



Discovery of Brown Dwarfs mining the 2MASS and SDSS databases.

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- **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 straightforward 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, sources selection, filtering,...) with different VO tools.
 - **First workflow (Aladin):**
 - Launch Aladin: Open a terminal and type: `java -jar Aladin.jar &`
 - Load a sky map (HiPS). On the left hand panel, go to the discovery tree and navigate through the folders: Collections → Image → Infrared → 2MASS and click on “2MASS color J (1.23um), H(1.66um), K(2.16um)”. The sky map will be displayed in the central panel.
 - **Discovery:** Search 2MASS-PSC and SDSS-DR12 sources around RA:08h 30m DEC:01d 30m with a 14 arcmin. Radius.
 - At the bottom-left of the main window, write **2MASS-PSC** in **select** box. The above list of available at data shrinks. Click on **2MASS-PSC**. New window pops up.
 - Write 08 30 00 +01 30 00 14' in the **position/radius** box.
 - Click **Load**. Aladin will load in the main window the CDS/II/246/out2MASS-PSC plane with 683 sources (you can see the number of sources by placing the cursor on the name of the plane).
 - If you wish you can modify the name of the plane, and colour and/or the shape of the symbols of this plane by doing the following:
 - Click on the **prop** button on the right panel of Aladin main window. A new window (“Properties of the plane...”) will pop up.
 - Write **2MASS-PSC** in **Plane ID**
 - Select the color and /or shape you wish.
 - Click on "Apply".
 - Repeat the same steps for the **SDSS-DR12** catalogue. A new plane (**CDS/ V/147/sdss12**) will be loaded with 12404 sources. Rename this plane as **SDSS-DR12**.

- **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 (cl=6). “cl” is a column of the SDSS-DR12 catalogue that provides information on the type of object (3=galaxy, 6=star).
 - 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 of the filter...” window.
 - Complete the filter condition. It should be $\{\text{class_tab2}\}=6$ {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.
 - 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:
 - $\{\text{umag_tab2}\} > 22.0$ && $\{\text{gmag_tab2}\} > 22.2$ && $\{\text{Jmag_tab1}\} - \{\text{Hmag_tab1}\} < 0.3$ && $\{\text{Hmag_tab1}\} - \{\text{Kmag_tab1}\} < 0.3$ {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:
 - Klik on **Simbad** at the menu above the central main window. A new plane is loaded with the Simbad entries at the field of view. Select the Simbad entry of our source by clicking on it.
 - The selected sources are shown at the bottom window. 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** → Select **II/246**. Click **OK** → A table called “II_246_out” will be uploaded in the TOPCAT main window.
 - Rename the table. In the TOPCAT main window, in **Current Table Properties** box, write **2MASS-PSC** in **Label** and press intro.
 - Repeat the same steps for the SDSS-DR12 catalogue: **VO** → **VizieR Catalogue Service**. In **Catalogue selection** box: **Survey** → **SDSS-DR12**. Select **VI147**. Click **OK** → A new table called “V_147_sdss12” will appear in the TOPCAT main window.
 - Rename the table. In the TOPCAT main window, in **Current Table Properties** box, write **SDSS-DR12** in **Label** and press intro.
 - 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 samples.
 - 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: (2MASS_PSC). RA/Dec columns: `_RAJ2000,_ DEJ2000`.
 - Table2: (SDSS-DR12). 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 (cl=6).
 - Select the table “*match(1,2)*”
 - 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, at **Current Table Properties** 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 by double clicking on the **Expresion** box and writing: `class==6 && umag>22.0 && gmag> 22.2 && Jmag-Hmag<0.3 && Hmag-Kmag<0.3`
 - 1 source is selected. RA:127.703265deg; DEC:1.475320deg.
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- **Third workflow (Advanced scripting in 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 was still 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 file available in the school web page.
 - *File* → *Load params* → Load the param file available in the school web page.
 - 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*.
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- **Fourth workflow (STILTS):**
 - Copy the file "*script_stilts*" from the school web page to your local computer. It should be in the same directory of the `stilts.jar` file.
 - Make it executable → `chmod u+x script_stilts.txt`
 - Execute it: `./script_stilts.txt`. A new file ("*candidate.txt*") is created. It contains the same single object found in the previous workflows.