- **Title:** Discovery of Brown Dwarfs mining the 2MASS and SDSS databases.

- **VO-Tools:** ALADIN, TOPCAT, STILTS.

- **Scientific background:** Brown dwarfs are objects occupying the gap between the least massive stars and the most massive planets. They are intrinsically faint objects so their detection is not straighforward and, in fact, was almost impossible until the advent of global surveys at deep optical and near-infrared bands like SDSS, 2MASS or DENIS among others. We propose here to mine the 2MASS-PSC and SDSS-DR9 databases to identify T-type brown dwarfs through an appropriate combination of colours in the optical and the infrared, an approach that perfectly fits into the Virtual Observatory.

- **Workflows:** In this use case, we explore different ways to do the same tasks (cross-match, sources selection, filtering,…) with different VO tools.

  - **First workflow (Aladin):**
    - Launch Aladin: Open a terminal and type: java -jar Aladin.jar &

    - Discovery: Search 2MASS-PSC and SDSS-DR9 sources around RA:08h 30m DEC:01d 30m with a 14 arcmin. Radius.
      - File –> Open → A new window *("Server selector")* will pop up.
      - In this new window, write 08:30 01:30 in the *"Target (ICRS,name)"* box
      - Click "Surveys" (in the *"Catalog servers"* column of the *"Server selector"* window).
      - Click on the 2MASS-PSC catalogue. "2MASS-PSC" will appear in the "Survey" box.
      - Click on "Submit". Aladin will load in the main window the 2MASS-PSC plane with 683 sources (you can see the number of sources by placing the cursor on the name of the plane).
      - Repeat the same steps for the SDSS-DR9 catalogue. A new plane will be loaded with 12404 sources.

    - Crossmatching: Find common sources in 2MASS-PSC and SDSS-DR9 catalogues.
      - In the Aladin main window → Catalog –> Cross match objects.
      - First catalogue: 2MASS-PSC. Second catalogue: SDSS-DR9. Default threshold (4 arcsec) and bestmatch option.
      - Click on "Perform cross-match". A new plane (*"XMatch"*) with 679 sources will be loaded.

    - Filtering:
      Select points sources using the SDSS flag (cl=6). "cl" is a column of the SDSS-DR9 catalogue that provides information on the type of object (3=galaxy, 6=star).
      - Hide (cursor on the name of the plane, click mouse right button and select hide, or click on the plane icon) the 2MASS-PSC and the SDSS-DR9 planes.
      - Click on the *"XMatch"* plane.
      - In the Aladin main window → Catalog –> Create a filter (or click on the "Filter" button on the right panel of Aladin main window) → Advanced mode –> Columns –> Columns in loaded catalogue. Select the *"cl_tab2"* column from the Xmatch catalogue.
      - Complete the filter condition. It should be ${cl_tab2}=6 {draw}
      - Click on "Apply". Then click on "Export" to create a new plane with the filtered sources.
      - A new plane "Filter.src" will be loaded in the Aladin main window. It contains 649 sources.

- If you wish you can modify the colour of this new plane by doing the following:
    - Click on the "Filter.src" plane.
    - Click on the "Prop" button on the right panel of Aladin main window. A new window ("Properties") will pop up.
    - Select the color you prefer.
    - Click on "Apply".
    - From this window you can also change the shape of the sources drawn in the Aladin main window.

Now, let's select sources with no detection in the u,g SDSS bands (u > 22.0 && g >22.2. Brown dwarfs are cool objects so they are not detected in the blue SDSS bands) and sources fulfilling the brown dwarf criteria provided by Burgasser et al. (2000, Apj, 531, L57).((J-H)<0.3 && (H-K)<0.3).
    - Hide the Xmatch plane.
    - Click on the "Filter.src" plane.
    - Repeat the same steps as in the previous filter. The filter condition now should be: ${umag_tab2} > 22.0 && ${gmag_tab2} > 22.2 && ${Jmag_tab1} - ${Hmag_tab1} < 0.3 && ${Hmag_tab1} - ${Kmag_tab1} < 0.3 {draw}
    - Click on "Apply". Then click on "Export" to create a new plane with the filtered sources.
    - A new plane "Filter.src~1" will be loaded in the Aladin main window. It should contain 1 source. (RA_2MASS:127.703265deg; DEC_2MASS:1.475320deg). NOTE: You will get information on the source by clicking on it.

- Analysis: We can now use Simbad to confirm the brown dwarf nature of this object:
    - In the Aladin main window: File –> Open.
    - In the *"Server selector"* window:
        - Click *"SIMBAD"* (in the *"Catalog servers"* column).
        - Click on "Grab coord" (*"Server selector"* window) and click on the source. The coordinates of the source will be copied to the *"Target (ICRS, Name)"* box.
        - Select a 30arcsec radius. Click *"Submit"*.
    - A new plane *"Simbad"* is loaded in the Aladin main window.
    - Click on the *"Simbad"* plane → *"Select all sources in selected plane"* (mouse right button). A table containing one row appear at the bottom of the Aladin main window.
    - Click on *"Main_ID"*. Simbad is launched in your browser with information on the source.

- **Second workflow (TOPCAT)**:
    - Launch TOPCAT: Open a terminal and type: java -jar topcat-full.jar &

    - Discovery: Search 2MASS-PSC and SDSS-DR9 sources around RA:08h 30m DEC:01d 30m with a 14 arcmin. radius.
        - In the TOPCAT main window: VO–> Vizier Catalogue Service. A new window *("VizieR Catalogue Service")* is created.
        - In the *VizieR Catalogue Service win*ndow:
            - Cone selection box:
                - change RA, DEC and radius units to "hh:mm:ss", "dd:mm:ss" and "arcmin", respectively.
                - Give the coordinates (RA: 08:30:00, DEC: 01:30:00) and radius (14).

- Catalogue selection box: Surveys –> select 2MASS PSC
- Clixk OK → A table called *"II_246_out"* will be uploaded in the TOPCAT main window.
- Repeat previous steps for SDSS-DR9. A new table called "V_139_sdss9" will appear in the TOPCAT main window.
- Alternatively, you could broadcast the 2MASS and SDSS DR9 catalogs from Aladin to TOPCAT using SAMP.
  - In Aladin, click on the "2MASS-PSC" plane. Click right mouse button and select "Broadcast selected tables to topcat". The table should appear in the TOPCAT main window. The same for SDSS DR9 sources.

- Crossmatching: Find common sources in 2MASS-PSC and SDSS-DR9 catalogues.
  - In the TOPCAT main window: Joins –> Pair Match (alternatively you can click on bottom with the two matches of the upper panel). A new window (*"Match Tables"*) is created.
  - In the *"Match Table"* window
    - In the Match criteria box:
      - Algorithm: Sky
      - Max error: 4 arcsec
    - Table1: II_246_out (2MASS_PSC). RA/Dec columns: RAJ2000, DEJ2000.
    - Table2: V_139_sdss9 (SDSS-DR9). RA/Dec columns: RAJ2000, DEJ2000.
    - Output Rows box:
      - Match selection: Best match, symmetric
      - Join Type: 1 and 2
    - Click *"Go"*.
    - A new plane "match(1,2)" with 679 sources is loaded.

- Filtering: Select points sources using the SDSS flag (cl=6).
  - In the TOPCAT main window: View –> Row subsets (Alternatively click on the 7th bottom of the upper panel)
  - In the "Row subsets" window:
    - Subsets –> New subset (Alternatively click on the 1st bottom of the upper panel)
  - In the "Define Row subsets" window:
    - Fill in the "Subset name" box (for instance, filt1).
    - Expression: cl==6. Click OK.
  - In the TOPCAT main window select "filt1" in the "Row Subset" box. 649 sources are selected.
  - To see the contents of the table: In the TOPCAT main window: Views / Table data (Alternatively click on the 4th bottom of the upper panel) A new window with the contents of the table is created.
  - To include the rest of filtering conditions: In the TOPCAT main window: Views → Row subset.
  - Modify the filter expression to: cl==6 && umag>22.0 && gmag> 22.2 && Jmag-Hmag<0.3 && Hmag-Kmag<0.3
  - In the TOPCAT main window, select *"all"* in the *"Row subset"* box. Then select *"filt1"*. 1 source is selected. RA:127.703265deg; DEC:1.475320deg.

- **Third workflow (Advanced scripting / ALADIN)**: ALADIN has a script mode to build a list of commands to be processed. The workflow can be executed automatically for a list of targets.

- If you closed Aladin, launch it again (java -jar Aladin.jar &). If your Aladin is open, click on any plane, click right mouse button and select *"Delete all planes"*.
- Tool > Macro Controller
- Cut and paste in an ascii files the commands given in SCRIPT (see below). If the bullets have been copied you will have to remove them from the ascii file.
- In the "Macros" window: File > Load script –> Load the script file you have just created.
- Cut and paste in another ascii files the parameters given in PARAMS (see below). If the bullets have been copied you will have to remove them from the ascii file.
- In the *"Macros"* window: File > Load params –> Load the param file you have just created.
- In the "Macros" window: Click on the coordinates and then click on "Exec. current params". You will find the source identied in previous workflows.

  - SCRIPT
    ```
    2mass = get VizieR(2MASS-PSC) $1 $2 14'
    sync
    sdss = get VizieR(SDSS-DR9) $1 $2 14'
    sync
    2massdss= xmatch 2mass sdss 4 bestmatch
    sync
    hide 2mass
    sync
    hide sdss
    sync
    filter candidates { ${cl_tab2}==6 && ${umag_tab2}>22.0 &&
      ${gmag_tab2}>22.2 && ${Jmag_tab1}-${Hmag_tab1}<0.3 &&
      ${Hmag_tab1}-${Kmag_tab1}<0.3 {draw} }
            (this is a single line)
    sync
    select 2massdss
    sync
    cplane candidates
    ```

  - PARAMS
    ```
    # RA DEC
    08:30:00,01:30:00
    ```

More information on how to build scripts in Aladin can be found at: "Aladin main window → Help > Help on script commands".

- **Fourth workflow (STILTS):**
  - Copy the file "stilts.script" from the school web page to your local computer.
  - Make it executable → chmod u+x stilts.script
  - Execute it → ./stilts.script → A new file ("candidate.xml") is created. It contains the same single object found in the previous workflows.