

Abell 1656: the Coma Cluster of galaxies

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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. We 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. We search for HST spectra in the region of A1656 and check whether the observed lines are consistent with those of cluster members.

Software to launch: Aladin, TOPCAT and CASSIS

Step-by-step:

1. Display the region of A1656 in Aladin

Choose an optical **Allsky Survey** (e.g. SDSS 9 colored) from the HiPS (Hierarchical Progressive Surveys) available in Aladin from the *File>Progressive Sky (HiPS)>image>optical* menu.

Type **A1656** (Coma Cluster) in the location slot in the main window and zoom/unzoom to work with galaxies in a region with radius of about **40'** around the Coma cluster. At the distance of Coma, 40' correspond to 1.1Mpc (with $H_0=71 \text{ Mpc}^{-1} \text{ km s}^{-1}$, $\Omega_V = 0.73$, $\Omega_M = 0.27$), a region large enough for our purposes. Tip: in order to check the radius of the region being displayed, read it at the bottom of the display window or in the small white box in the

bottom right corner. As a second option, draw a 40' long arrow with the "dist" button .

2. Load the SDSS-DR9 catalog and select galaxies

Load the SDSS-DR9 catalog from the "Surveys" tab in the server selector window, radius 40', **check 'retrieve all columns'**.

Filter SDSS and leave only galaxies (**cl=3**) that are also SDSS primary sources (**mode=1**):

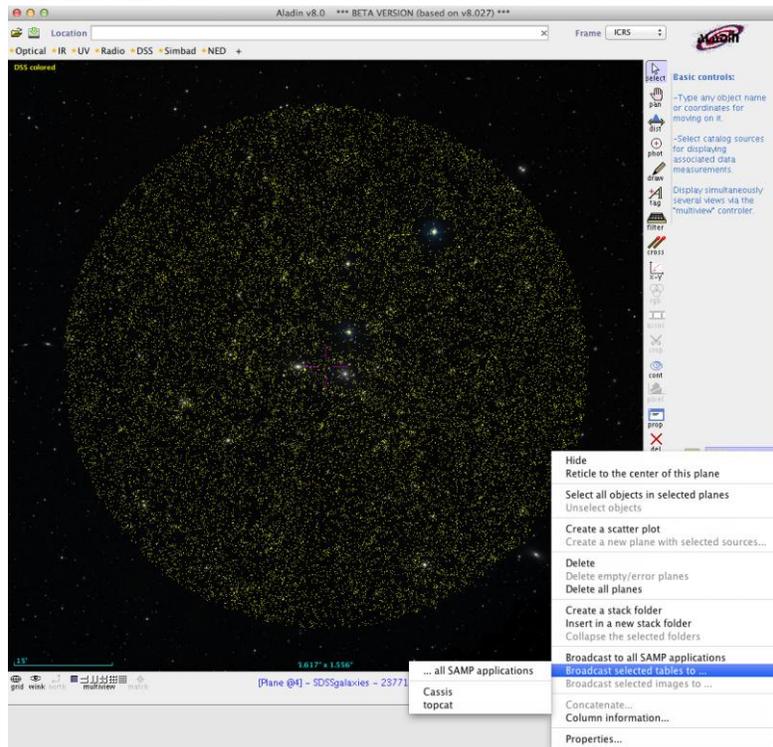
- select the catalog plane, in the **Catalog tab**, select **Create a filter in Advanced Mode** by writing the following expression:

$\{\text{cl}\}=3 \ \&\& \ \{\text{mode}\}=1 \ \{\text{draw}\}$

note that you may insert **cl** and **mode** in the expression selecting them from "Columns->Columns in loaded catalogs". Try also the "math" button in case you need symbols not on your keyboard.

- In the filter window, press '**Apply**' and then '**Export**' to create a new plane with only the filtered sources. Rename this new plane SDSSgalaxies using the '**Properties**' function and, if necessary, change the markers for clarity. The new filtered catalog should have 23770 sources.

- **Broadcast the filtered catalog to Topcat.** You can do so, either by right-clicking on the catalog plane and selecting *Broadcast selected table to...>topcat*, or by clicking the icon of the antenna in the right bottom corner of the window.



In Topcat, display the column metadata (), deselect all (make all table columns invisible with ) and select () **only the four columns we need: RAJ2000 (\$15), DECJ2000 (\$17), zsp (\$31) and rPmag (\$83).**

3. Create a subset of galaxies with photometry (rPmag) and redshift (zsp) in SDSS

In the main TOPCAT window, open the **subset window** () and create a subset of galaxies with magnitude rPmag brighter than $rPmag_{lim}=17.77$ (completeness limit of the SDSS spectroscopic sample):

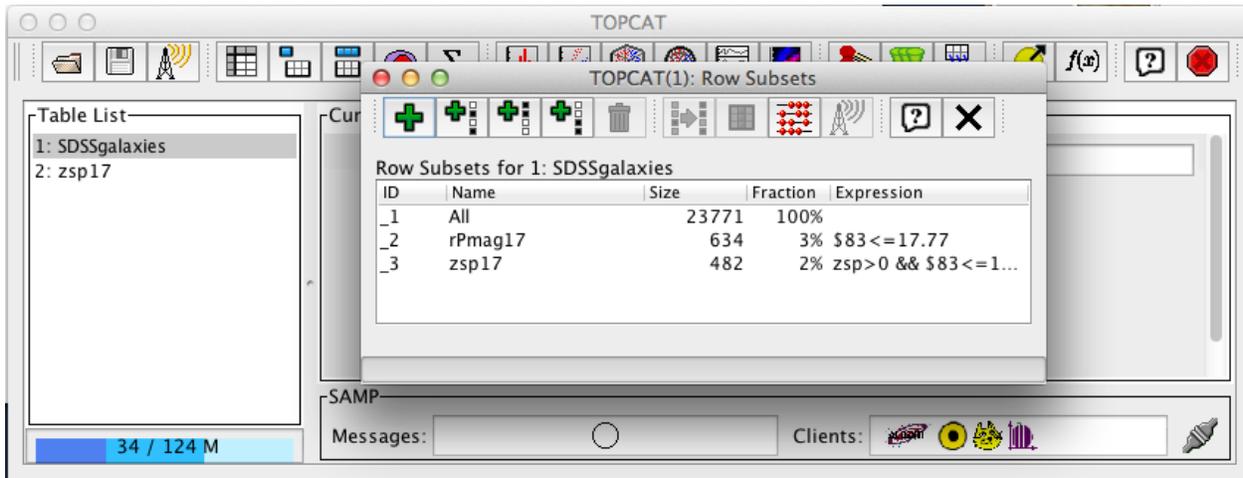
- press  to define a new row subset
- subset name: rPmag17
- Expression: \$83 <= 17.77
- NOTE: Topcat expressions do not differentiate small/capital letters and SDSS contains both rpmag and rPmag. In this case you have to use \$ID of the column rather than its name. \$ID can be found with Views->Column Info.

Create another subset of the SDSS catalog, named zsp17, with the subset expression $zsp > 0 \ \&\& \ rMag \leq 17.77$. For more complex expressions it may be useful to reference already defined subsets rather than repeating their defining expressions, in this case:

rPmag17 && zsp>0

NOTE: operations/functions in Topcat act on the selected row subset, not on the whole table!

In the main window of Topcat select the subset zsp17 and **duplicate the table** (*File -> Duplicate Table*). **Rename the new table to zsp17**. You can note the redshift completeness of the rPmag17 sample is 76% (=482/634).



4. Eliminate bright stars from SDSSgalaxies catalog

Bright stars may have been mistakenly included in the SDSS catalog of extended objects. We now identify and remove these objects, if any.

Find the magnitude of the brightest galaxy in Coma: in Aladin, select the eastern of the two central bright elliptical galaxies and verify that $rPmag_E = 11.718$.

In Topcat:

-Create a subset of probable stars with $rMag < 11.7$, name it “stars”

-In the main Topcat window, check “Broadcast row”, open the table **stars** () and scroll through the rows. The selected entries will be displayed in Aladin. Use the maximum zoom factor available and check that these objects are indeed stars

In Topcat, create a subset **rPmag17ok** of rPmag17 without objects brighter than $rPmag = 11.7$ (or modify the definition and name of rPmag17 directly in the subset window). Completeness rises slightly (482/622).

5. Improve completeness with other sources of redshifts in Vizier.

In Topcat create the subset **rPmag17oknoz** of **rPmag17ok** (use subset selection from table browser or create subset with expression **!(zsp>0)** together with the expression for

rPmag17ok). The new subset has 140 entries, select it in Topcat main window and duplicate the table. Rename the new table **rPmag17oknoz**.

In Topcat, search optical catalogs with redshifts

-go to *VO* -> **Vizier Catalog service**

- Select *Cone selection*

-Object name = **A1656**, click on *resolve*

- radius = **40'**

-In the *catalog selection* section:

-select the *by keywords* tab and type 'redshifts'

-sort names, check *Clusters_of_Galaxies, Redshifts*

-load the **Rines+ 2003** catalogs

-two tables are loaded. Delete the cluster catalog and keep only galaxies

Find redshifts in Rines+ catalogue for galaxies without redshift in rPmag17:

- **X-match the rPmag17oknoz and the Rines catalogs** (*Joins* -> *pair match* or  icon). Use **sky** algorithm with **5'' max error** and choose *Best Match*.

Transmit the catalog **matched** with 18 galaxies to Aladin for inspection (or scroll entries in topcat having checked **broadcast row**)

6. Create the 'final' catalog including Rines+ redshifts

Compute the quantity *cz* (km/s) and add it in a new column to the *zsp17* catalog:

-In the Table Columns window () go to *Columns>New Synthetic Column* or click the  button

-Name: *czsp*

-Expression: *toInteger(zsp*300000)*

Concatenate the two tables **zsp17** and **matched** (*Joins* -> *Concatenate Tables*).

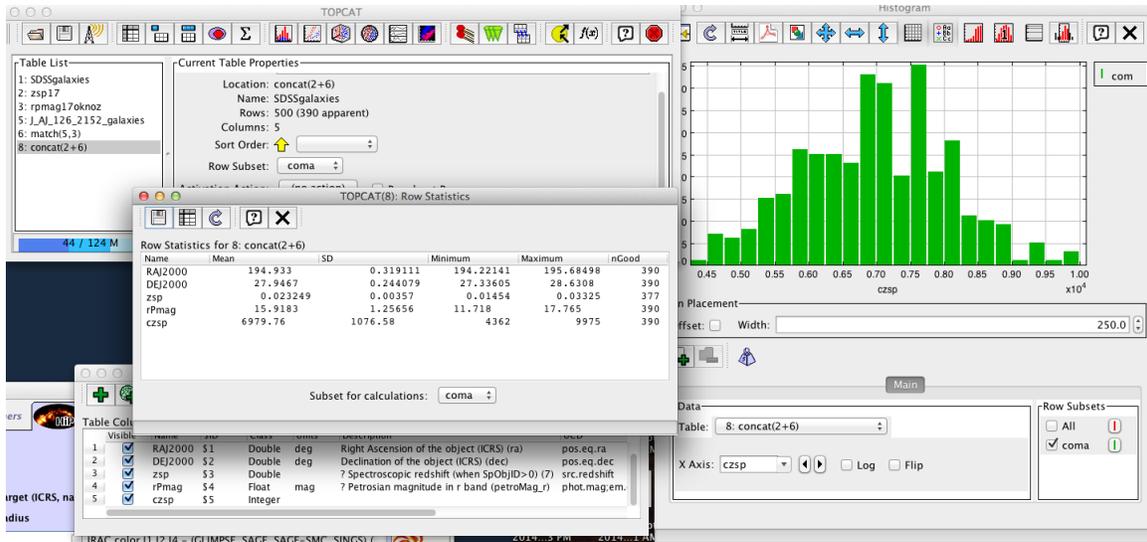
Coordinates have to correspond to coordinates and *czsp* to *cz*. The final catalog contains 500 galaxies, and the redshift completeness of **rPmag17** is $500/634 = 79\%$.

7. Determine the *cz* distribution, <cz> and dispersion in Topcat

View the histogram of *czsp* values with the  button.

Isolate the main peak of Coma in the histogram by selecting the appropriate region with your mouse by zooming and panning (toward *cz=0*) the histogram until only the main peak of the *cz* distribution is visualized. Create a new subset named **Coma** (*Subset > new subsets from visible*)

Select the **Coma** subset in the main window of Topcat and open the Row Statistics window () . The mean velocity should be close to $\langle cz \rangle = 7000$ km/s and the velocity dispersion close to $SD = 1100$ km/s, both in agreement with more refined analyses.



8. Look for HST spectra in the Coma Cluster

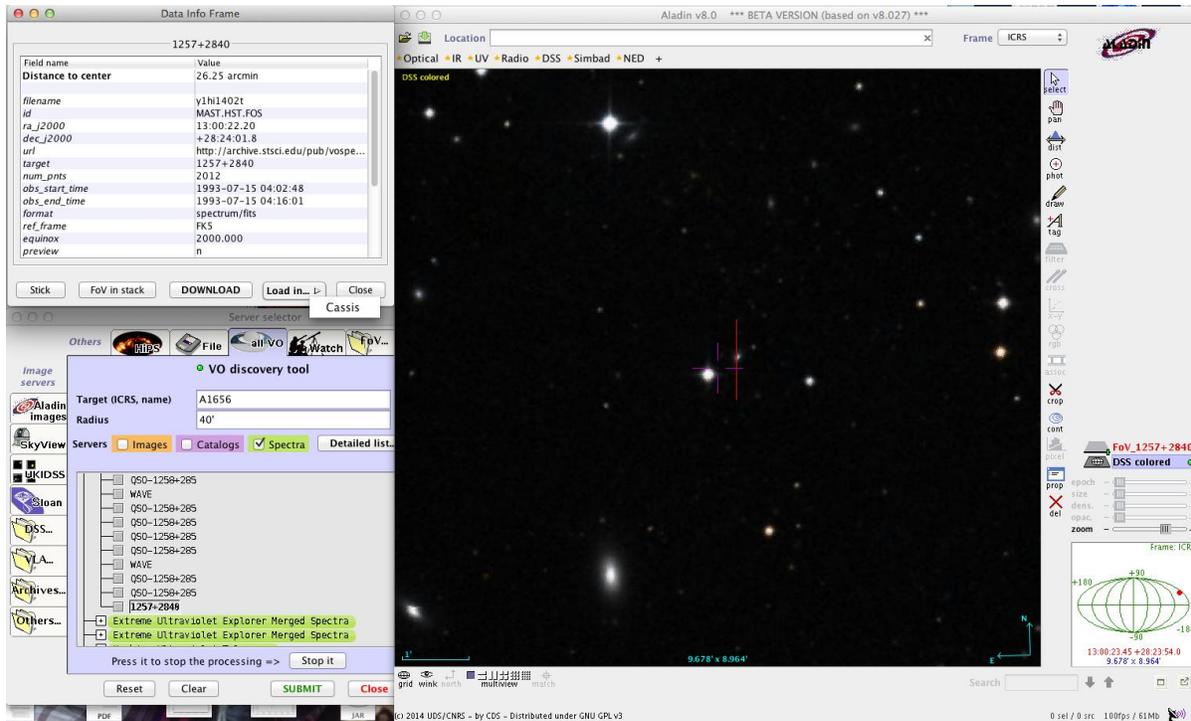
Go back to the Aladin window. Open the server selector () and select the  tab.

- Target: **A 1656**
- Radius: **60'**
- Unselect the Images and Catalogs servers (in order to get information **only on spectra** available in this region).
- Press **SUBMIT**

Browse the different menus and look at the “S” appearing on the image for some services. Each “S” corresponds to the location of a spectrum.

Open the “**Hubble Space Telescope Spectra**” menu and click on the **QSO 1257+2840** name. This opens the Data Info Frame that gives access to information about this observation.

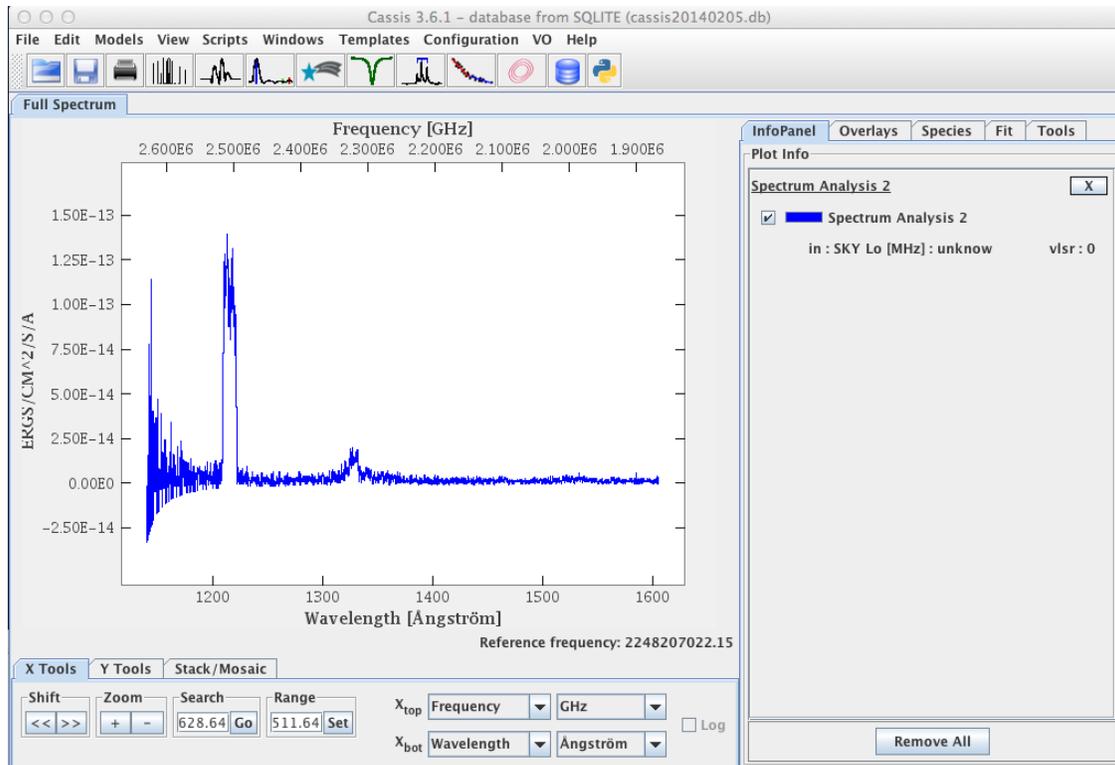
Click on “**FoV in stack**” and visualize the slit location on the image in the main Aladin window.



In the Data Info Frame, select *Load in...> Cassis*

9. Visualise and analyse the HST spectrum with CASSIS

Choose the **Spectrum Analysis** option and then click **Display**. The spectrum is now displayed in the CASSIS main window.



We can clearly see two lines: one around 1250 Å and one around 1350 Å. We will now check that these are consistent one with the hydrogen line Ly- α at rest, and the other at a velocity beyond that of the Coma cluster.

Select the **Species** tab. Choose the **Full NIST** database in the Template section. Unselect all species by clicking on the “Sel.” column. Select only the HI lines.

The maximum Eup threshold given by default is too low for our use case. Remove the 150.0K and replace it by * to get all HI transitions without any energy threshold.

Check “*Show signal*” and click **Display** at the bottom of the window.

InfoPanel Overlays **Species** Fit Tools

Thresholds and Settings

Eup min : 0.0 max : * K ▾

Aij min : 0.0 max : *

Vlsr data : 0.0 plot : 0.0 km/s ▾

Template

Full NIST ▾

Name	Tag	Source	Sel.
H I	1101	NIST	<input checked="" type="checkbox"/>
He II	4102	NIST	<input type="checkbox"/>
He I	4101	NIST	<input type="checkbox"/>
Li III	7103	NIST	<input type="checkbox"/>
Li II	7102	NIST	<input type="checkbox"/>
Li I	7101	NIST	<input type="checkbox"/>
Be IV	9104	NIST	<input type="checkbox"/>
Be III	9103	NIST	<input type="checkbox"/>
Be II	9102	NIST	<input type="checkbox"/>
Be I	9101	NIST	<input type="checkbox"/>
B V	11105	NIST	<input type="checkbox"/>
B IV	11104	NIST	<input type="checkbox"/>
B III	11103	NIST	<input type="checkbox"/>
B II	11102	NIST	<input type="checkbox"/>
B I	11101	NIST	<input type="checkbox"/>
C VI	12106	NIST	<input type="checkbox"/>

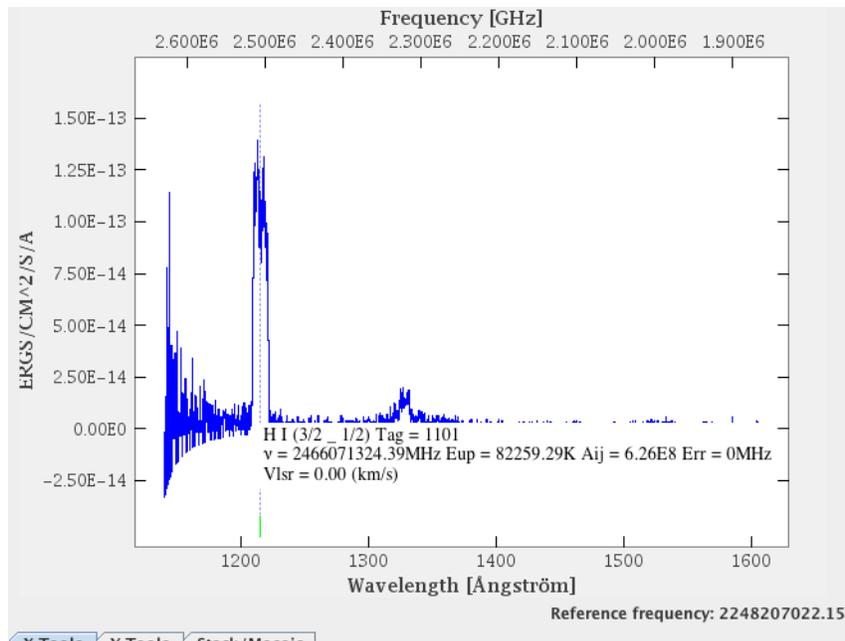
Display

Show signal █

Show image █

Display

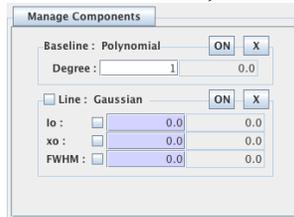
A green tick appears below the largest of the two lines in our spectrum, confirming that this line is a Hydrogen line at zero velocity. You can click on this green tick to get more information on the line parameters. A right click on the text will let you edit this overlay (useful for copy-paste)



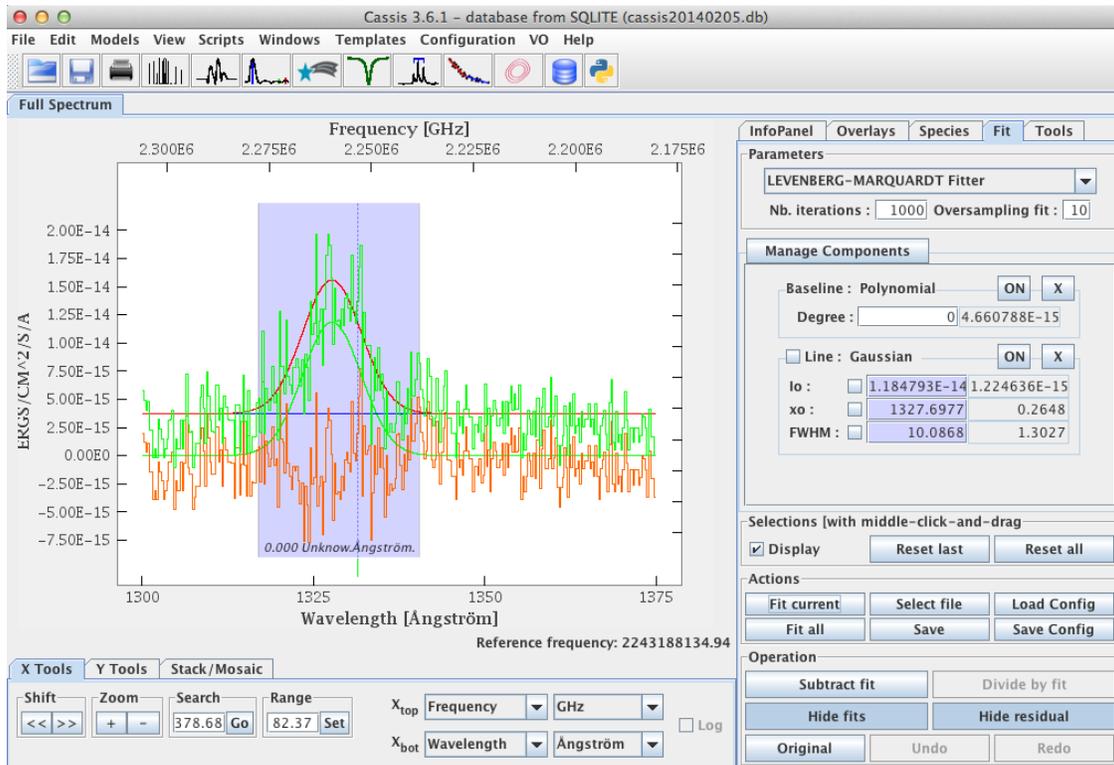
10. Fit a gaussian and a continuum to the hydrogen line

By clicking the left button and dragging the mouse, select the region of the spectrum 1275 Å – 1375 Å.

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 fields should be filled with initial values in order to start the fitting procedure. The initial values can be filled by hand, but a simpler way to proceed is the following:
 - use the middle button of your mouse to click and drag over the wavelength region of the line (on some notebooks, the middle button can be simulated by pressing the CTRL or ALT keys while moving the finger on the pad)
 - the position of the peak (xo), its height (Io) and the width of the line (FWHM) are estimated automatically from your selection. This selection (purple region in the plot) can be erased using the **Reset last** or **Reset all** buttons.
- Press **Fit current** to perform a fit of the line+baseline and look at the result.
- The different components of the fit can be selected or unselected in the InfoPanel.
- Go back to the Fit panel and note the central wavelength of this line resulting from the best fit: 1327.7 Å (this result could slightly change for different wavelength ranges).
- Given that the rest wavelength for the Lyman α line is 1216.5 Å, we can compute the velocity of the galaxy $v=cz=c*\Delta\lambda/\lambda_0=27420$ km/s or a redshift $z=v/c=0.0914$. In order to visualize the peak of the HI line, select the Species tab and change the VLSR field to 27423 km/s: the green tick under the Lyman α line moves under the redshifted component. Clearly, the galaxy is not a member of the Coma cluster but a background object.



We now check the information on the QSO available in the Simbad database:

- Go back to the Aladin window and center your image on the HST spectral slit

- Open the server selector () and select the  tab

- Click on **Grab coord** and in the main Aladin window click on the central position of the spectral slit and expand the region with your mouse to include the whole spectral Field of View (~50")

- A new plane is created in Aladin with all Simbad objects in this region. Click on the Seyfert 1 galaxy that falls on the slit. Its name is NAME X COMAE GALAXY.

- Click on the name of this galaxy in order to open a web browser with all the information stored in Simbad for this object.

- Among the many informations on this galaxy, you can see that the radial velocity is of 26083 km/s

- Note that this galaxy is not part of the Coma cluster (we just obtained a mean velocity of 7000 km/s for the cluster). You can also look at the hierarchical link "parent" on NAME X COMAE GALAXY in Simbad and see that the probability that this galaxy is a member of the Coma cluster is 0%.