- **Title:** Discovery of Brown Dwarfs mining the 2MASS and 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. We propose here to mine the 2MASS-PSC and SDSS-DR12 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 tutorial we will explore different ways to do the same tasks (cross- match, source 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-DR12 sources around RA:08h 30m DEC:01d 30m with a 14 arcmin. radius.

        ◦ *File –> Open Server Selecto*r → A new window will pop up.

        ◦ Click the **All VizieR** button in the **Catalog servers** column (right side of the window).

        ◦ Write 08:30:00 +01:30:00 in the **Target (ICRS,..)** box.

        ◦ Type 2MASS-PSC in the **Catalog** box. Radius must be 14 arcmin. Then click **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: CDS/2MASS-PSC).

        ◦ Repeat the same steps for the SDSS-DR12 catalogue. A new plane (CDS/SDSS-DR12) will be loaded with 12 404 sources.

      - Crossmatching: Find common sources in 2MASS-PSC and SDSS-DR12 catalogues.

        ◦ In the Aladin main window: *Catalog –> Cross match objects*.

        ◦ First catalogue: 2MASS-PSC. Second catalogue: SDSS-DR12. Default threshold (4 arcsec) and bestmatch option.

        ◦ Click on **Perform cross-match**. A new plane (*"XMatch"*) with 679 sources will be loaded.

      - Filtering:

        ◦ In this step we will select point sources using the SDSS flag (class=6). "class" is a column of the SDSS- DR12 catalogue that provides information on the type of object (3=galaxy, 6=star).

- In the Aladin main window, click on the *"XMatch"* plane. The name of the plane would appear highlighted.

- 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*. A new window (*"Available columns"*) will pop up. Select the *"class_tab2"* column from the Xmatch catalogue. The label of this column will be copied to the *"Properties"* window.

- In the "*Properties*" window, complete the filter condition. It should be ${class_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 and/or the shape of the sources 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 and /or shape you wish.
  - Click on *Apply*.

○ 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).

- Click on the icons on the left of the names of the planes to hide them all but *"Filter.src"*.

- Click on the *"Filter.src"* plane.

- Repeat the same steps as in the previous filter. The filter condition now should be (Filter.src panel in the "*Available columns*" window) :

${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 can 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 --> Tools --> Tick on *"Simbad pointer"*

○ Put the cursor on the source.

○ After a few seconds a small window with basic information of the object will appear.

- By clicking on the object name (in blue) a new tag will open in your browser with the information available in Simbad for this particular object.

- **Second workflow (TOPCAT):**

  - Launch TOPCAT: Open a terminal and type: java -jar topcat-full.jar &

  - Discovery: Search 2MASS-PSC and SDSS-DR12 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* window:

      - *Row selection* box:

        - Change RA, DEC and radius units to "hh:mm:ss", "dd:mm:ss" and "arcmin", respectively.
        - Type the coordinates (RA: 08:30:00, DEC: 01:30:00) and radius (14).

      - *Catalogue selection* box: By keyword–> *Keyword: 2MASS → Search catalogues → S*elect II/246. Click *OK* → A table called *"II_246_out"* will be uploaded in the TOPCAT main window.

      - *Catalogue selection* box: Survey–> *SDSS-DR12*. Select V/147. Click *OK* →A new table called *"V_147_sdss12"* will appear in the TOPCAT main window.

      - Alternatively, you could broadcast the 2MASS and SDSS DR12 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 DR12 sources.

  - Crossmatching: Find common sources in 2MASS-PSC and SDSS-DR12 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). RA/Dec columns: _RAJ2000,_ DEJ2000.
        - Table2: (V_147_sdss12). 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 point sources using the SDSS flag (class=6).

    - In the TOPCAT main window: *Views –> Row subsets* (Alternatively click on the 7th bottom of the upper panel starting from the left)

- In the "*Row subsets*" window: *Subsets –> New subset* (Alternatively click on the 1st bottom of the upper panel starting from the left)

- In the "*Define Row subsets*" window:
  - Fill in the "*Subset name*" box (for instance, filt1).
  - Expression: class==6. Click **OK**. 649 sources are selected.

- 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 starting from the left). A new window with the contents of the table will pop up.

- To include the rest of filtering conditions: In the TOPCAT main window: *Views → Row subset*.

  - Modify the filter expression to: class==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**.

  - In the Aladin main window: *Tool –> Macro Controller*

  - In the "*Macros*" window: *File –> Load script* –> Load the *script.txt* file available in the web page of the school.

  - In the "*Macros*" window: *File –> Load params* –> Load the *param.txt* file available in the web page of the school.

  - In the "*Macros*" window: Click on the coordinates and then click on **Exec. current params**. You will get the source identified in previous workflows.

  - More information on how to build scripts in Aladin can be found at: "Aladin main window" → *Help –> Help on script commands*. A list with the command used during our Aladin session can be found at → *Tool –> Script console*

- **Fourth workflow (STILTS):**

  - Copy the file "*script_stilts*" file from the school web page to your local computer.
  - Make it executable → chmod u+x script_stilts_granada2020.txt
  - Execute it → ./script_stilts_granada2020.txt → A new file (*"candidate_granada2020.txt"*) is created. It contains the same object found in the previous workflows.