2. QUERYING ASTRONOMICAL DATABASES USING *VO*−TOOLS

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Abstract

The aim of this work is to get used to astronomical tools which can be used to query databases from different surveys as well as some data from single observations. In order not to make this a programming/computer lab some real science cases are implemented so that the use of the programs becomes meaningful. The task is divided into 3 different science cases explaining the different applications of the programs. While the first task is explained in great detail, the second task will have to be solved by you. The last task will then introduce a further program where the gained knowledge will be used to complete a rather complicated problem.

1 Introduction

The growing amount of available astronomical data requires more and more space and new ways have to be found to access those data. Obviously this can not be solved by simply uploading all available databases as querying them for certain data would take days. So for all the data registers have to be written and the use of programming languages such as Structured Query Language (*SQL*) are inevitable in order to avoid an overload of the data servers. The *Virtual Observatory* (*VO* hereafter) tools offer an access to those survey data without requiring any programming skills. The over 20 JAVA-applications, which automatically connect to the Internet and are linked with each other, have different applications. Three of them will be presented in this task. The databases are stored on servers so that some of them are just accessible by the *VO* tools in order to maintain connection and download speed. Apart from catalog requests the tools can be used to find spectra and images and can be used to process and analyze the obtained data.

The installation of those JAVA programs is rather easy, just go to the web page (if you do not have java installed, do so on *http://www.java.com/de/download/manual.jsp*):

http://www.ivoa.net/

and click on "For Astronomers" at the bottom and then VO Software. Then choose "ALADIN" and click on the Download button on top of the appearing page. At present, the official version is v10.076, which is revised wrt to earlier versions and which would require a major revision of this script in order to use it. We will thus use the previous Aladin version 9.0 (Aladin9.0.jar), which can be found at the bottom of that page.

TOPCAT is downloaded via *http://www.ivoa.net/* by clicking on the respective symbol in the "Software" menu. Then chose the "Standalone Jar File" and download topcat-full.jar follow the instructions given on this page.

The jar-files for Aladin v9.0 and topcat are also available on the astrolab-WEB in the "material for download section". You can find this at

https://www.lsw.uni-heidelberg.de/users/jheidt/praktikum/Astrolab_material/astrolab_data.html

You can start the programs by:

java -jar Aladin9.0.jar and **java -jar topcat-full.jar**, respectively.

This task is thought to help you to explore the programs on your own, that is why the number of explaining images was minimized. Images showing the different parts of the programs can be found in the Appendix, you should take a look at them first so that you know how the different parts (e.g. menu bar) will be called in the manual.

2 Mining Brown Dwarfs (TOPCAT+ALADIN)

2.1 Theory

Brown dwarfs (BD) are stellar objects on the cold end of the main sequence. Their properties can be described by temperatures as low as $T \lesssim 2000$ K and with masses $M \lesssim 0.1 M_{\odot}$. This implies absolute magnitudes as low as $M \approx 15$ and extreme red colors of roughly $B - V \approx 2.0$. Since those objects are not massive enough to start the hydrogen fusion, it is thought that those "stars" (usually characterized by hydrogen fusion) just originate from a molecular cloud and generate heat by contraction. As their is no inner energy production (apart from contraction) those objects slowly cool down and end their lives as cool objects with envelopes consisting of complicated elements, such as Lithium. It is obvious that due to their extreme properties a detection of such objects is a rather difficult task.

Try to think about the following questions (you can answer them later as you progress through the task):

- What is the limiting magnitude of SDSS in the u and g band?
- What is the maximum distance a brown dwarf can be observed in the g filter?
- What are the differences in magnitude between the SDSS u, the 2MASS K and the SDSS g and 2 Mass K band assuming a blackbody spectrum?
- What are the limiting magnitudes (SNR $\approx$ 10) of the 2MASS J and K bands?
- What is a possibility to mine for BD using surveys?

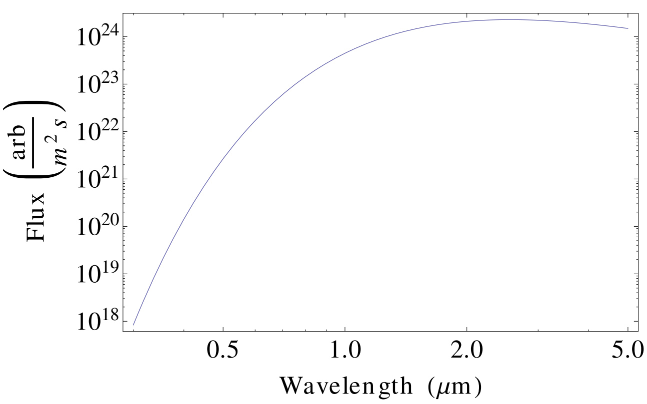

Figure 1: *Flux distribution of a black body with $T \sim 2000$ K in a log-log plot.*

Obviously a good answer for the latter question is to cross-match the SDSS and 2MASS catalog for all sky regions which were observed by both surveys. Then all objects lacking a SDSS detection in the u and g filter are extracted. A further analysis is necessary in order not to get biased, e.g. by unresolved background objects. So all objects have to be proven to be BD by analyzing their colors in the color-color diagram created by 2MASS data. This will then yield BD with $T \lesssim 2000$ K.

2.2 Use of programs

2.2.1 Mining for BDs in TOPCAT

As mining the whole SDSS catalog would take, even with the fast *VO*-tools, several hours we have to limit the area which should be explored. The following field will be used from now on:

RA: $08^{\mathrm{h}}30^{\mathrm{m}}00^{\mathrm{s}}$ **DEC**: $01°30'00''$ **Radius**: $14'$

Cone search Now TOPCAT has to be started and the different tools will be explored. We start with obtaining the field from the SDSS catalog:

- click in the menu bar on *VO* and then on *Cone Search*
- type in the field *Keywords* "SDSS" and click *Find services*
- when the list appears, scroll to the right and inspect the different fields
- choose *The SDSS Photometric Catalog, Release 8*
- enter now the right ascension, declination and field radius as cone parameters and click "OK". Don't forget to use the hh:mm:ss unit for RA and dd:mm:ss for Dec.
- rename the new table in the TOPCAT main window (e.g. "SDSS_DR8") by clicking in the *Label* field, entering a name and hitting "Enter"

Do the same for the *Two Micron All Sky Survey* (2MASS) catalog but **pay attention that you choose the point-source catalog (PSC)** as we do not want to study resolved background objects! If one of the catalogs does not work look for one from another server.

Cross-match The next task is to cross-match those two extracted catalogs in order to find the BD candidates. Therefore we have to perform a pair match, which can either be done by clicking on the two matches in the toolbar or by clicking on *Joins* in the menu bar and choosing pair match. The pair match window pops up.

Different algorithms for matching the two tables can be found in the first line. Among them:

- "Sky" − match coordinates within a fixed radius
- "Sky with errors" − match coordinates within the error radius plus a fixed radius
- "Sky 3D" − match coordinates (including distance) within a fixed radius
- "Exact value" − match tables by comparing the exact value (e.g. name) of a chosen column

As no error of the coordinate is given in the catalogs, it is obvious that we should choose "Sky" with an appropriate error radius. Find out about the spatial resolution of 2MASS. You can use that spatial resolution for the error radius.

We then choose the two tables which we just extracted from TOPCAT, the coordinate fields should be filled automatically, otherwise go to the TOPCAT main window and click on the symbol "column metadata" and look what the names of the coordinate columns are.

You can now choose how you want to match the two tables. While "Best Match Only" gives one output row per matched coordinate pair, "All Matches" gives all rows which are within the error radius. The "Join Types" have the following meaning:

- "1 and 2" − the joined table will consists of all matched objects which were in both tables

- "1 or 2" − the joined table will consists of all objects which were in one of the tables (but will not be there twice)
- "All from 1" − the joined table will consists of all objects from table 1 but with the additional columns from table 2
- "1 not 2" − the joined table will consists of all objects from table 1 which were not matched with an object from table 2

We obviously want to have the objects found in SDSS and 2MASS, so "1 and 2" has to be chosen. The cross-match can be performed by clicking on "Go".

In the TOPCAT main window a new table with the name "match()" will be created (around 680 rows), which should be renamed (e.g. "Matched Objects"). Now it is the time to explore the potential of TOPCAT. Play around a bit with the tools. Find and explore at least the following tools as you will need them soon:

- table browser
- table parameters
- table columns
- column statistics

Another big advantage of TOPCAT is that it can not only handle big data sets but can also visualize them, try to obtain the following plots:

- a cumulative (what does it mean?), normalized histogram of the g-magnitude
- the dependence of the u-mag on the z-mag (plane plot)
- spherical polar scatter plot of the coordinates (you might have to zoom in, in order to see something...)
- the behavior of the u-, r- and z-magnitude as a function of the J-magnitude in form of a stacked plot

As we now want to mine our data set we have to set some constraints on our data. We will set one optical constraint by a complicated but fast and one infrared constraint by an easier but more time expensive method.

Setting constraints As we only want to choose objects which do not have a detection in the u and g band of SDSS we have to exclude all objects with $u < 22$ and $g < 22.2$ as this is the detection limit of SDSS. So we click on the row subset symbol in the toolbar. Click on the green plus to create a new subset. Type a name (e.g. "SDSS_noDetection") and enter the following expression in order to obtain all non-detected objects, which are point-like (SDSS: class=6):

$$umag > 22 \;\&\&\; gmag > 22.2 \;\&\&\; cl == 6 \qquad \underline{\text{or}} \qquad \$9 > 22 \;\&\&\; \$11 > 22.2 \;\&\&\; \$5 == 6$$

It might be that you have to enter another number after the $, you can find out about this by clicking on the column meta data in the toolbar and check the ID of the respective column. The && is the logical AND, the logical OR can be called by ||. When the subset (6 objects) is created it can be chosen in the TOPCAT main window by clicking on the respective table and then choosing the respective subset name in "Row Subset". Do so as this subset has to be chosen for the following task.

In order to limit the number of outcome objects further, another constraint has to be applied, namely a color constraint. Theory claims that BDs should have the following colors $(J-H) < 0.3$ and $(H-K) < 0.3$. We could of course just define a new subset but in order to show the potential of TOPCAT we will use another way. Choose the star subset with no detections in SDSS u and g and then click on the symbol for the plane plot in the toolbar. A plot consisting only of the subset will appear. Open the table browser as well by clicking on the respective symbol (display table cell data). Now you can just click on a point in the plane plot an this will be highlighted in the table browser, try this also the other way round. Now we can enter for the X- and Y-Axis

j_m-h_m and h_m-k_m

respectively. One can see now that only 1 object fulfills the criterion mentioned above. By clicking on it, it will be highlighted in the table browser. But as we want to create a subset just consisting of this one point, we can either zoom in until only this single point is visible and then click on "Define a new row subset containing only currently visible points" or by clicking on "Draw a region on the plot to define a new row subset", drawing a circle around this point and clicking on the symbol again. Now you should be left with an object named SDSS J083048.80+012831.0.

Adding table columns One further thing to notice about TOPCAT is that you can define new columns based on the existing ones. You can do so by clicking on the column meta data and then add, depending on what you want, a coordinate or independent column. Try to create a new column containing the coordinates of the object in sexagesimal format. Furthermore add a column showing the flux (in counts per second) of the object in the SDSS z band by using the following formula:

$$F_\nu^z \left[\frac{counts}{Hz\ m^2\ s}\right] = \frac{1}{7.4 \cdot 10^{-10}} \cdot 10^{-0.4 \cdot zmag}$$

Find out about the available functions by clicking on the "f(x)" symbol and then in the category "Math".

Data visualization One last thing to do is to justify our selection. Therefore we want to download a catalog of known brown dwarfs and check their properties. We open a *Cone Search* in the TOPCAT main window and type "Brown dwarfs" as keyword. We choose the catalog by "Burgasser et al. (2004). The title of the catalog is "Brown dwarfs in the 2MASS Survey (Burgasser+, 2004)". " and download it completely (100 rows) − think about a way to do this. As we also want to check the optical properties of those objects we have to perform a multiple cone search in the SDSS, i.e. we look for the SDSS counterpart for every object individually. Click on the respective icon in the toolbar or in the VO menu bar. Type SDSS as keyword and choose again DR8. Then pick the right input table and give a reasonable search radius, you should obtain 45-50 objects depending on the chosen error radius. Plot the u against the g magnitude and check if the same selection criterion was chosen. By creating a new column you can check furthermore if the estimate regarding the difference between SDSS u and 2MASS K band was appropriate. Plot a histogram of the difference and give the mean as well as the standard deviation of it using the statistics tool in the TOPCAT main window.

2.3 Exploring the surrounding field using ALADIN

SAMP If not yet done, open ALADIN. We now want to broadcast the extracted BD object to ALADIN and look for other interesting objects in the surrounding field. So the first task will be to broadcast the table (containing 1 row) to ALADIN. All the programs are linked to each other using the communication tool SAMP. If the programs are linked to each other you can see a connected plug in the lower right corner of TOPCAT and a broadcasting antenna in ALADIN. If the plug is not connected/antenna is not broadcasting click on the plug. Either the plug will be connected afterwards or it will ask you which type of HUB you want to use, choose "external". If the connection is still not established, JAVA seems to have crashed. Just restart both programs and try to connect again. Now click on the table the brown dwarf was selected from and choose the row subset only containing the brown dwarf. Then click on *Interop* and click on "Send table to ..." → "ALADIN". The table should now appear in ALADIN as a plane on the right side and in the image as a circular marker.

Image tools and server selector Click on this marker and a table below the image will pop-up showing all information obtained by the broad-casted table. As we now want to visualize this region we have to download some images. Click on "File" → "Open..." and the *Server Selector* window will appear. Click on "all VO" and see that the coordinate of our object was already entered so that you just have to choose a field radius ($\lesssim 5'$). Delete the ticks for "Catalogs" and "Spectra" and then hit the "Submit" button. All available servers are now queried.

Now open the UKIDSS tree (which is also an infrared survey) and download the respective images for the Y-, H-, K-filter by ticking the white box in front of them and then clicking on "Submit". The images will now be downloaded in the plane stack in ALADIN. Now we want to match those images and create an infrared false color image. This can be done within one step by simply clicking on the *rgb* icon in the toolbar. In the appearing window we choose the Y, H, K images to be the blue, green, red part of our image respectively. After hitting "Create" the image will be created in the plane stack and will be shown immediately after it finished. As we now want to see the brown dwarf candidate the coordinate plane has to be shifted to the top of the stack (the eye on top of the stack shows the direction of sight). Now you should see that the marker of the object is slightly misplaced to a rather green object. You can determine the angular separation between the actual object and its dedicated coordinates by clicking on the *dist* icon in the toolbar and then clicking on the object and dragging (with mouse button hold) it to the marker. Note the distance. Why is this the case? Is the difference significant?

As already mentioned this is a false color image so that it appears green in infrared wavelengths but should be rather red in the optical regime. We can prove this by downloading the respective SDSS images. In order to accomplish that we zoom out of the image and open the "Server Selector" again. Now the SDSS tree has to be opened and we furthermore open the u Filter tree (Sometimes there is a bug that you couldn't find the SDSS tree. However, it must be located somewhere inside the other surveys tree. Just check them one by one). When we now hold the mouse button (no clicking!) above the available images the alignment and size of the SDSS image compared to the RGB image is shown. Mark one of the images containing the object and then do the same steps for the r and z filter of SDSS. Be aware that you choose the same image for both filters because otherwise the image will look odd. After downloading those images create an RGB image using the r and z images of SDSS and the H image of UKIDSS. Now you should see that the image is totally dominated by infrared emission. Determine again the distance between the object and the dedicated coordinates. Why did the orientation change? You can explore the cause of this by clicking on the multi view icon (4 images) in the left corner. Tick 2 images of UKIDSS and SDSS respectively and check their relative orientation. Click the "match" button to orientate all the images in the same way.

Downloading catalogs The last thing to do is to check the objects which are in the adjacent region of the brown dwarf candidate. To accomplish that click on the multi view button (1 image) and then the *open* button again. This time tick only the "Catalogs" option. Click in the "Radius" field and enter $2'$ and hit the "Submit" button. Tick the "NED database" (NASA extragalactic database) and the "ROSAT All Sky Survey" (RASS) and hit "Submit" again. Now all the objects of this catalogs which are in the field are highlighted by respective colors. If you click on the objects you will get detailed information (obtained by the catalog) in the box below the image.

3 T Tauri stars in Chamaeleon (TOPCAT+ALADIN)

3.1 Theory

T Tauri stars (TTS) are young pre-main sequence stars with masses of the order of $M_\odot$ but slightly increased luminosity so that they are located above the main sequence in a HRD. Some of them are that young that they have not started to burn hydrogen yet so that they (strictly speaking) can not even be called stars. As all of them have not reached thermal equilibrium yet (if they do, they are main sequence stars) they gain energy mainly by contraction. This ”fast” process leads to massive outbursts in form of jets and an explosion of the dust envelope the star originated from. The overall luminosity of those objects is much higher than for normal stars as they emit from IR (dust) to X-ray (scattering processes in jets) frequencies.

3.2 Use of programs

Identifying sources The aim of this tutorial is it to identify T Tauri stars by their X-ray data (using the RASS) in a young cluster near the Chamaeleon star-forming region. First of all we have to download the entire catalog named ”ROSAT All-Sky Survey: Chamaeleon Star Forming Region Study”. In order to find the already known T Tauri stars in the FOV, found by Covino et al. (1997), the yellow marked sources in figure 2 have to be found in our catalog. If you can not find the coordinates, try plotting ”-Ra” on the X-axis or broadcast the table to ALADIN and activate the coordinate grid in the viewing options. Cross-match the RASS-sources with the 2MASS point-source catalog and check if the sources have an IR detection. Select RX J0837.0-7856 and the one closest to it (RX J0840.5-7833). Mark those objects as a row subset.

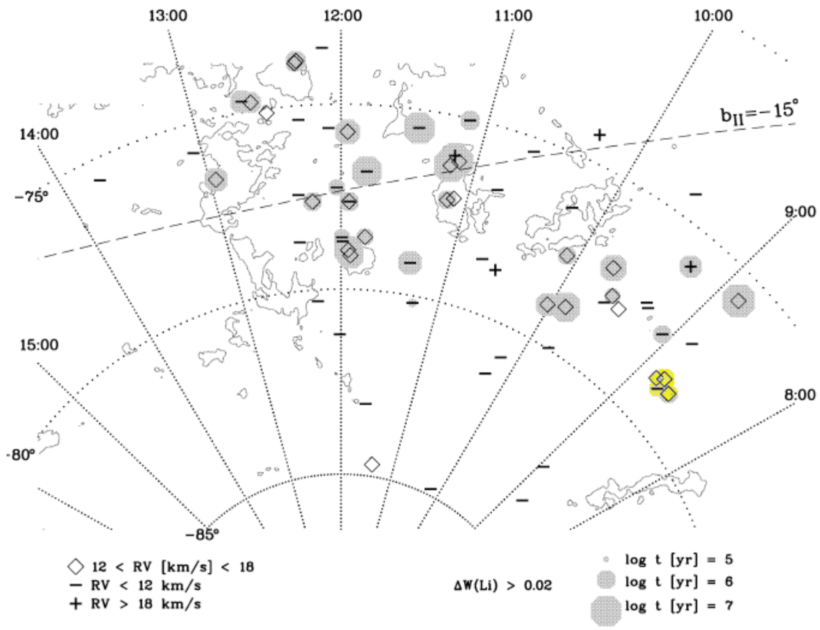

Figure 2: *In Chamaeleon detected X-ray sources with their measured radial velocities by Covino et al. (1997)*

Proper motion We expect that all TTS clustered around the star-forming region should have the same proper motion which should be distinguishable from the general cluster proper motion. That is why we would like to query (in TOPCAT) an astrometric catalog, namely the "Naval Observatory Merged Astrometric Data set" (NOMAD by Zacharias et al.), with the following parameters:

RA: 130.5° **DEC**: $-79.0°$ **Radius**: 0.5°

Plot a histogram of the J-magnitude. What can you say about the completeness limit of 2MASS? Compare it to the magnitude given in the Internet for an object with SNR ≈ 10. Now cross-match the 4 objects with the NOMAD catalog using an appropriate error radius (find out about the pointing accuracy). Remember as long as the "Best matches only" option is activated you can not choose a too large radius. You can see the separation of the two coordinates as a new column in the matched table. Check the proper motion of the 2 objects. Are these the real values? Why (not)? What is the property determining the accuracy of the proper motion measurement? As we now want to find out about objects with proper motions similar to the T Tauri object a proper motion (pmra vs. pmdec) plot of the $\sim 16,000$ NOMAD sources has to be made. Choose the J-magnitude as auxiliary axis. After you found the T Tauri object in this plot create a subset of $10 - 20$ adjacent objects with a similar J-magnitude and call it "PM candidates".

Color-magnitude constraint After we have chosen some T Tauri candidates by proper motion constraints we can highlight those objects now in a Vmag vs Vmag-Kmag plot. Some of them will fall together with the main sequence but a couple of candidates (i.e. the three on top of the main sequence) are definitely located on a sequence parallel above the main sequence. Now we can choose the sources which passed the proper motion and the color constraint by deselecting the row subset: "All" and marking all objects of the "PM cand" which lie apparently on a sequence parallel to the main one.

Soft X-ray matches Broadcast the subset of TTS objects to ALADIN and download a soft X-ray image by ROSAT (RASS CHA WTTS) or Chandra. How many sources have a ROSAT counterpart? Why do the other ones have no counterpart?

4 Age and IMF determination by creating a real HRD (TOPCAT, ALADIN and VOSA)

4.1 Theory

You already met the idea of color-magnitude diagrams (CMD) and Hertzsprung-Russel-diagrams (HRD) quite often in theory. This tutorial will give an insight of the necessary effort to create a real HRD. In order to accomplish that an appropriate star selection has to be made first. We will focus on main sequence stars from the open cluster Collinder 69, create a spectral energy distribution (SED) for every star individually and fit a theoretical SED onto the data in order to obtain detailed information about age, effective temperature, luminosity and initial mass function (IMF). This method of creating a HRD is a good compromise between time effort and precision. A more extensive way of creating such a diagram would be to take spectra from the UV to the far-infrared range of the individual stars and fit model spectra to those. The creation of a SED is more time effective and the data used for it can be simply obtained by survey databases.

The outline of this task is to obtain a catalog with photometric data of some of the objects of Collinder 69. Then all the data are send to VOSA where the magnitudes will be converted to fluxes and the stellar type will be determined. A further analysis on the SED will be performed in order to obtain more detailed information on the individual stars, namely effective temperature and luminosity. By fitting theoretical isochrones the age and initial mass of most of the stars belonging to the cluster will be obtained. Furthermore the pro and cons of the different fitting methods will be discussed.

4.2 Use of programs

Cluster constraints As Collinder 69 (C69 hereafter) is one of the closest open clusters with an apparent magnitude of 2.8 mag a lot of information of the individual cluster members is available. It is especially interesting to see that this cluster is spread over $70'$ of the sky. The photometry from red to mid-infrared wavelengths ($650 - 8000$nm) was already obtained/summarized by Barrado y Navascues (2007, ByN hereafter). Download this catalog using TOPCAT, it should contain 167 rows and 18 columns.

If you determine the average scale of the cluster data you'll see that it is much lower than the dimension mentioned above. Obviously this cluster will contain more stars than the 167 from the selected catalog. As it is interesting on which criteria the objects were chosen, we need a table containing all known cluster members. Download it from

www.univie.ac.at/webda/

by clicking on the "galactic open clusters" link and enter "Collinder 69". After clicking on "available data" chose "Coordinates J2000" in the left column. A table containing the cluster member number a reference and the coordinates in sexagesimal format will appear. Copy the content from this web page into a local file on your desktop. Replace the empty spaces between the columns with commas and load the file into TOPCAT as CSV-file. By downloading the respective fields from the 2MASS and NOMAD catalogs you can figure out what kind of stars where chosen for the photometry by ByN. Plot proper motion, coordinate and color magnitude (e.g. H vs H-V) diagrams for the sample from *WEBDA* and ByN respectively and see which constraint was set on the probable cluster members.

As we want to broadcast the obtained data to another program (the Internet application VOSA) we need to add a distance column. Try to find some stars with known parallaxes in the field of C 69. Why are the parallaxes deviating so strongly? Compare your computed distance value to the one given by *WEBDA*. Add a column containing the distance of C69 in pc to the table of ByN. Save the table containing all photometric data points, the distance and the coordinates as a "CSV-noheader" file on your hard drive.

4.2.1 VOSA

Go again to

http://www.ivoa.net/

"For Astronomers", VO Software, and klick on "VOSA". Use the following account:

Email: *praktikum@lsw.uni-heidelberg.de*

PW: *praktikum*

Accquisition of photometric data On the appearing window click on "Stars and brown dwarfs". It is the next task to convert the file given as TOPCAT-output into a file, readable by VOSA. Click on "ASCII" in the sentence regarding the conversion and a new tab will open up in the browser. Now upload the TOPCAT file and select the content of every column, namely coordinates, distance and a further column for every photometric data point. Do not forget to select the type of filter. The php file appearing after hitting "Go" should be saved as a normal text file on your hard drive. You can then go back to the VOSA tab and upload the newly created file by entering a description, choosing "magnitudes" and clicking on "Upload". It should now appear in a blue window below and you can check if it worked out by simply clicking on "Show". Be aware that you, if you upload several files, always chose the right one by marking it and clicking "Select" afterward. Now the photometric data available in the *VO* database should be queried for further data points. Click on "VO Phot", deselect all photometric catalogs and reselect the SDSS catalog. After hitting "Query selected servers" the data of the two databases are obtained which can take up to 5 minutes. You should now see a table containing 1 SDSS column which should be empty as no data points were found in the SDSS database. Click on "SED" to see the spectral energy distribution obtained by the uploaded photometric data.

Fitting the SED We are now interested to fit those distributions so that a model fit has to be applied. Click on the respective field (χ^2-fit) in the menu bar and a new window showing various models will show up. The most important models describe the following cases with the effective temperature T_{eff} and the logarithmic gravitation $\log_{10}(\text{g}/[\text{cm/s}^2])$ as independent parameters:

- NextGen model – main sequence stars with intermediate masses (K to A stars)
- DUSTY00 model – main sequence stars with low masses (M, T stars) and brown dwarfs
- COND00 model – main sequence stars with low masses (M, T stars) and brown dwarfs
- Kurucz model – main sequence stars with intermediate and high masses (K to O stars)
- Husfeld model – hot sub-dwarfs (O and B class) missing thermal equilibrium
- TLUSTY – main sequence stars with high high masses (O, B stars)

Select the 4 appropriate fitting methods and click on "Next: Select model parameters". In the following window you can add some constraints on the effective temperature T_{eff} and the gravitation constant log(g). Obviously the computing time will depend on the size of the chosen parameter space so that it is wise to start with some narrow interval and see if the results are fit well by the given parameters. In addition you can check if a large number of objects has temperatures close to the given maximum temperature. You will have the chance to go back and change the parameter space any time you want.* If you need a hint which parameters you should choose, start with the NextGen-model and chose some narrow constraint on the gravitation constant and give a wide range for the temperature. In the results you will see some typical temperatures for the stars.

After hitting "Make the fit" a new page will be loaded, the fitting is done when the page stops loading. Now click on "Model fit" once more and a table containing the chosen parameters as well as the χ^2 value are shown. After activating the "Show graphs" button the SEDs and their respective fits are shown below the table. Now you should get an overview over the parameter space for effective temperature and the gravitational constant. You can also click through the list of objects (column on the left side) and see the different fits applied to the data points individually and, if necessary, you can choose another best fit then the one chosen by the χ^2 constraint by clicking on "Best" (it will then be marked gray).

Data processing The next thing to do is to hit the "Model Bayes Analysis" button. This will give you the probability of every parameter depending on the chosen model for every object individually. This will give you a measure of reliability of the computed parameters.

In order to obtain the HR diagram with the respective values for mass, age, luminosity and effective temperature we have to fit evolutionary tracks (isochrones) to the data points. This is done by clicking "HR Diag." in the menu bar, leave everything unchanged, and activate the button creating the HRD. A new windows shows up, highlighting the evolutionary tracks for the different models. Apart from

*__NOTE:__ It might happen that some of the model fits are not available or the respective server is overloaded. You can check that by choosing the model with a very narrow parameter space and click on make the fit. If the first object is not fit after 1 or 2 minutes the service is probably offline. Be furthermore aware that the computing time is scaling linearly with the number of fit objects and the possibilities in parameter space. So in order to have a reasonable computing time you can either minimize the object sample or the number of models and their respective parameter space.

the table showing all the details of every individual object, you can see a plotting menu and a list of the different parameters for the isochrones. By deselecting some of them and hitting the "Plot" button afterward, you can see which isochrone belongs to which model and how the isochrones depend on time and initial mass. Do you see some data points lying apart from the isochrones? What is their origin? What is the precision of the age and mass fits? What does it rely on? What types of stars are dominating? Was this expected?

Exporting the results Click on the "Save results" tab in the menu bar. Make a tick in the "VOT" column and at the HRD row. After downloading and unzipping the file you can simply open it with TOPCAT. Run a multiple cone search (or pair match if the session is still open) with your objects and the 2MASS data. Now plot again a color magnitude diagram and choose as the auxiliary axis the newly obtained measurements. Is the dependence of luminosity, initial mass and effective temperature as expected? Make a histogram of the initial mass and discuss the obtained function. Using the statistics tool estimate the age of the cluster. You might want to exclude obvious non-members first. Compare the obtained data with data from *WEBDA* or *Wikipedia*. Is the difference within range? Why (not)?

Summary Download the catalog of Bayo et al. (2008) and compare your results to theirs. What are the differences in the determined temperatures, age and luminosity. Compare both ages to the *WEBDA* data. Which of both gives better results? Why? Using the luminosity-temperature plot with the infrared color (2MASS) as auxiliary axis, can you "exclude" objects as cluster members? Why (not)? Plot a histogram of the mass of the different members. What can you say about the completeness?

Finally we want to explore some further features of the *VO* tools. The aim of this final task is to query the logs of the ESO image database and to download some images. Go to the TOPCAT main window and open the *VO* menu and open the *Simple Image Access* (SIA). Query the Digitalized Sky Survey hosted by ESO (DSS Eso, if there are two, query the latter one) around C69. You will retrieve a table with 4 rows and 11 columns. When you click on the "(no action)" button behind "Activation Action" a new window will show up. As we now want to visualize the available images we have to start ALADIN (remember that the SAMP connection should be established). In the new window we choose the column where the URL for the respective image is written and choose ALADIN as standard image viewer. When we now click on an image in the table it will be downloaded to the ALADIN stack. Do that with the blue, red and infrared image (check the column "SurveyName" to figure out who is who) and rename them in the ALADIN window. Create an "RGB" image and plot the objects which were fit earlier over this image. Click on "Tools" in the menu bar and activate the "Simbad automatic pointer". If you now hold the mouse over an object the catalog name of the star will appear. If you then click on the appearing window on the object name a new tab in your standard browser will open and you will see the *Simbad* page of the object. Scroll down and click on "CDS portal" and explore the given information.

In order to obtain a more fancy image, we furthermore download an image from the IRAS Galaxy Atlas and plot the contours of the infrared image by clicking on "cont". The contour plot will appear as a drawing plane in the stack. Finally we combine the IRAS image together with the infrared and blue image to a new "RGB". Try to change contrast and color saturation by holding down the right mouse button and dragging the mouse from the left to the right and from the lower to the upper end. Click on "pixel" top see how you change the color behavior. Check the color contrast of the single images (IRAS, IR and blue) and chose a better function to fit the brightness behavior. After you have chosen an appropriate function for all three images, create a new "RGB" and enjoy the result.

5 Additional tasks

This section gives some extra tasks for interested students who want to solve some further tasks with the given tools. Apart from this suggestions own project ideas are welcome and can be solved instead of the following tasks. Further ideas and tasks can be found on *EURO−VO* page by clicking on "Scientific Tutorials" in the menu. Also the first two tasks within this tutorial can be found with some additional illustrations in their original form on the web page. You can also revisit the tools page and pick some other tools and try to explore it on your own − if it does not work, there is usually a tutorial belonging to every tool.

Membership of HD 1879 It is a huge problem to confirm the membership of a single star in the field of view to the observed cluster. This extra task highlights the problem of this topic. Try to figure out if the brightest star in the field of view, HD 1879, is part of the cluster or not. Try to find out which photometric/proper motion data are available using the CDS portal. After testing the proper motion, position in the CMD, try to fit VOSA models to the objects assuming that the distance is the same as for C69. Use "Bayes Analysis" to get a probability distribution of the different parameters. Test if the computed position in the HRD corresponds to some specific stellar class. Discuss the possibility that HD 1879 belongs to the cluster.

Galaxy fitting VOSA also has a galaxy SED fitting facility which should be used in this task. In the table below you see 3 example galaxies for which you should fit a galaxy model. After downloading the photometric data with VOSA you can test various fitting parameters and discuss the advantages of the different models and discuss their results. On what does the quality of the fit depend? Can you explain the results with the information given on the web page of the "NASA extragalactic database"?

Object	RA [deg]	DEC [deg]
1	180.45623780	2.42146800
2	180.46192930	-0.65536590
3	162.72210000	13.4122000

Temperature of the brown dwarf Try to find out about the temperature of the brown dwarf extracted in the first tutorial using the VOSA tool.

A Bibliography

B Acknowledgment

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C Additional Figures

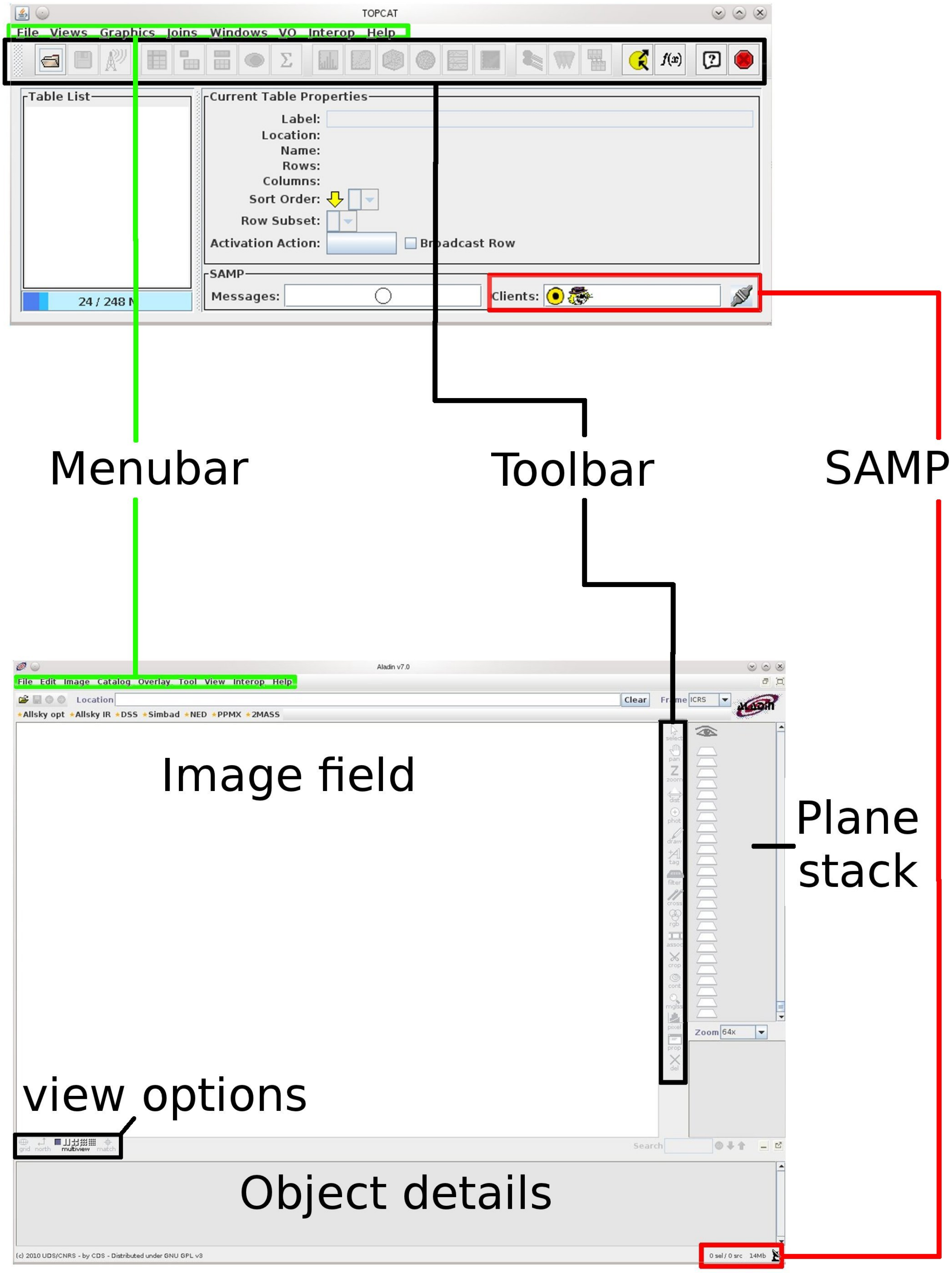

Figure 3: *This figure shows an overview of TOPCAT and ALADIN.*

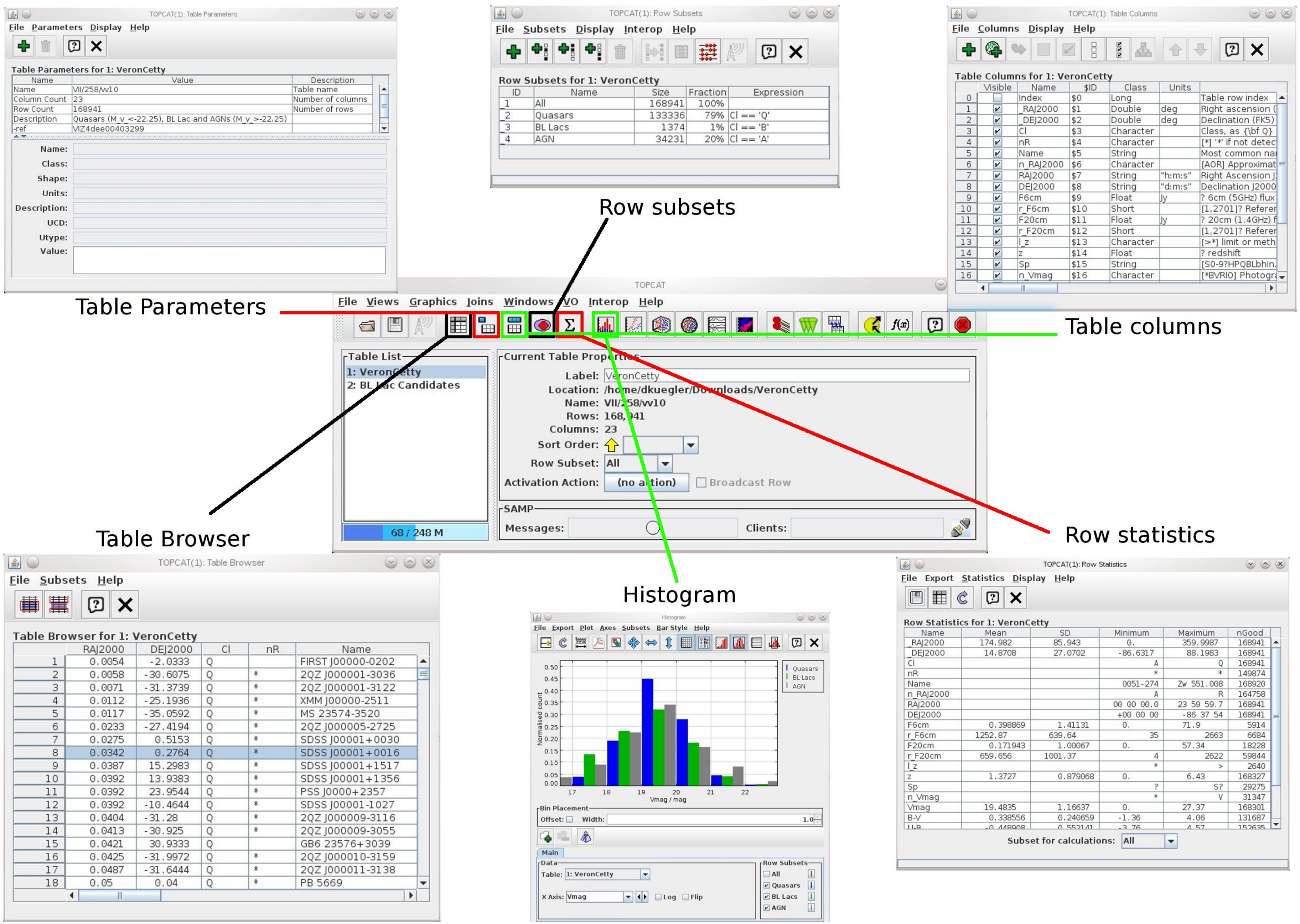

Figure 4: *This figure shows an overview of some of the TOPCAT tools.*

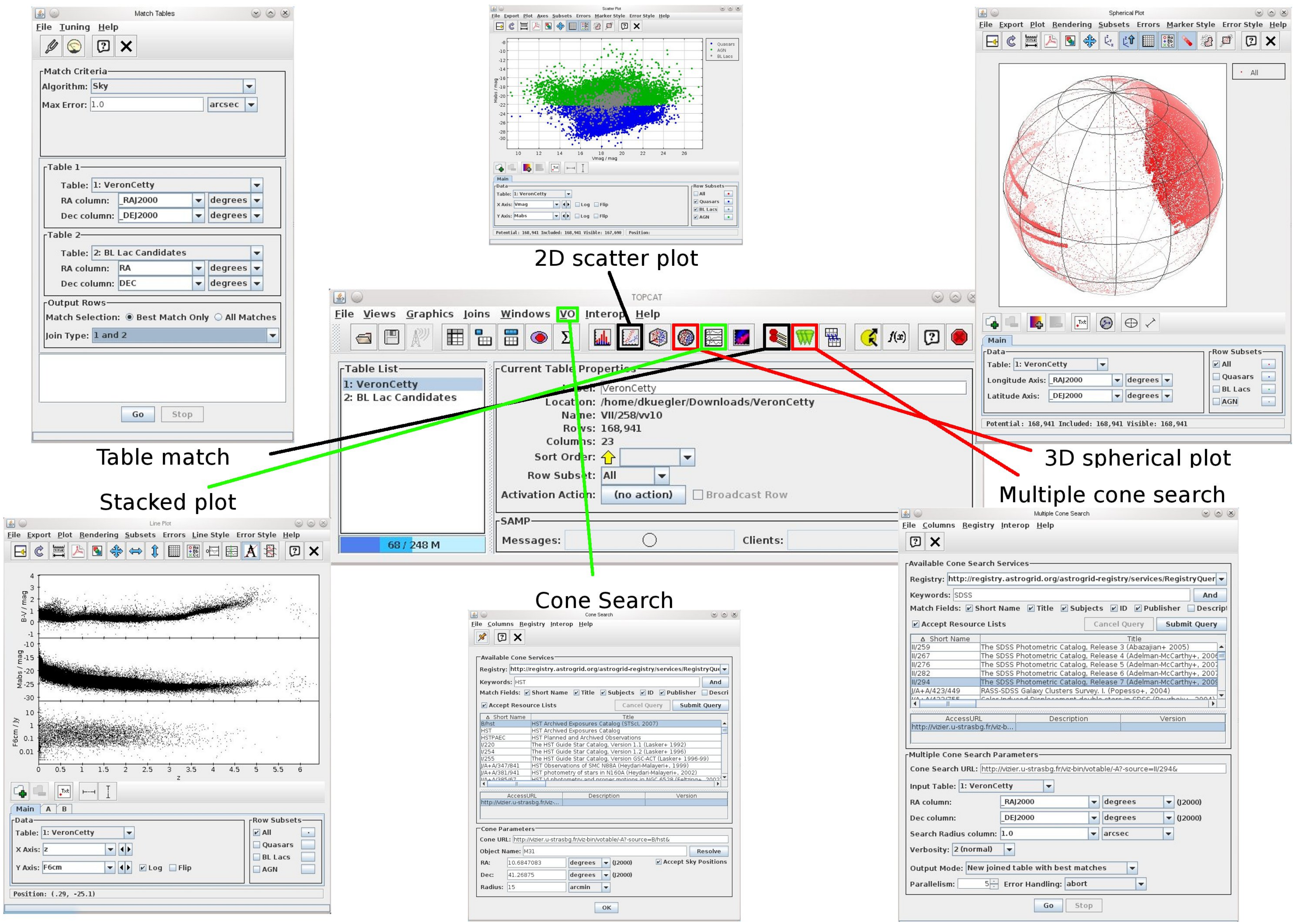

Figure 5: *This figure shows an overview of the remaining TOPCAT tools.*

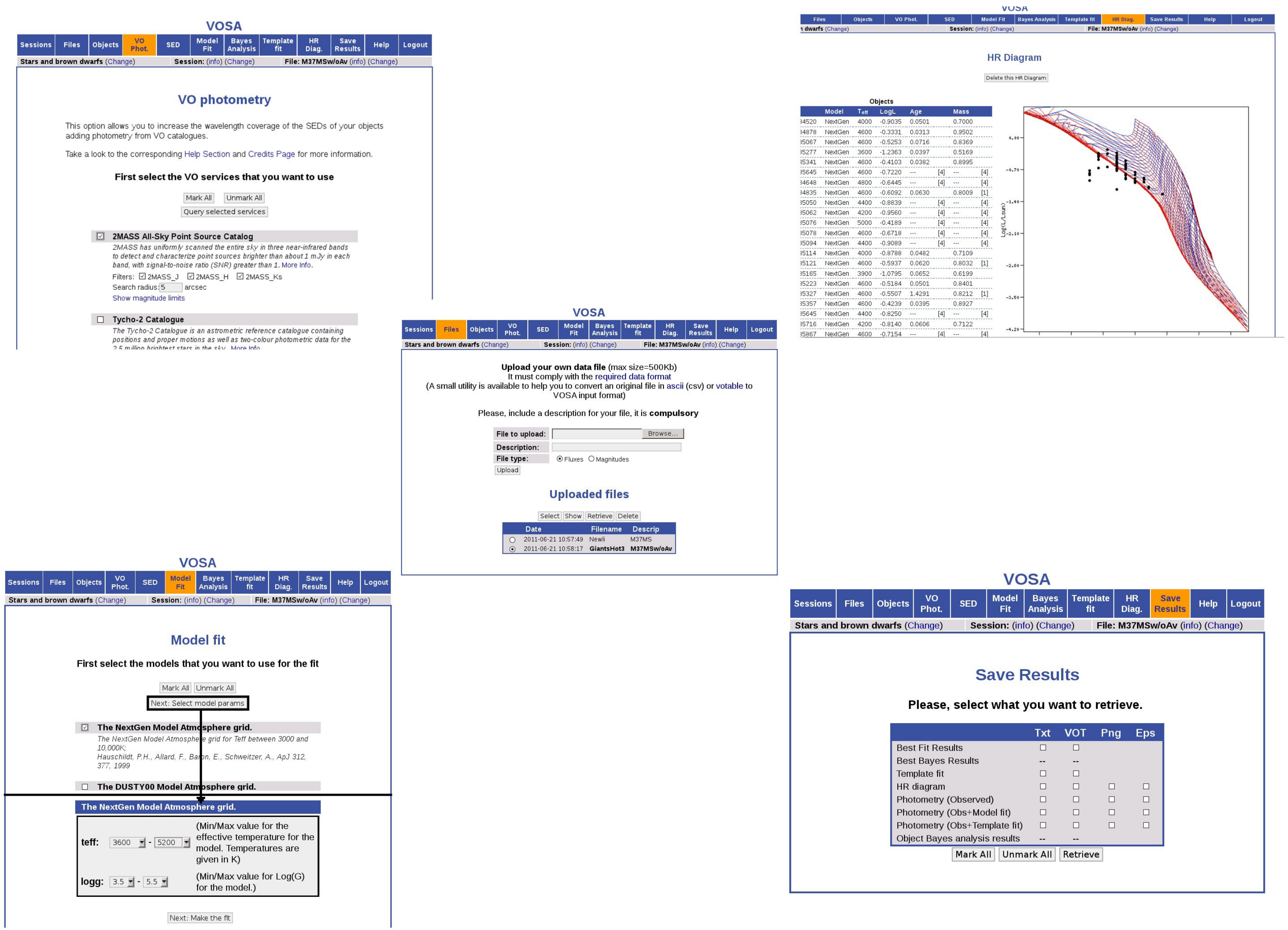

Figure 6: *This figure shows an overview of the VOSA tools.*