

Virtual Observatory Tools for Solar System

SkyBoT: Identification of solar system objects

To follow this lecture, you will need a Web browser connected to the Internet, and a shell to launch scripts (e.g., `bash`, `csh`), as well as the Aladin and TOPCAT VO tools installed.

Context: The main characteristic of Solar System Objects (SSOs) compared to other astronomical sources is their apparent motion (for VO purposes discussed here), leading to ever-changing coordinates. This is due to their proximity, counted astronomical units when star distances are given in parsecs, and extragalactic sources in redshift. This proximity also implies large parallaxes, even for observers separated by a few hundred kilometers only. As a result, VO tools dedicated to SSOs must account for the **epoch** of observations, as well as the **observer's location**. With the upcoming Gaia stellar catalog, the epoch of observation will also become a necessary quantity for astronomical purposes.

Goals of the tutorial: Get familiar with cone-search utilities, including SkyBoT dedicated to Solar System Objects. Find all the Kuiper Belt Objects observable from C2PU (Calern) within SDSS fields.

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Exercise 1 Cone searches with SkyBoT

This exercise introduces the Sky Body Tracker (SkyBoT) tool. SkyBoT lists all Solar System Objects (SSOs) present within a given field of view at a given epoch. Alike all the services hosted at IMCCE on the VO Solar System Portal, (<http://vo.imcce.fr>), SkyBoT requests can be submitted in different ways (HTTP, Webservice), and results can be provided in different formats (votable, text, html).

Please refer to the online help for more details: <http://vo.imcce.fr/webservices/skybot/?documentation>

1. Launch Aladin
2. Display the POSS-II image (F-DSS2, $0.658 \mu\text{m}$) at coordinates (height/width of 13 arcminutes)

```
RA   03 22 33
DEC  +12 58 48
```

Several trails are present on the image. They correspond to objects that moved during the exposure, i.e., solar system objects.

3. List all the known SSOs present in the field of view.
 - (a) In the Aladin Image Server, select SkyBoT in the list of servers (from its icon in the right column). There are 7 fields, that will be discussed hereafter: Target, Radius, Epoch, Observer location, Search For, Max. uncertainty, Display filter.
 - (b) By default, the Aladin Image Server fills the Target, Radius, and Epoch fields to correspond to the image. So you can simply SUBMIT the request.
 - (c) A new layer has appeared, showing the SSOs with their arrow of motion, from the request Aladin sent to SkyBoT cone search utility: <http://vo.imcce.fr/webservices/skybot/?conesearch>.
 - (d) There is clearly something wrong: the observed SSOs and the predictions do not match! This is however due to an **erroneous dating** of the POSS plate. Repeat the SkyBoT cone search and change the observing epoch to 1991-10-06T09:43:12 (i.e., one day later).

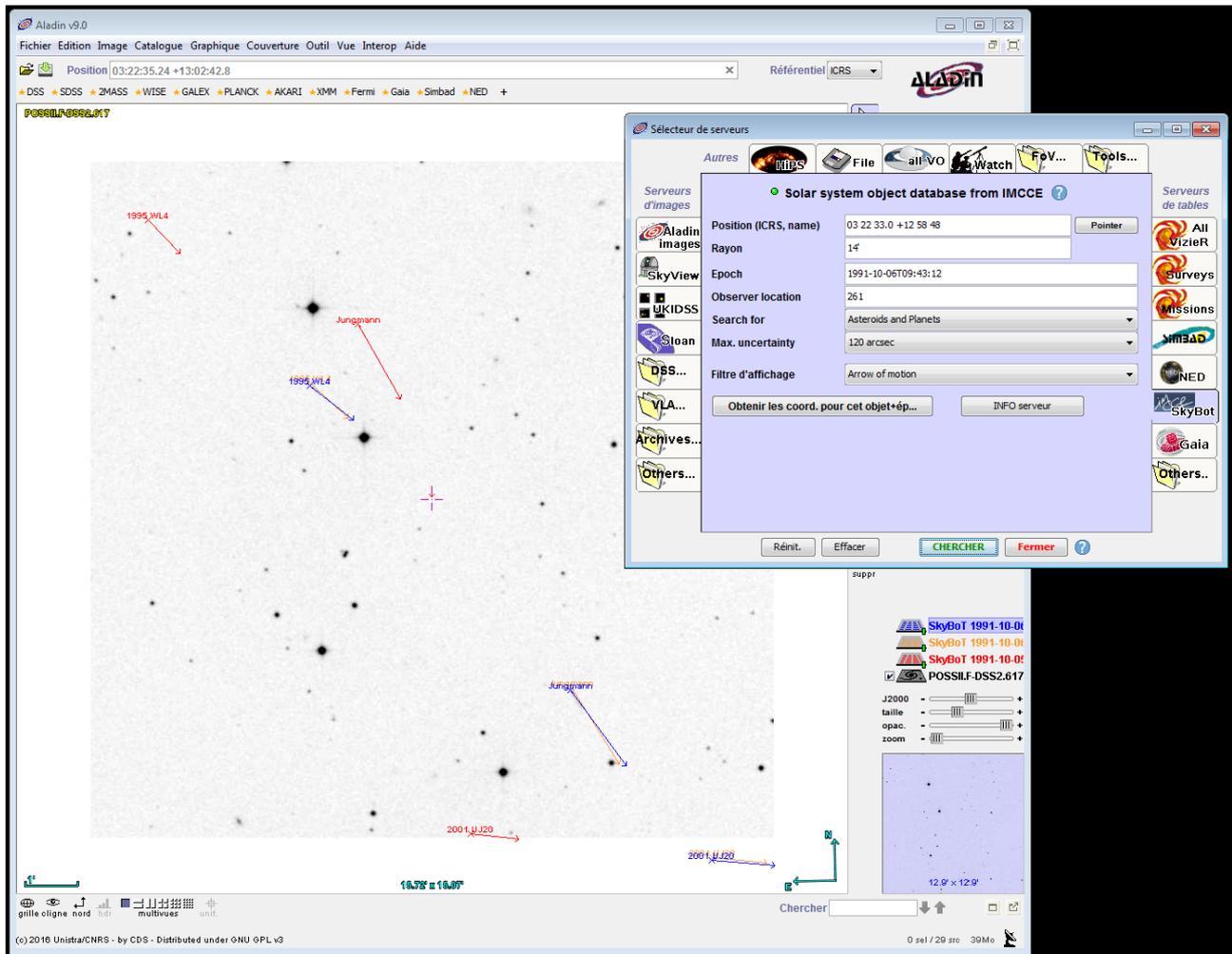


Figure 1: Skybot query through Aladin software.

- (e) The match vastly improved, but you can still notice a mis-alignment between the *orientation* of the arrows of motion and the trails on the image. Repeat the SkyBoT cone search and change the observer location to 261 (500 is geocenter, 261 is Mount Palomar where the DSS plate was taken, see <http://vo.imcce.fr/webservices/data/displayIAUObsCodes.php> for the list of observatory codes).

As illustrated above, a precise definition of time and observing geometry is critical in the case of SSOs.

Exercise 2 Querying SkyBoT without GUI

Previous exercise introduced *SkyBoT* cone search tool. We will see here how this service can be queried without a graphical interface, allowing its use within data processing pipeline.

Please refer to the online help for more details: <http://vo.imcce.fr/webservices/skybot/?documentation>

SkyBoT cone search can be queried from a simple URL:

http://vo.imcce.fr/webservices/skybot/skybotconesearch_query.php?

This provides a simple and easy interface for processing pipelines. The syntax is straightforward and thoroughly described online (<http://vo.imcce.fr/webservices/skybot/?conesearch>). Each parameter can be provided in the URL with the following pattern:

`-parameter1=value1&-parameter2=value2&...`

```

[00:57] -- $ curl "http://vo.imcce.fr/webservices/skybot/conesearch?-ep=1991-10-06T09:43:12&-ra=50.5958&-dec=12.98&-rm=14&-obs=261&-mime=text&-from=TutoV02017"
# Flag: 1
# Ticket: 1506207437735
# Num | Name | RA(h) | DE(deg) | Class | Mv | Err(arcsec) | d(arcsec) | dRA(arcsec/h) | dDEC(arcsec/h) | Dg(ua) | Dh(ua)
40441 | Jungmann | 03 22 22.2250 | +12 55 12.801 | MB-Middle | 18.2 | 2.544 | 215.491 | -10.7214 | -17.467 | 1.17047905007 | 2.04858841256
12797 | 1995 WL4 | 03 22 42.4442 | +13 01 0.683 | MB-Inner | 18.5 | 0.022 | 313.743 | -8.2819 | -7.897 | 1.32539620109 | 2.19585264858
240023 | 2001 UJ20 | 03 22 11.2860 | +12 51 58.677 | MB-Inner | 20.6 | 3.150 | 443.662 | -12.1452 | -1.220 | 1.06398014338 | 1.94785979635
382017 | 2011 BK53 | 03 22 6.0814 | +13 09 3.465 | MB-Inner | 21.9 | 3.397 | 663.215 | -16.5369 | -7.598 | 1.76126481334 | 2.6171970155
37898 | 1998 FG65 | 03 22 6.2011 | +13 10 40.999 | MB-Middle | 20.0 | 0.145 | 754.029 | -17.5123 | -12.893 | 2.22357415950 | 3.06786181582
107485 | 2001 DG37 | 03 23 16.4773 | +12 54 3.973 | MB-Middle | 20.6 | 5.177 | 831.897 | -14.1268 | -7.541 | 1.77008546487 | 2.62391347560

```

Figure 2: Skybot query in a console with curl.

Hence one can query the service by building a URL corresponding to his needs (observer's location, epoch, field of view, coordinates) and downloading the result locally using `curl` or `wget` commands:

```

$ curl "http://vo.imcce.fr/webservices/skybot/skybotconesearch_query.php?-ep=now&-ra=148&-dec=16"
$ wget "http://vo.imcce.fr/webservices/skybot/skybotconesearch_query.php?-ep=now&-ra=148&-dec=16"

```

1. Copy-paste the following URL in your Web browser:
http://vo.imcce.fr/webservices/skybot/skybotconesearch_query.php?-ep=now&-ra=148&-dec=16&-rs=500&-obs=500&-mime=html&-from=TutoV02017
2. Observe how changing the numerical values of the coordinates (`ra`, `dec`), radius of the search (`rs`, in arcseconds), and observer's location (`obs`) affect the result.
3. The format of the output is controlled by the `mime` parameter: try `text` instead of `html`, and then `votable` (the default, which is how Aladin interacts with SkyBoT).
4. Construct the URL corresponding to the latest query in [Exercise 1](#).

Answer: <http://vo.imcce.fr/webservices/skybot/conesearch?-ep=1991-10-06T09:43:12&-ra=50.5958&-dec=12.98&-rm=14&-obs=261&-mime=votable&-from=TutoV02017>

Exercise 3 The Solar System Objects on the celestial sphere

*SkyBoT cone search is fast because the ephemerides for all the known SSOs are pre-computed weekly, and stored in a tree-like database with a time step of 10 days for the period 1890-2060. Detailed ephemerides for the requested observing epoch in the SkyBoT cone search are thus computed only for objects likely to be in the requested field of view. This database can be queried to retrieve the position of **all** SSOs at a given epoch, using the SkyBoT-3D service, providing a statistical view of the distribution of SSOs on the sky or in space. In this exercise, we search for all the Kuiper Belt Objects (KBOs) visible from a given location, larger than 300 km, and within SDSS fields, as for planning their observations with SDSS filters.*

Please refer to the online help for more details: <http://vo.imcce.fr/webservices/skybot3d/>

In a very similar way to SkyBoT, SkyBoT-3D can be queried from a simple URL. The syntax also follows the same general pattern (`-parameter1=value1&...`). In what follow, we will use the following end-point:
http://vo.imcce.fr/webservices/skybot3d/getAster_query.php?

1. Open TOPCAT and Aladin.
2. Use the `getAster` method of SkyBoT-3D to download the position of all KBOs at current epoch. Take particular attention to the following parameters:
 - `class`: To choose KBOs only.
 - `mime`: To choose a machine-readable format (VOTable recommended).
 - `getFile`: To directly download the data and not a link to the data.

Answer: http://vo.imcce.fr/webservices/skybot3d/getAster_query.php?-ep=now&-class=KBO&-mime=votable&-coord=spherical&-from=TutoV02017&-getFile=1

3. Open the file in TOPCAT. Note that by directly providing the URL to TOPCAT (in the "Open File" dialog), it will query SkyBoT-3D, download the data, and open it directly.

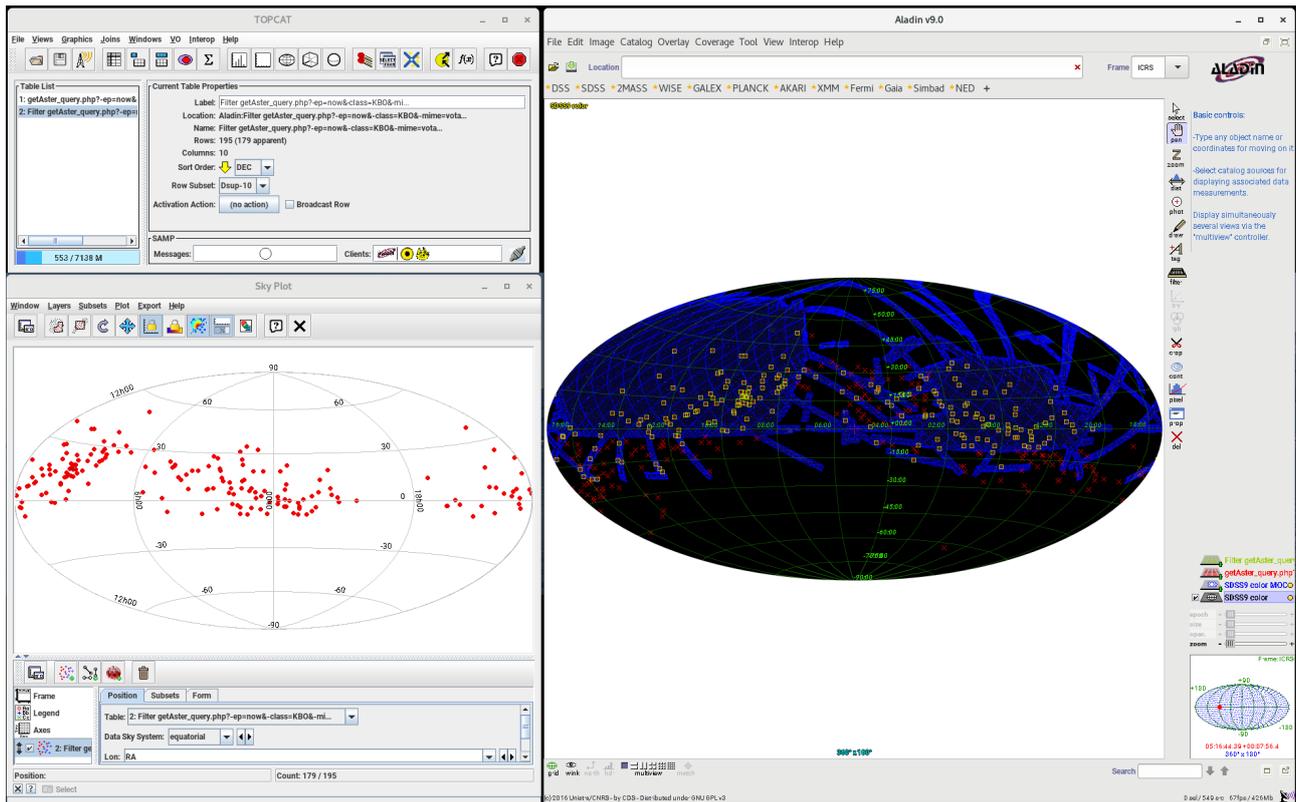


Figure 3: Subset of KBOs ($H < 6$ and $\delta > -10^\circ$) matching SDSS9 coverage.

4. Create a new subset containing only KBOs with an absolute magnitude H smaller than 6.0, corresponding to a diameter of 300 km.
5. Send this subset to Aladin [Interop menu]
6. In Aladin, load the SDSS9 colored HiPS [File menu \rightarrow Progressive sky \rightarrow Image \rightarrow Optical \rightarrow SDSS \rightarrow SDSS 9 color]
7. Load the coverage of SDSS survey [Coverage menu \rightarrow Load the coverage (MOC) of the current survey]
8. Select the KBOs within the SDSS [Coverage menu \rightarrow Filter a table by MOC], and send the filtered table back to TOPCAT [right click on the table, and Broadcast selected table...]
9. In this new table, create a new subset of KBOs with declination higher than -10° , corresponding roughly to objects with a peak airmass below 2.
10. You can use the Sky Plot tool in TOPCAT to visualize how the original KBO sample compares with the selection made in Aladin, and the last sample further trimmed in declination.

In summary, the availability of the SkyBoT database via SkyBoT-3D provides a very quick access to statistical properties of SSOs. In the example above, one can find targets to observe with a few steps of selection using TOPCAT and Aladin.

Optional: The solar system in 3-D

The `coord` parameter of SkyBoT-3D allows to download the position of SSOs in cartesian coordinates in the ECJ2000 reference frame.

1. Open TOPCAT.
2. Use the `getAster` method of SkyBoT-3D to download the position of the outer main-belt asteroids (MB>outer) and Jupiter Trojans (Trojan) at current epoch. The different classes of SSOs are described in the documentation: <http://vo.imcce.fr/webservices/skybot/?documentation> \rightarrow Sso classes.

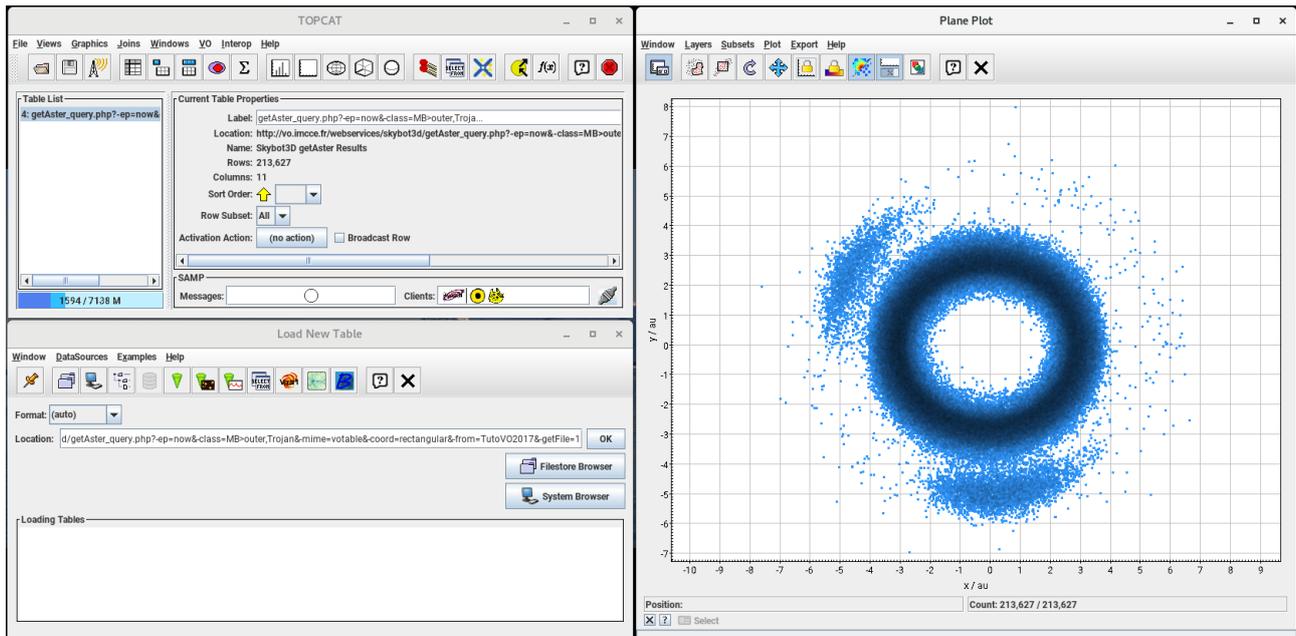


Figure 4: Top view of the solar system showing the outer main-belt asteroids and Jupiter Trojans.

3. Load the table in TOPCAT.
4. Create a view of the solar system as seen from the top.

Answer: http://vo.imcce.fr/webservices/skybot3d/getAster_query.php?-ep=now&-class=MB>outer,Trojan&-mime=votable&-coord=rectangular&-from=TutoV02017&-getFile=1

Exercise 4 Generate ephemerides with Miriade

Miriade offers a suite of methods to compute the position, orientation, time of rise, set and transit of SSOs, as well as to plan observations. This exercise aims at introducing the computation of position ephemerides by computing and displaying the solar analemma.

Here again, we will query *Miriade* by sending queries to the end-point of the dedicated method (`ephemcc`), using the “`-parameter1=value1&...`” syntax. Please refer to the online help for more details: <http://vo.imcce.fr/webservices/miriade/?ephemcc>

The oldest clocks were based on the apparent position of the Sun in the sky: the sundials. If you are familiar with them, you know there is a difference between the time indicated by the Sun and that of our clocks (based on extremely regular atomic clocks) due to the non-circular orbit of the Earth and the tilt between the ecliptic plane and Earth equator.

Miriade end-point to compute positional ephemerides:
http://vo.imcce.fr/webservices/miriade/ephemcc_query.php?

1. Use *Miriade* to compute the position of the Sun over an entire year, at a fixed time every day, starting from equinox (e.g., 2017-09-21T12:00:00), from Calern (IAU code 010), in a local reference frame (Azimuth/Elevation or hour angle/elevation). Pay attention to the following parameters:
 - `ep`: Starting epoch of computation.
 - `name`: The object for which to compute ephemerides (Sun is identified by `p:Sun`).
 - `nbdt`: Number of epochs to compute
 - `step`: The time interval between two epochs
 - `tcoor`: The type of coordinates

