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Abell 1656: the Coma Cluster of Galaxies

Massimo Ramella & Giulia Iafrate
INAF - Osservatorio Astronomico di Trieste

Caroline Bot & Thomas Boch
updated for the doctoral day in Paris

Jenny G. Sorce
updated with the new template for ASTERICS & new plots

Katharina A. Lutz
updated to Aladin v10

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Template by Jenny G. Sorce

Contents

1 Introduction

Goal:

- Examine the Coma cluster of galaxies (Abell 1656) using VO data and tools in order to perform a quick evaluation of the mean redshift and velocity dispersion of the cluster.
- Use redshifts and photometry (Petrosian r magnitude) of the SDSS survey and then add redshifts of the CAIRNS survey (Rines et al. 2003) in order to improve the completeness of the redshift sample.
- Look for hydrogen lines in HST spectra in the direction of this cluster and check whether the lines are consistent with foreground or with galaxy velocities.

The software packages we require to tackle these tasks are Aladin, TOPCAT and CASSIS.

2 Display the region of Abell 1656 in Aladin

- Launch Aladin: Open a terminal and type: `java -jar Aladin.jar &`.
- In Aladin, enter 'A1656' (Coma Cluster) in the **Command** slot of the main window.
  

- Zoom/unzoom to work with galaxies in a region of about 40 by 40 arcmin around the Coma cluster. At the distance of Coma, 40 arcmin corresponds to 1.1 Mpc (with H_0=71 $\mathrm{km\,s^{-1}}$ $\mathrm{Mpc^{-1}}$, Ω_Λ=0.73 and Ω_m=0.27), a region large enough for our purposes. Tip: The cyan/blue numbers at the bottom of the main viewing window and in the overview panel in the bottom right corner of Aladin indicate the area shown in the main viewing window (Figure 1). As a second option draw a 40' long arrow with the **dist** button 
  .

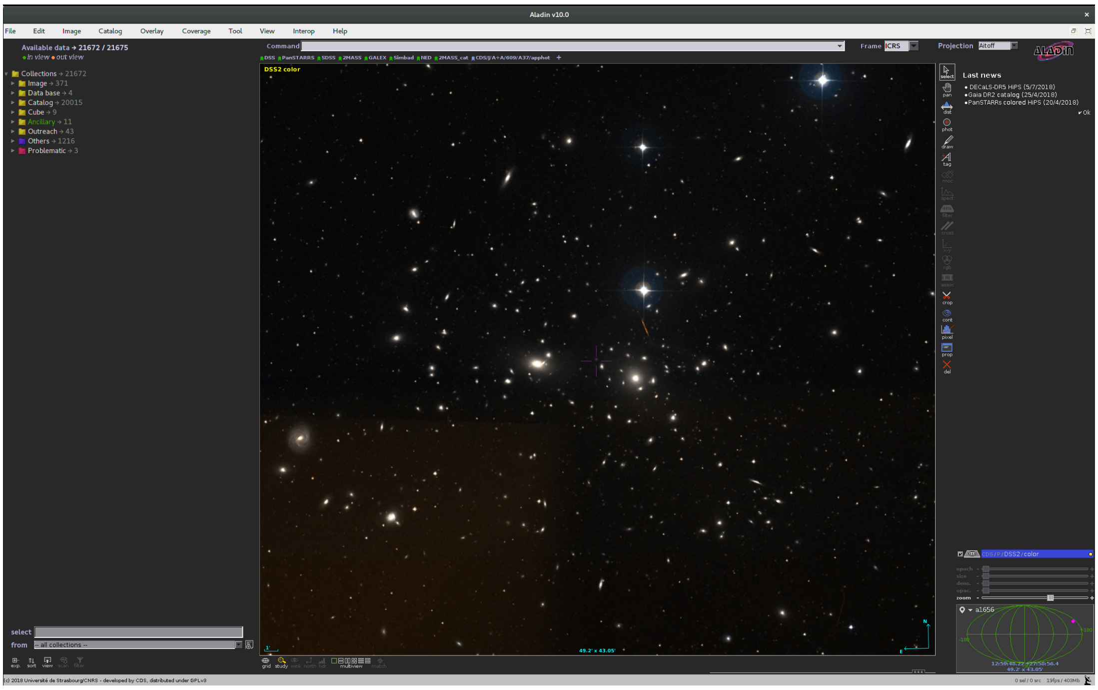
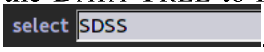
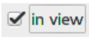


Figure 1: Abell 1656 (Coma Cluster) in Aladin

3 Load the SDSS-DR9 catalogue and select galaxies

- Load the SDSS-DR9 catalogue through the DATA TREE: Type "SDSS" in the **Select** line below the DATA TREE to limit the resources shown in the DATA TREE to those connected to SDSS 

. You can further narrow down your search by restricting the collection of data sets with **from** 

. More complex filters can be created by clicking on . Under "Catalog" → "VizieR" → "II-Photometric Data" click on SDSS-DR8, make sure that the **in view** box is ticked 

and click **Load** (Figure 2).

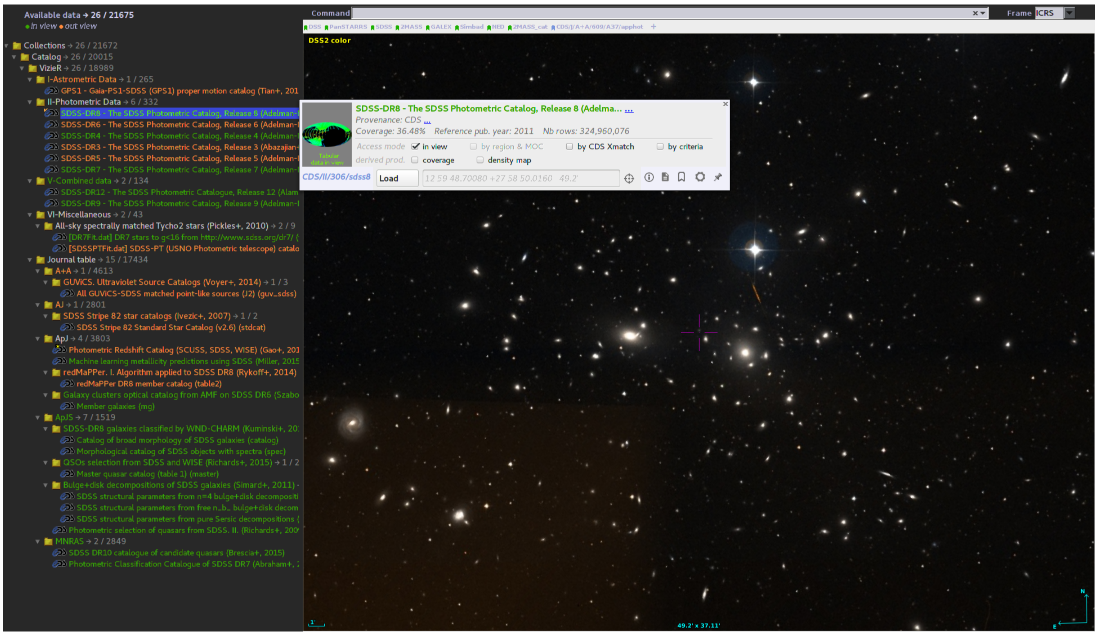


Figure 2: The Aladin DATA TREE when filtered to "SDSS" resources in "large catalogues". Green resources have entries in the area of the sky that is currently shown in the main viewing window, orange ones not. The grey pop-up window allows you to load the data in different ways, e. g. load all data within the field of view or filter the catalogue by MOC.

- Catalogue data of approximately 50,000 sources have now been loaded. To limit this sample to galaxies (cl=3) that are also SDSS primary sources (mode=1) we continue as follows (Figure 3):
  - In the Aladin stack (right), select the catalogue plane, click on the **Filter** button 

and write the following syntax in the **Advanced mode** tab:
    `${cl}=3&&${mode}=1{draw}`
    Clicking **Apply** ensures that our sample is selected according to our selection criteria and that only sources that adhere to these criteria are shown in the main viewing window.
  - Still in the filter window, clicking **Export** will build a new plane with only filtered sources included.
  - Note that the **Pick** line above the free syntax field is helpful to create other filters.

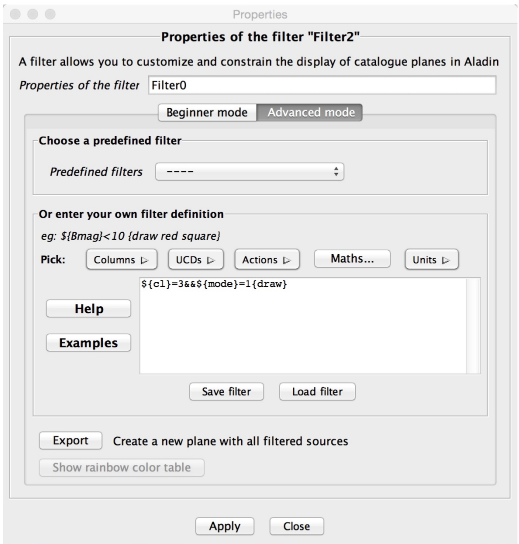


Figure 3: Filtering with Aladin

- Rename this new plane SDSSgalaxies using the **Properties** button. Depending on your field of view the new filtered catalogue includes around 35,000 sources.
- Broadcast the filtered catalogue to TOPCAT. You can do so by right-clicking on the catalogue plane and selecting **Broadcast selected tables to...> topcat**. Beware that TOPCAT must be launched for this function to be enabled.

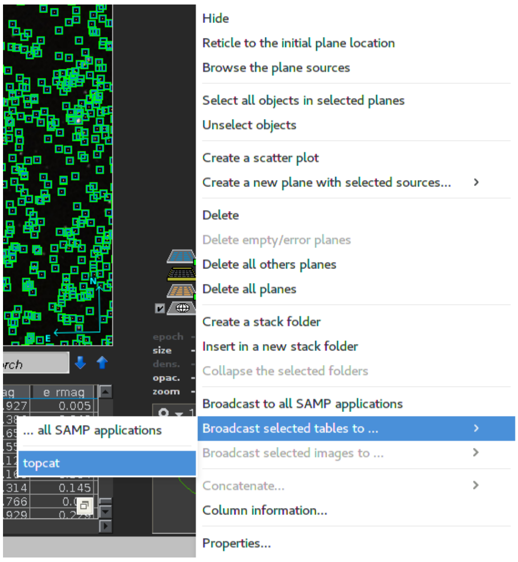


Figure 4: Broadcasting the filtered catalogue to TOPCAT.

- In TOPCAT, display the column metadata with . In the new window, deselect all rows and then select only the four necessary columns: RA_ICRS ($10), DE_ICRS ($11), zsp ($12) and rmag ($17).

4 Identify the brightest sources as being stars contaminating the sample

- In the main TOPCAT window, open the subset window and build a subset of the brightest sources (with magnitudes rmag<11.5):
  - In the subset-window, click on to define a new row subset.
  - **Subset name**: 'stars'.
  - **Expression**: `$17<11.5` or `rmag<11.5` (Note: TOPCAT expressions do not differentiate small/capital letters. Depending or the column names of the table you might have to use $ID of the column rather than its name. $ID can be found with **Views** → **Column Info** or in the main TOPCAT window).
- There are two options to check in Aladin that each source in the star subsample is indeed a star:
  - In the main TOPCAT window, select the 'stars' subset of the SDSSgalaxies catalogue Row Subset: Stars and broadcast it to Aladin (**Interop** → **Send table to** → **Aladin** or). Switch to Aladin and look through the sources by clicking on their entry in the table. Zoom/unzoom as necessary.
  - In TOPCAT go to **Views** → **Activation Action** or . In the newly opened window, tick the box of and select **Send Sky Coordinates**. Upon selection you can edit the settings for this activation action. See Figure 5 for the options chosen for our case. If you now display the table cell data ( ), you can click on any table entry and the corresponding source will be displayed in Aladin. Again zoom/unzoom as necessary.

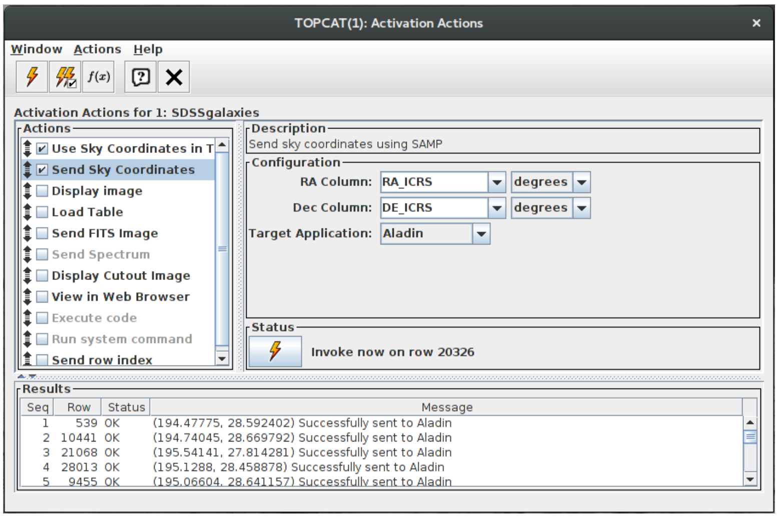


Figure 5: Setting up activation actions in TOPCAT.

5 Build a subset of galaxies with photometry (rmag) and redshift (zsp) in SDSS

- In the main TOPCAT window, open the subset window again and build a subset of galaxies (no stars, i.e. `rmag>11.5`) with magnitude rmag brighter than 17.77 mag (completeness limit of the SDSS spectroscopic sample) and redshift information. This can be done with the subset expression: `zsp>0 && rmag<=17.77 && rmag>11.5`. Call this subset ‘zsp17’.

- In the main window of TOPCAT select the subset ‘zsp17’ and duplicate the table (**File** → **Duplicate Table**).
- Rename the new table to ‘zsp17’.

6 Improve the completeness with other sources of redshifts in VizieR

- In TOPCAT, build the subset ‘nozsp17’ that contains galaxies with the same magnitude selection as before but no redshifts (use `!(zsp>0)` instead of `zsp>0` in the above expression). Again depending on your field of view the new subset contains between 100 and 200 entries.
- Select the subset ‘nozsp17’ in TOPCAT main window, duplicate the table and rename the new table ‘nozsp17’.
- In TOPCAT main window, search optical catalogues with redshifts:
  - Go to **VO** → **VizieR catalogue service**.
  - Select **Cone selection**: **Object name**=‘A1656’, click on **resolve**, **radius**=‘40’ arcmin. Then select **All Rows**.
  - In the **catalogue selection** section: select the **by Keywords** tab and enter ‘redshifts Rines’, load the **Rines+ 2003** catalogue. Two tables are loaded. Delete the cluster catalogue to keep only the galaxy one (**File** → **Discard Table(s)**).

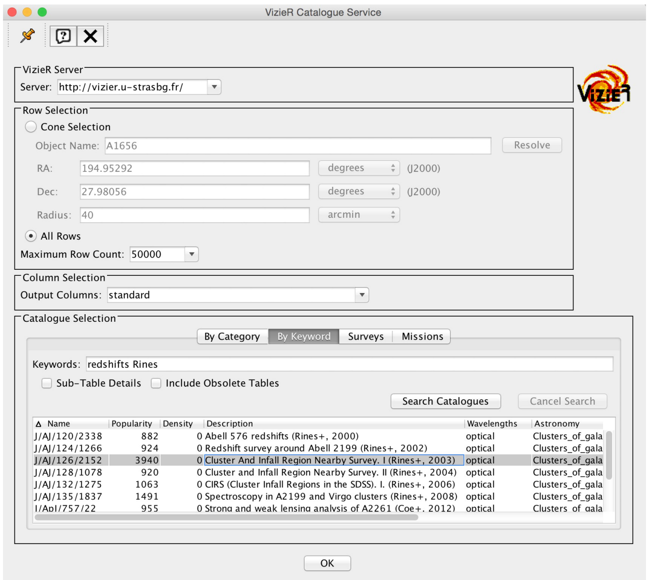


Figure 6: Loading a catalogue from VizieR with TOPCAT.

- Find redshifts in Rines+ catalogue for galaxies without redshift in nozsp17:
  - X-match the ‘nozsp17’ and the Rines catalogue (**Joins** → **pair match** or )

– Use **sky** algorithm with ‘5 arcsec’ max error and choose **Best match, symmetric**. See Figure 7 for more details.

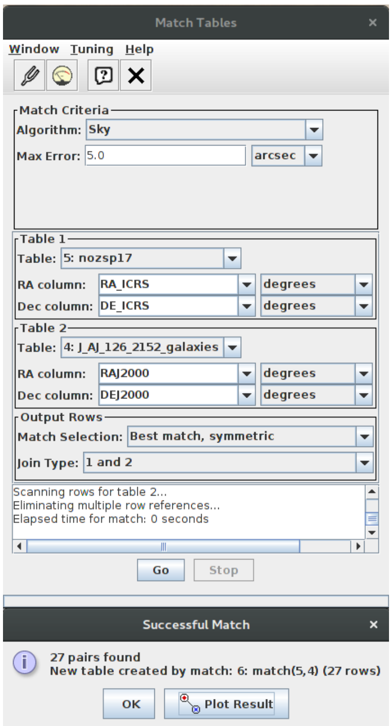


Figure 7: X-matching with TOPCAT.

7 Build the final catalogue including Rines+ redshifts

- Add a new column to ‘zsp17’ catalogue to get the apparent radial velocity cz:
  - Click **Table Columns**, then do **Columns** → **New Synthetic Column** or click.
  - **Name**: ‘czsp’
  - **Expression**: `toInteger(zsp*300000)`
- Concatenate ‘zsp17’ and match tables (**Joins** → **Concatenate Tables**). Fill in the **Appended Table** tabs. The final catalogue contains around to 700 galaxies.

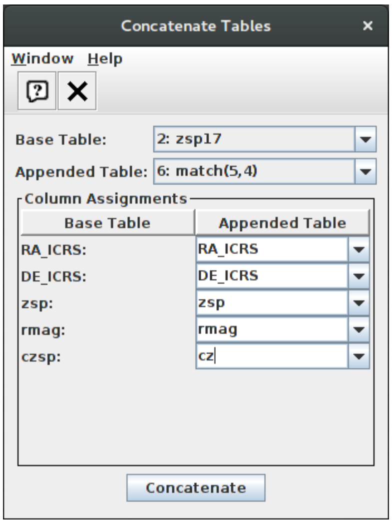


Figure 8: Concatenating with TOPCAT.

8 Determine the cz distribution, <cz> and dispersion in TOPCAT

- View the histogram of 'czsp' values with
- Isolate the main peak of Coma in the histogram by selecting the appropriate region scrolling your mouse or playing with **Axes** (**Range** tab) and **Bins** (**Bin size**) Axes Bins (see Figure 9 for an example).

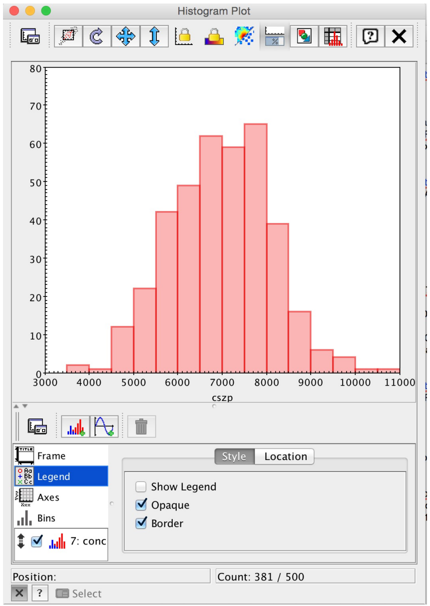


Figure 9: Main peak of the Coma cluster.

- Build a new subset named 'Coma' using the range of cz observed in the histogram (proceed as before to build new subsets or once having zoomed in on the Coma peak use this button:).
- Select this Coma subset in the main window of TOPCAT and open the **Row Statistics** window Σ . You will find something like <cz>≈7000km s^{-1} and SD≈1000km s^{-1} both in excellent agreement with more refined analyses (Figure 10).

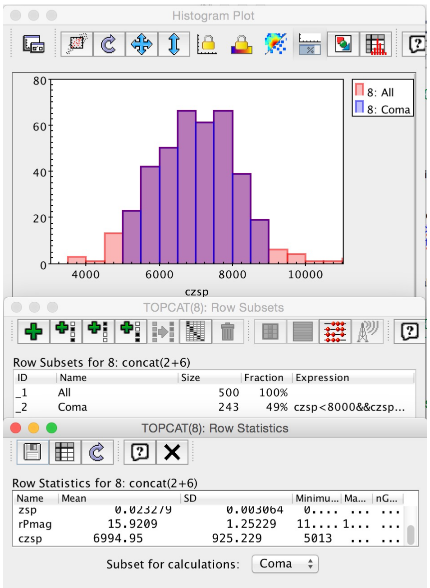


Figure 10: Statistics with TOPCAT.

9 Look for HST spectra in the Coma Cluster

- Go back to the Aladin window. Adjust the main viewing window such that once again it is centred on "A1656" and has a field of view of approximately 40×40 arcmin.
- Type "HST" in the **Select** line and set **from** to "- - all collections - -". Narrow down the search in the Data discovery Tree filter window  by ticking the box of **SSA** (for Simple Spectral Access) in the **Technical** tab.
- Select **Others** → **SSA** → **mast.stsci** → **Hubble Space Telescope Spectra**, tick **in view** and then **Load** the table.
- Find the table entry for source 1257-2840 and (left-) click on the link in the url of the spectrum (in the first column). This will open an menu and allow you to broadcast the spectrum to CASSIS (if CASSIS is up and running).

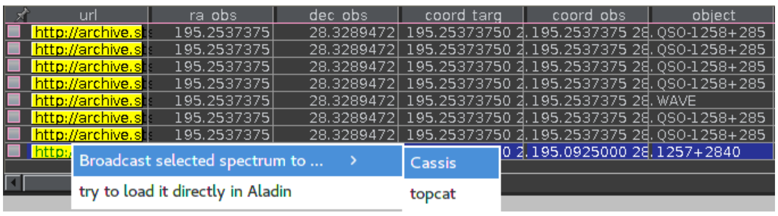
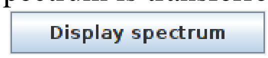


Figure 11: Broadcast the spectrum of 1257-2840 to CASSIS.

10 Visualize and analyse the HST spectrum with CASSIS

- Once the spectrum is transferred to CASSIS, the **Spectrum Manager** appears. Select **Display Spectrum** 

. The spectrum is now displayed in the CASSIS main window. Two lines are clearly visible: one around 1250 Angström and one around 1350 Angström (see Figure 12).

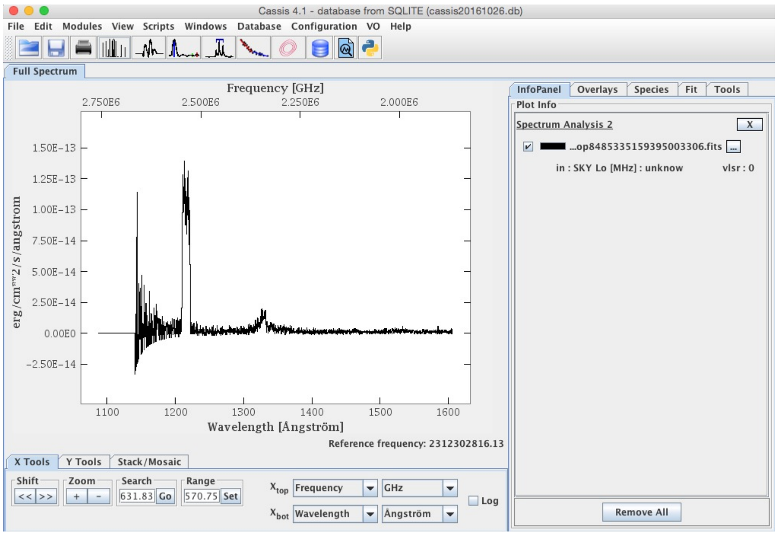


Figure 12: Visualisation of the spectrum with CASSIS.

- To check that these are hydrogen lines (Lyα), one at the local velocity, the other at the velocity of the Coma cluster (Figure 13):
  - Select the **Species** tab. Choose the **Full NIST** database in the **Template** section.
  - Unselect all species by clicking on the **Sel.** column.
  - Select the sole **HI** line by ticking only this line.
  - The maximum **Eup threshold** is by default too low for our case. Remove the '150.0K' and replace it with ' * ' to get all the HI transitions without any threshold in energy.
  - Tick **show signal** and click **Display** at the bottom of the window. A green tick appears below the largest of the two lines. This confirms that this line is an Hydrogen line at a zero velocity. Clicking on the green tick gives more information on the line parameters. A right click allows you to edit the overlay (useful for a copy-paste).

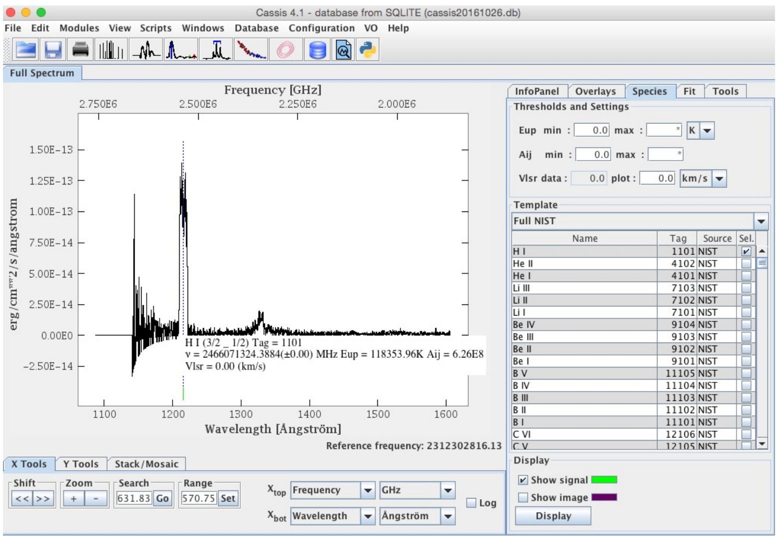


Figure 13: Spectrum with CASSIS. The the blue, dotted line and the green dash mark the location of the Lyα line at a line of sight velocity of $0.0\,\mathrm{km\,s^{-1}}$

- To look for the LSR velocity of the galaxy in SIMBAD:

- Go back to the Aladin window and centre the image on the pointing centre of the HST spectral observations by double-clicking on the table row of the source 1257-2840. Zoom in or out as necessary.
- Make sure that the **Simbad Pointer** is activated (a tick next to **Tool** → **Simbad pointer**).
- Hover over of the pointing centre of the HST spectral observations until a small window appears.

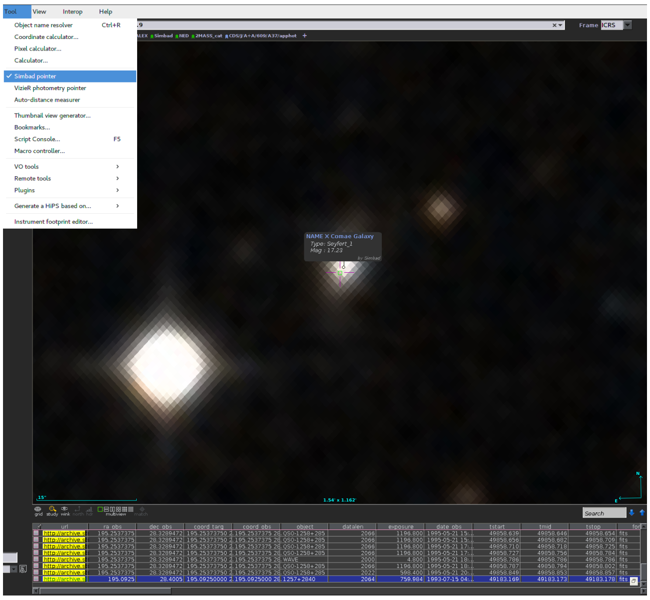


Figure 14: How to enable and operate the SIMBAD pointer in Aladin.

- Clicking on the name of this galaxy (NAME X COMAE GALAXY) opens a web browser with all the SIMBAD information for this object.
- The radial velocity for this galaxy is 27332.1 $\mathrm{km\ s^{-1}}$.
- Note that this galaxy is not part of the Coma cluster since the velocity of the Coma cluster is 6845 $\mathrm{km\ s^{-1}}$. This value can be found with SIMBAD looking for A1656. The hierarchical link parents on NAME X COMAE GALAXY in SIMBAD confirms that the probability of this galaxy to belong to Coma is 0%.

* Go back to CASSIS and change the **Vlsr plot** field from 0 to 2.7e4 $\mathrm{km\ s^{-1}}$ (Figure 15). As soon as you click **Display** again, the green tick corresponding to the HI line moves right under the second fainter line in the HST spectrum. This confirms that this line is associated to this Seyfert 1 galaxy.

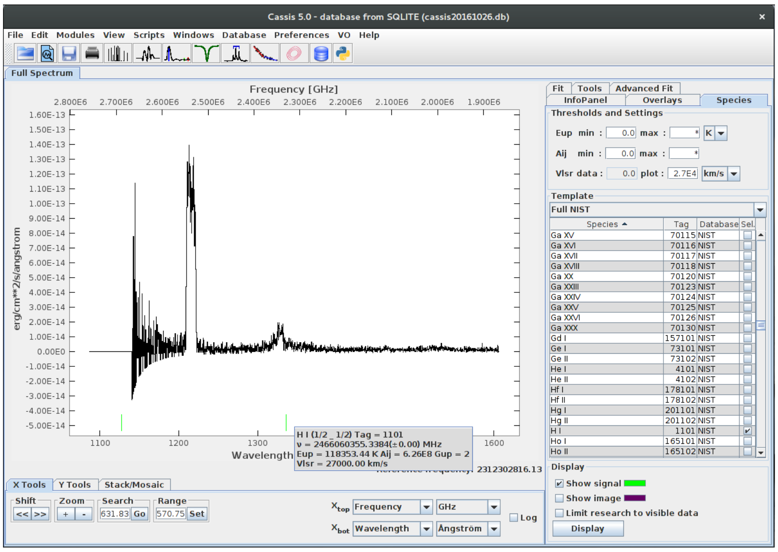


Figure 15: HI line of the Seyfert 1 galaxy.

11 Fit a gaussian and a continuum to the hydrogen line

- Focus on a small portion of the spectrum, centred on the HI line of the Seyfert 1 galaxy and fit the line with a Gaussian profile and a continuum: In the **spectrum analysis** (if necessary open by clicking ) window, reduce the wavelength range: 1300 to 1375 Angström and click .
- In the CASSIS main window, select the **Fit** tab and add two components using the **Manage Components** menu: a polynomial baseline and a Gaussian line.
- Change the **degree** of the polynomial to ‘ 0 ’ in order to fit a constant baseline.
- For the Gaussian component, the purple/blue fields should be filled with initial values in order to start the fitting procedure. They can be filled by hand but a useful way of filling them in is: use the middle button of your mouse to click and drag the region of the line or alternatively with a trackpad press both ctrl+alt and click and drag to draw the region. Beware that the Gaussian parameters should stay violet/blue (do not click on any of them) if you want them to fill in automatically. The position of the peak (**xo**), its height (**Io**) and the width of the line (**FWHM**) are estimated automatically from the selection. This selection, visible in purple/blue on Figure 16, can be erased using the **reset** buttons in **Selections [with middle-click-and-drag]**.
- Click on **Fit current** to perform a fit of the line+baseline. The different components of the fit can be selected or deselected in the **InfoPanel**.
- Go back to the **Fit** panel and note the central wavelength of this line as inferred from the best fit: 1327 Angström.

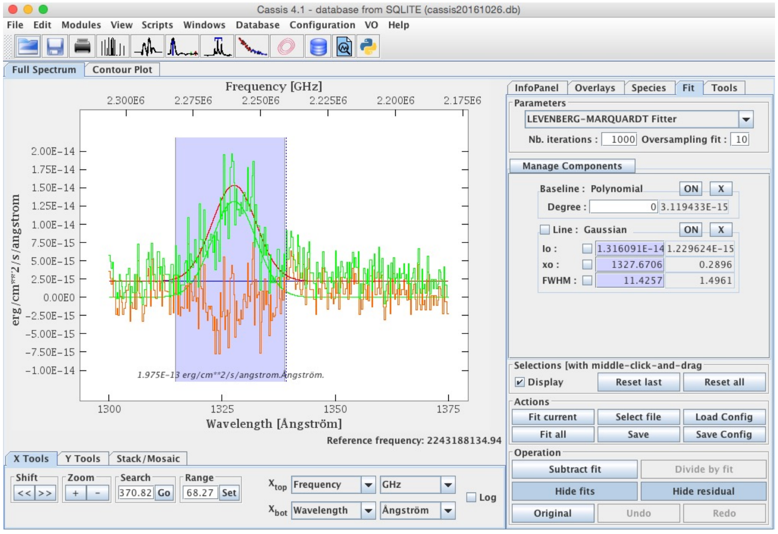


Figure 16: Fit of the spectrum.

- Given that the rest wavelength for the Lyman α line is 1215.67 Angström, the velocity of the galaxy is v=c$\times\Delta\lambda/\lambda_0$=27,420 $\mathrm{km\ s^{-1}}$ or in redshift, z=v/c=0.0914.
- This value can be compared to the value given in SIMBAD.