Using interoperability to select a population of galaxies: VO tutorial (RCSED)

The idea this time is to use data from a catalog created from catalogs and spectra from the Sloan Digital Sky Survey (SDSS), UKIDSS, and GALEX.
The team then observed these objects using various instruments, including the HST and the Russian 6m telescope.
This work was a collaboration between the Sternberg Astronomical Institute in Moscow, the Paris Observatory, and Harvard University. Notable contributors include Igor Chilingarian, Ivan Zolotukhin, and A.L. Melchior.
Compact elliptical galaxies (cE) are, as their name suggests, small galaxies. They are rare objects that are generally observed in the vicinity of massive galaxies, such as Messier 32 around the Andromeda galaxy. Their metallicity is very high, contrary to what one would expect from low-mass galaxies. They are thought to be the remnants of more massive galaxies that have been stripped of their companions by tidal forces.

In this tutorial, we will demonstrate the benefits of using the interoperability of the Virtual Astronomical Observatory (IVOA), as well as the tools developed to search through a large data catalog. These tools are so powerful because they use standard protocols to retrieve data, but also because they interact with each other. This tutorial is based directly on the work of the scientific team that has produced several articles and shown that this type of galaxy, of which only a few examples were known, is more widely present, even in areas where they have no close companions.

The Virtual Observatory tools used are:
TOPCAT (http://www.star.bris.ac.uk/~mbt/topcat/) to process the catalog
Aladin (http://aladin.u-strasbg.fr/aladin.gml) to process the images
CASSIS (http://cassis.irap.omp.eu/) for the spectra.
The catalog built by the scientific team Reference Catalog of Spectral Energy Distributions, http://rcsed.sai.msu.ru/), whose mirror will be used at the Paris Observatory at PADC http://padc-tap-rcsed.obspm.fr).

INSTRUCTIONS

Prerequisites before starting:

- Download and install the tools. You will find them at the following links. You will need Java
  - TOPCAT: http://www.star.bris.ac.uk/~mbt/topcat/topcat-lite.jar
  - Aladin: http://aladin.u-strasbg.fr/java/Aladin.jar

The subject of this tutorial is shared on the Visio system, which makes it easy to copy and paste to avoid mistakes and save time.
I will provide you with a link to a Dropbox-like site:
https://share.obspm.fr/index.php/s/ZY4RYL5KtebzLFd

- Launch the applications (on Windows or Mac, double-click on the file; on Linux, use the command line):
  - TOPCAT: java -jar topcat-lite.jar

◦ Aladin: java -jar Aladin.jar
◦ Cassis: https://cassis.irap.omp.eu/?page=installation

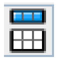
Start by loading the complete catalog of over 800,000 sources:

1. Load the main table of the RCSED catalog into TOPCAT. We will use the standard TAP (Table Access Protocol) to retrieve the remote catalog and the Registry to find the service.

VO → Table Access Protocol → in the keyword window, type “rcsed” → Find services → select the result (there are two: the original catalog in Moscow and a mirror at the Paris Observatory).
→ Use service padc-tap-rcsed

All the tables of the TAP service will appear. In the ADQL Text window, paste

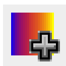
```
SELECT
objid, mjd, plate, fiberid, ra, dec, ssp_age, exp_tau, ssp_met, ssp_met_err, ssp_veldisp, ssp_veldisp,
z, corrmag_nuv, corrmag_g, corrmag_r, corrmag_z, corrmag_k, kcorr_nuv, kcorr_g, kcorr_r,
kcorr_z, kcorr_k, petror50_r
FROM
   specphot.rcsed
```

This table will appear in the list with the name “TAP_1_specphot.rcsed”
Note: To retrieve all the data, you must change the value of Max Rows: “2000 (default)” to “20000000 (max)”. This takes a little time, as there are more than 800 000 lines of data!
For information on the list of tables, units, and formats, click on the icon. 

2. First step: Use this catalog to visualize the superstructure of galaxy distribution in space. We will display the objects in 3 dimensions:

Simple 2D display: Graphic menu → Sphere plot (Old). You will see a direct display because the coordinate columns are identified automatically. The sky coverage is partial for this catalog.
In 3D: the distance is calculated using Hubble's law, which gives a distance based on the law of distance v = H0 d, with our astronomical data C z = H0 d (we will take HO = 72 kms-1 Mpc-1)
Select a distance axis on the sphere with the icon 

Set z * 3e5 / 72

Colors are corrected for galactic extinction but also for the effect of the filter filter coupled with spectral shift (kcorr).
To color a dimension, use the icon 

COLOR: corrmag_k - kcorr_k - 5 * log10(z * 3e5 / 72) - 25

Alternatively, you can use a Cartesian data display with a spherical → Cartesian projection using Graphics → 3D Plot Old:

X: cos(ra / 57.3) * cos(dec / 57.3) * z * 3e5 / 72
Y: sin(ra / 57.3) * cos(dec / 57.3) * z * 3e5 / 72

Z: sin(dec / 57.3) * z * 3e5 / 72
COLOR: corrmag_k - kcorr_k - 5 * log10(z * 3e5 / 72) - 25

It is possible to play around with the color palette to improve the rendering and make it easier to observe.
You will notice that, even with a sample of this size, the distribution is not uniform. The structure is reminiscent of what is observed in large simulations with filaments originating from dark matter.

3. Add a new column to the table named gr_fit, resulting from a somewhat complex calculation, to describe a relationship between the magnitudes of different wavelengths and the absolute magnitude in order to find classification criteria in a multidimensional cube. This criterion attempts to determine the type of galaxy without observing its image.

This polynomial is an optical-ultraviolet color-color-magnitude relationship for classical galaxies. You will find explanations of this classification criterion in the article http://adsabs.harvard.edu/abs/2010MNRAS.405.1409C.
:
In the main window, use the menu:
Views → Column info → Columns → New Synthetic Column → Name: gr_fit

Expression

0.0008569*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),0)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),0) +0.4145246*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),0)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),1) -0.3126628*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),0)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),2) +0.1915254*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),0)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),3) -0.0604829*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),0)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),4) +0.0100710*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),0)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),5) -0.0008631*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),0)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),6) +0.0000304*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),0)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),7) +0.1037934*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),1)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),0) -0.2982120*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),1)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),1) +0.2527798*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),1)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),2) -0.1029656*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),1)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),3) +0.0219900*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),1)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),4) -0.0023795*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),1)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),5) +0.0001031*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),1)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),6) -0.0146987*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),2)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),0) +0.0487196*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),2)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),1) -0.0351197*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),2)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),2) +0.0100174*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),2)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),3) -0.0012482*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),2)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),4) +0.0000568*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),2)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),5) +0.0003963*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),3)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),0) -0.0029259*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),3)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),1) +0.0021275*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),3)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),2) -

0.0004860*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),3)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),3) +0.0000349*pow((corrmag_z-kcorr_z-25-5*log10(luminosityDistance(z,72.0,0.3,0.7))+21.6665),3)*pow((corrmag_NUV-corrmag_r-kcorr_NUV+kcorr_r),4)

For those who would like to see a representation of this cube, it can be displayed by taking – Optional for the practical work

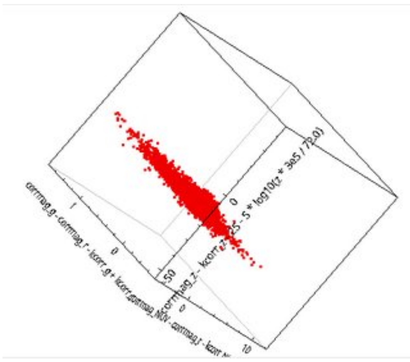
4. Use the 3D display with the axes t(Mz, NUV-r, g-r), i.e.:

X: corrmag_z - kcorr_z - 25 - 5 * log10(z * 3e5 / 72.0)
Y: corrmag_NUV - corrmag_r - kcorr_NUV + kcorr_r
Z: corrmag_g - corrmag_r - kcorr_g + kcorr_r

Once these formulas have been applied to the three coordinates, we will limit the values of the axes for better visibility:

X Range: from -25 to -16
Y Range: from 0 to 7
Z Range: from 0 to 1

Now, change the z axis to the gr_fit column. You will see a flatter shape in this new Optics / UV diagram space color – color – magnitude for galaxies.
You can see this surface being drawn by rotating the cube in Topcat for all types of galaxies.



For more details on this choice of axis, refer to the reference article:
http://adsabs.harvard.edu/abs/2012MNRAS.419.1727C

5. We will now apply the selection criteria for Compact Elliptical Galaxies by creating a subset based on criteria specific to this type of object.

cE galaxies are low in luminosity and are located in a specific region of the data cube. The team first constructed a region by hand using the interactive tools in topcat, and then determined a more formal selection criterion.
We will create a subsample using these criteria by creating a collection named cE using the menu

Views → Row Subsets → Subsets → New subset →
Name: cE
Expression:
(corrmag_NUV - corrmag_r - kcorr_NUV + kcorr_r) > 4.0 &&
(corrmag_g - kcorr_g - 25 - 5 * log10(luminosityDistance(z, 72.0, 0.3, 0.7))) > -18.7 && (petror50_r < 2.0 || petror50_r / 206.265 * luminosityDistance(z, 72.0, 0.3, 0.7) < 0.7) && (corrmag_g - corrmag_r - kcorr_g + kcorr_r - gr_fit) > 0.03 && ssp_age > 4000.0 && ssp_veldisp > 60.0

6. Now that the sample has been reduced, we want to get an optical view of the selected objects. We will therefore use the SAMP protocol so that Topcat asks Aladin to display the selected object.
Launch Aladin if you haven't already done so.
Select the SDSS color atlas.
In the left window of Aladin, expand: image -> optical ->SDSS -> SDSS9 Colored

We will ask TOPCAT to send Aladin the coordinates of the object selected in the catalog menu: TOPCAT main

window select Row Subset: cE and in Views -> Activation Action check Send Sky Coordinates.
Open the catalog and select several lines in turn. The image of the galaxy appears in Aladin; adjust the resolution with the mouse wheel. Observe the color of these objects in the atlas. These galaxies do not have heated gas and therefore appear with a dominant color.

7. We will simplify and shorten the steps followed by the team for classification and suggest looking directly at the spectra from these objects in order to refine the classification. Unlike other galaxies, these objects do not have young stars that heat gas. We should not see any emission lines in the spectrum.
The protocol for accessing the spectra is SSA. We will use the compilation of these objects' spectra made by the same team. Again, we will use Topcat for selection but a dedicated spectrum client for visualization.
Menu VO → SSA → keyword → type “rcsed” → find service, the
service address appears http://padc-tap-rcsed.obspm.fr/specphot/ssap.q/ssa/ssap.xml?&MAXREC=800000

Take M31 as the coordinate and request the resolution of the object (Andromeda galaxy). Set Diameter to 360 to include the entire catalog.
Perform a cross-correlation between the SSA output and the collection using algorithm = sky and, for the second table, location_ra and location_dec as columns. Take 1 arcmin as Error max. This is not the right method because the service refuses to return the entire database. You will have to make multiple requests.

Join → multiple SSA → keyword → type “rcsed” → select TAP Specphot.rcsed   columns ra and dec and search column radius 1 arcmin → Go
You already have more than 300 cross-matched objects.
In Cassiss VO→ samp → connect to hub
To observe the spectrum, start cassis if you haven't already done so and set the cross-match file to action activation →Send Spectrum
In cassis click on spectrum analysis
on spectrum manager click on select spectrum then on spectrum analysis click on dispaly