what is displayed in the main viewer can be saved in all commonly used formats such as FITS, pdf, jpg or png. The spectral unit used for the display can also be interactively chosen (e.g., nm, Ångström, GHz), and, provided a rest frequency or wavelength is specified, can be converted into units of velocity (e.g., km/s).

Beyond the basic visualisation capabilities of the viewer a number of analysis tools are offered. Examples are provided in the following.

### Analysis tool examples

It is often convenient to collapse a number of datacube slices along the wavelength direction to, e.g., increase the signal-to-noise level in the resulting “reconstructed image” or sum over an emission line. This action is initiated from the viewer display panel, opening the spectral profiler where a region can be interactively marked with the cursor or provided by numeric values (see Figure 2). In the example shown, a selected

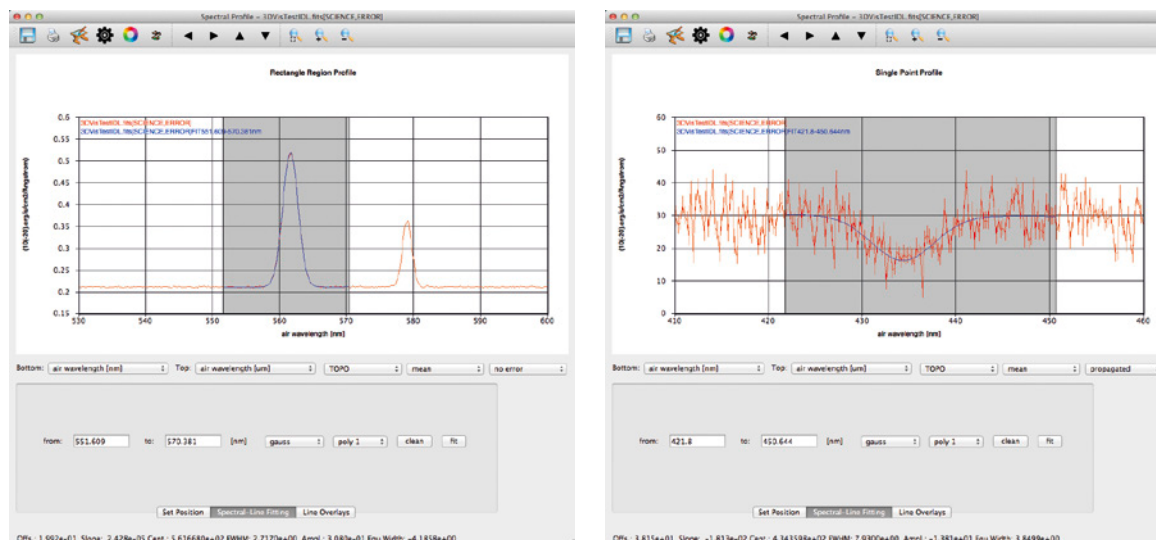


Figure 3. Example of Gaussian emission line fit plus continuum (“poly1”) which is applied over the region marked by the grey shaded area. The fit is shown in blue, and the results are shown in the status bar at the bottom of the window.

either by cursor interaction or numerical input. A range of fitting options, such as the inclusion of a first order continuum is available. Then with a click of a button, a fit is carried out in the specified region and the result shown graphically (blue solid line in Figure 3) and numerically — the fit results with estimated errors are provided at the bottom of the spectral profiler window and on the command line.

The visualisation of data errors, where available, was a requirement for the development of the viewer. In Figure 4 we show an example of a spectrum where the error estimates given in the dataset are displayed for each data point. Not only can one use the errors for visualisation, but they are also used, for example, in Gaussian line fitting, if they are displayed (see Figure 4). When no external error estimates are provided or an independent estimate is desired, the tool will optionally provide error estimates derived from internal data statistics, e.g., for spectra averaged over a user-defined region.

### Software download and documentation

The ESO 3D viewer for optical/near-infrared data originating from the VLT is not distributed separately but incorpo-

rated into the standard ALMA CASA software viewer. From CASA version 4.0 onwards, the features described in this article will be available as part of the CASA viewer. The CASA software is freely available<sup>1</sup> and full installation is required to make use of the viewer. CASA is also part of the ESO Scisoft software collection<sup>2</sup>.

A user manual for the viewer, particularly targeted at users with optical/near-infrared data, has been produced as part of the project. Additionally, for the somewhat less patient users, we provide a “cook-book” with five simple step-by-step examples on how to use the relevant functionality of the viewer. This includes examples ranging from basic tasks such as loading a cube and displaying a spectrum, to obtaining a 2D fit in the image plane. The manual and cookbook are available<sup>3</sup>.

### Use of the 3D visualisation tool

The ESO 3D viewer provides a way of visualising VLT integral field unit data products conveniently. An effort has been made to harmonise the output of the VLT data reduction pipelines and the interface to the viewer. If error estimates are available in the data products — particularly relevant for second generation VLT instrumentation — the viewer can display the extra information and make use of errors in the internal calculations.

Feedback and problem reports concerning optical/near-infrared data for the

Figure 4. Example of spectrum visualisation with errors. A Gaussian fit (blue line) is applied to an absorption line in the grey-shaded region, including error estimates for each data point; numerical results of the fit are given at the bottom of the window.

viewer are provided by ESO via the user portal or by email<sup>4</sup>. General support for the CASA software is also available<sup>5</sup>. Users who make use of this tool for analysis of their optical/near-infrared 3D data are kindly requested to refer to this article in any publications.

### Acknowledgements

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### Links

- <sup>1</sup> CASA software available: <http://casa.nrao.edu/>
- <sup>2</sup> ESO Scisoft collection: <http://www.eso.org/sci/software/scisoft/>
- <sup>3</sup> ESO 3D viewer manual and cookbook available from: <http://www.eso.org/pipelines/>
- <sup>4</sup> Email for help on 3D viewer: [usd-help@eso.org](mailto:usd-help@eso.org)
- <sup>5</sup> Help on CASA software available from: <http://almascience.eso.org/>