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

21st October 2020. Updated to: Aladin v11.024; TOPCAT v4.7-2: and STILTS 3.2-2

- **VO-Tools:** 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, sources selection, filtering,…) with different VO tools.

  - **First 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.

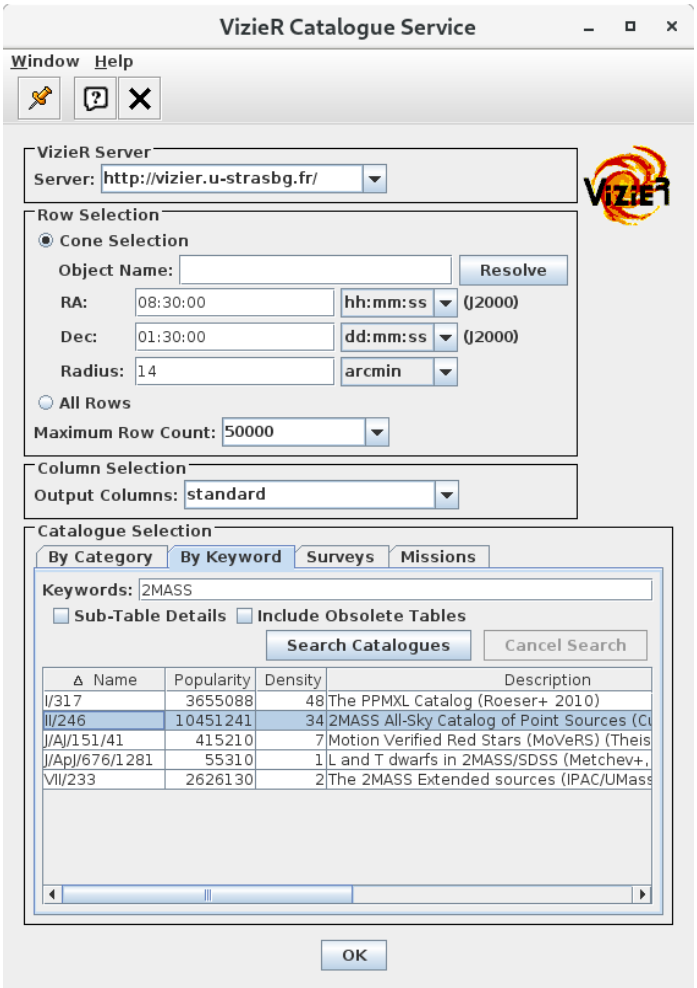
      - In the TOPCAT main window: *VO → Vizier Catalogue Service*. A new window *("VizieR Catalogue Service")* is created.

      - 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. The table contains 683 sources.



- 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 catalgoue: *VO → Vizier Catalogue Service*. In *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. The table contains 12404 sources.

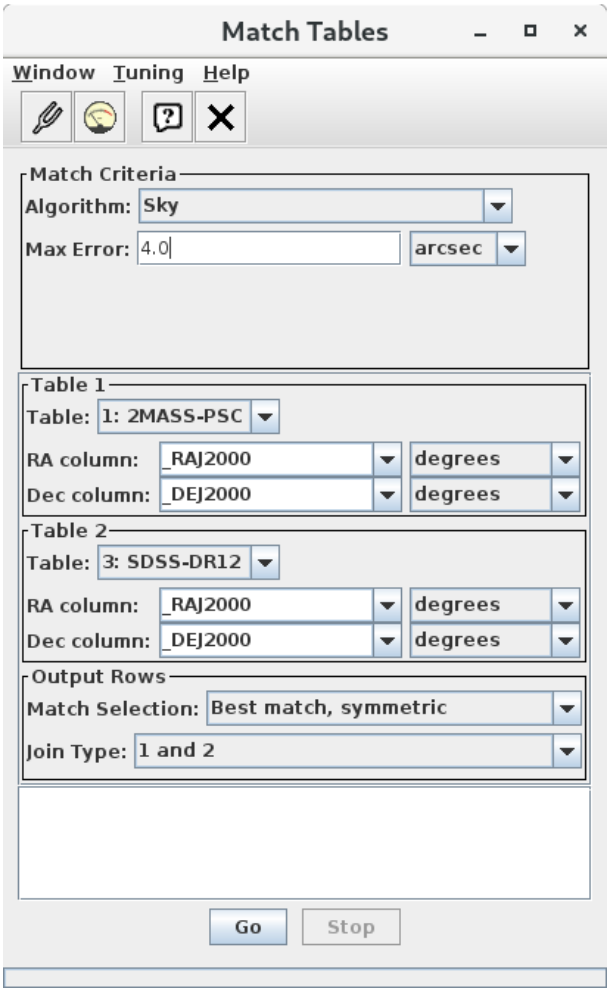
- Rename the table. In the TOPCAT main window, in ***Current Table Properties*** box, write **SDSS-DR12** in ***Label*** and press intro.

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

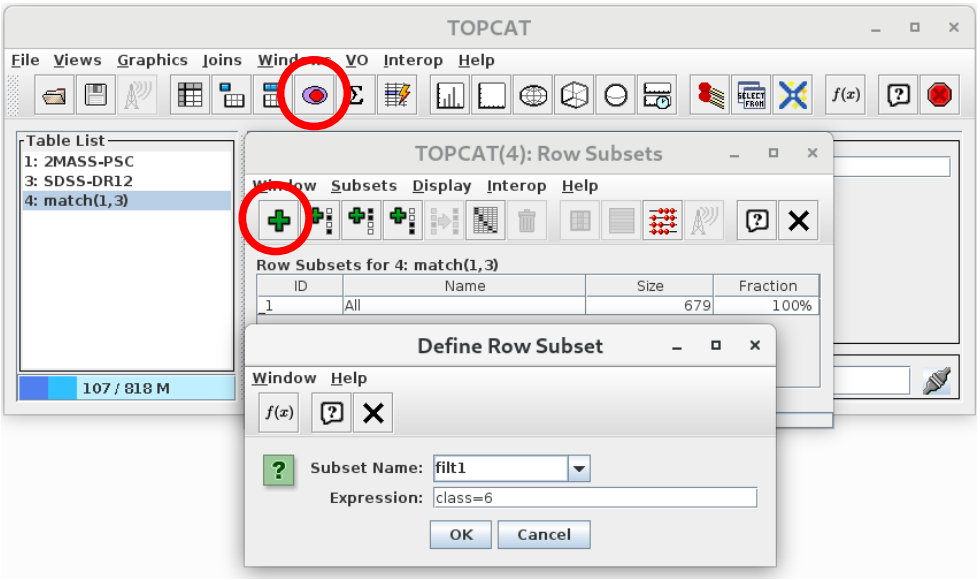
  - In the TOPCAT main window: *Joins → Pair Match* (alternatively you can click on bottom with the two matches of the upper panel). A new window (*"Match Tables"*) is created.

  - 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.



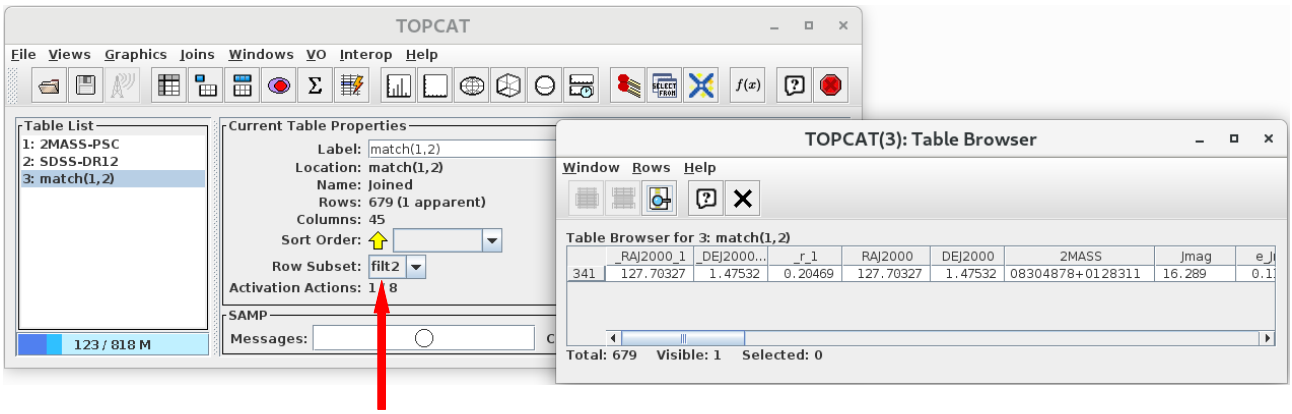
- In the TOPCAT main window, at ***Current Table Properties*** select *"filt1"* in the ***Row Subset*** box. 649 sources are selected.

- 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*.

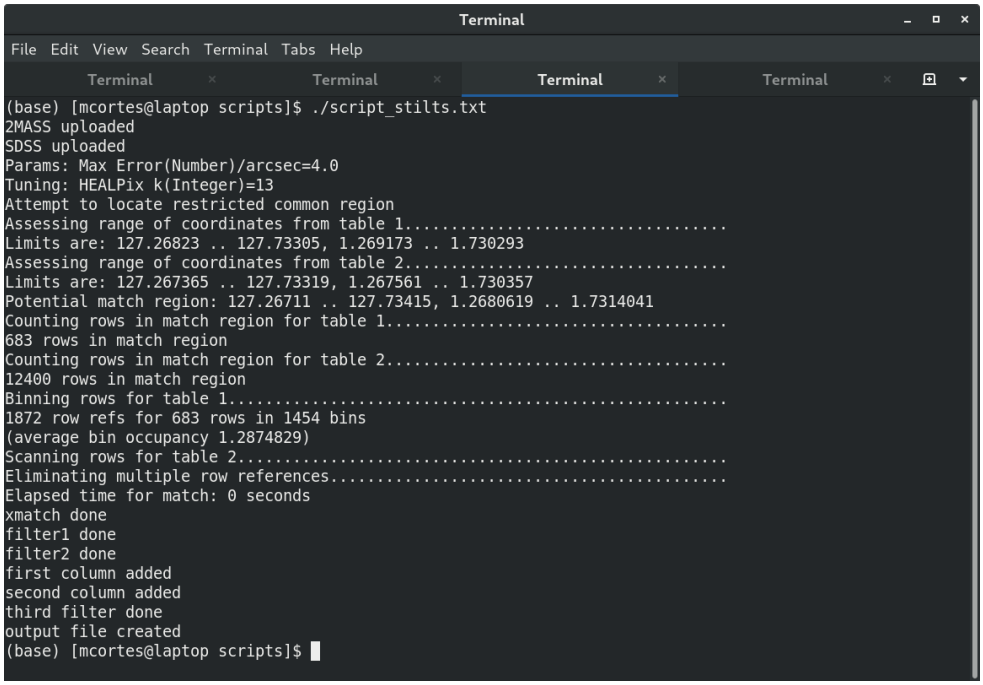
  - Modify the filter expression by doble clicking on the ***Expression*** box and writing: class==6 && umag>22.0 && gmag> 22.2 && Jmag-Hmag<0.3 && Hmag-Kmag<0.3. Name this subset "*filt2*".

  - In the TOPCAT main window, at ***Current Table Properties*** select *"filt2"* in the ***Row Subset*** box. The source that satisfy these criteria is 2MASS J08304878+0128311, with coordinates RA:127.703265deg; DEC:1.475320deg.



- **Second workflow (STILTS):**

  - Copy the code from here your local computer. It should be in the same directory of the stilts.jar file. Name it “script_stilts.txt”
  - 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.



The script, step by step:

1. As in the previous workflow, we first perform a search in 2MASS through VizieR:

java -jar stilts.jar tpipe in='http://vizier.u-strasbg.fr/viz-bin/votable/-A?-source=II/246&-out.max=unlimited&verb=3&RA=127.5&DEC=+1.5&SR=0.2333333' out=2mass.xml

2. The same search is carried out in SDSS-DR12:

java -jar stilts.jar tpipe in='http://vizier.u-strasbg.fr/viz-bin/votable/-A?-source=V/147&-out.max=unlimited&verb=3&RA=127.5&DEC=+1.5&SR=0.2333333' out=sdssdr12.xml

3. We now cross-match both catalogs indicating the error, match selection and join type:

java -jar stilts.jar tskymatch2 ifmt1=votable in1=2mass.xml ifmt2=votable in2=sdssdr12.xml ra1=RAJ2000 dec1=DEJ2000 ra2=RA_ICRS dec2=DE_ICRS error=4 find=best join=1and2 ofmt=votable out=crossmatch.xml

4. We select point sources in the output table using the “class” flag in SDSS:

java -jar stilts.jar tpipe ifmt=votable in=crossmatch.xml cmd='select "class==6"' ofmt=votable out=filter1.xml

5. In the resulting table after applying the filter in “class”, we select sources with umag > 22.0 and gmag > 22.2 in SDSS filters:

java -jar stilts.jar tpipe ifmt=votable in=filter1.xml cmd='select " umag > 22.0 && gmag > 22.2 '" ofmt=votable out=filter2.xml

6. In the resulting table after applying the magnitude cut, we add a column named (Jmag-Hmag) with the difference of *J* minus *H* 2MASS magnitudes.

java -jar stilts.jar tpipe ifmt=votable in=filter2.xml cmd='addcol Jmag-Hmag "(Jmag-Hmag)'" ofmt=votable out=addcol1.xml

7. In the resulting table after applying the magnitude cut, we add a column named (Jmag-Hmag) with the difference of *H* minus *K* 2MASS magnitudes.

java -jar stilts.jar tpipe ifmt=votable in=addcol1.xml cmd='addcol Hmag-Kmag "(Hmag-Kmag)'" ofmt=votable out=addcol2.xml

8. We now select sources with *J-H* < 0.3 mag:

java -jar stilts.jar tpipe ifmt=votable in=addcol2.xml cmd='select "Jmag-Hmag < 0.3'" ofmt=votable out=filter3.xml

9. In the resulting table, we select sources with *H-K* < 0.3 mag:

java -jar stilts.jar tpipe ifmt=votable in=filter3.xml cmd='select "Hmag-Kmag < 0.3'" ofmt=ascii out=candidates.txt

The output should be a file named “candidates.txt” containing the brown dwarf 2MASS J08304878+0128311.