

Authors: Miriam Cortés-Contreras, Enrique Solano. CAB (INTA-CSIC). Spanish Virtual Observatory (SVO), January 2022. Updated by Alba Aller, CAB (INTA-CSIC, SVO), October 2022.

NOTE: The tutorial has been tested using Firefox v89.0.2 (64-bit).

- **Scientific background:** Transients can be defined as astrophysical phenomena whose duration is significantly lower than the typical timescale of the stellar and galactic evolution (from seconds to years in contrast to millions or billions of years). Supernovae, novae, gamma-ray burst..., are some examples of transient events. In most cases, a fast, multiwavelength characterization is required to properly understand the true nature of the transient. Follow-up observations made by both professional and amateur astronomers using ground- and space-based facilities are key to achieve this goal.

Here we propose an alternative approach using the existing information in astronomical archives and benefiting from the advantages that the Virtual Observatory offers in terms of discovery, access and analysis of astronomical data. Using **TOPCAT**, **Vizier** and **SPLAT-VO**, and two services developed in the framework of the Spanish Virtual Observatory (**SVO Discovery Tool** and **VOSA**) we will validate and characterize a cataclysmic variable identified by the Gaia Science Alerts project. Cataclysmic variable stars (CVs) are interacting binary systems composed by a white dwarf that accretes material from a companion star. Because of its accreting nature, the system irregularly presents an important increase of brightness and then drop back down to a quiescent state.



Cataclysmic variable (source: Wikipedia)

■ Workflow:

1. **Target selection.** From the Gaia Science Alerts project we will select an object classified as “unknown” and suspect of being a cataclysmic variable:
 - Open your web browser and go to: <http://gsaweb.ast.cam.ac.uk/alerts/alertsindex>
 - In the search box (top right) type “Gaia19fdn”. This object has been classified as unknown and has the following statement under the *Comment* column: “Gaia source coincident with CV candidate brightens by more than 1 mag”.

Index to Gaia Photometric Alerts

If you publish any results based on these Gaia discoveries, we would appreciate an acknowledgement along the lines of: "We acknowledge ESA Gaia, DPAC and the Photometric Science Alerts Team (<http://gsaweb.ast.cam.ac.uk/alerts/>)"

These are all the alerts raised to date. You might wish to view or download these as a table in CSV format or using any of the tools described in this page. See here for an explanation of the columns.

Show 10 entries Search: gaia19fdn

Name	TNS	Observed	RA (deg.)	Dec. (deg.)	Mag.	Historic mag.	Historic scatter	Class	Published	Comment	RVS
Gaia19fdn	AT2019vcr	2019-11-16 14:48:51	151.31404	19.18553	17.03	18.22	0.20	unknown	2019-11-18 14:26:12	Gaia source coincident with CV candidate brightens by more than 1 mag	

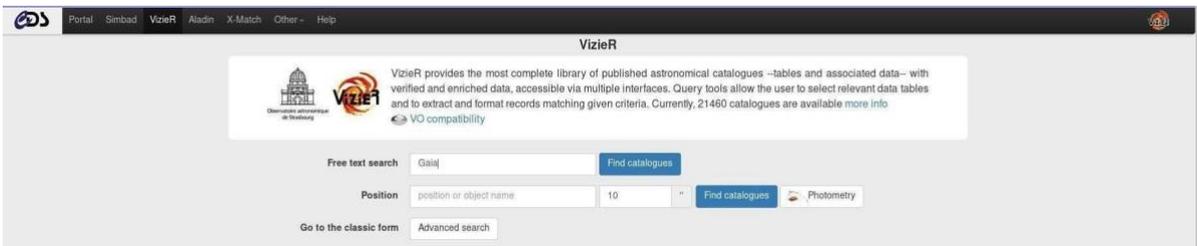
Showing 1 to 1 of 1 entries (filtered from 18,183 total entries) Previous 1 Next

- Click on the name "gaia19fdn" (column "Name"). A new tab will open with a file card containing information like the coordinates and the magnitude variation over time.

2. HR diagram. Cataclysmic variables occupy the intermediate region in the Hertzsprung-Russell diagram (HRD) between the main sequence and the white dwarf locus.

We will draw our target in a HRD diagram using TOPCAT and the VizieR service.

- **Obtaining the data:**
 - We will gather Gaia EDR3 data from the VizieR service. Open your web browser and go to <http://vizier.u-strasbg.fr/>
 - Write "Gaia" in the **Free text search** and click on the *Find catalogues* button.



- Look for "Gaia DR3 Part 1. Main source (Gaia Collaboration, 2022)" in the list of results and click on the VizieR button to query the VizieR table.

Catalogue	Records	Description	Access
I/324	1.223e+9	The Initial Gaia Source List (IGSL) (Smart, 2013)	VizieR Ftp ReadMe TAP Xmatch
I/337	1.147e+9	Gaia DR1 (Gaia Collaboration, 2016)	VizieR Ftp ReadMe TAP Xmatch
I/345	1.719e+9	Gaia DR2 (Gaia Collaboration, 2018)	VizieR Ftp ReadMe TAP Xmatch
I/347	1.332e+9	Distances to 1.33 billion stars in Gaia DR2 (Bailer-Jones+, 2018)	VizieR Ftp ReadMe TAP Xmatch
I/350	1.825e+9	Gaia EDR3 (Gaia Collaboration, 2020)	VizieR Ftp ReadMe TAP Xmatch
I/352	1.468e+9	Distances to 1.47 billion stars in Gaia EDR3 (Bailer-Jones+, 2021)	VizieR Ftp ReadMe TAP Xmatch
I/355	1.914e+10	Gaia DR3 Part 1. Main source (Gaia Collaboration, 2022)	VizieR Ftp ReadMe TAP Xmatch

- The query returns several catalogues for Gaia DR3 Part 1. Click on the first one ([l/355/gaiadr3](#)).

Catalog


[Gaia DR3 is available in CDS](#)
[Gaia DR3 in Vizier](#)

The Vizier service is now hosted by CDS domain (cds.uistra.fr). Please, modify your configuration for the new domain.

I/355		Gaia DR3 Part 1. Main source (Gaia Collaboration, 2022)	Similar Catalogs	2022yCat.1355...0G	ReadMe+ftp
		acknowledge and cite Gaia DR3			spectrum timeSerie
<input type="checkbox"/>	l/355/gaiadr3	(c) Gaia data release 3 (Gaia DR3). (original column names in green) [timeSerie] (1811709771 rows)			spectrum
<input type="checkbox"/>	l/355/paramp	(c) 1D astrophysical parameters produced by the Apsis processing chain developed in Gaia DPAC CU8 (1590932717 sources) (astrophysical_parameters) (original column names in green) (1590932717 rows)			
<input type="checkbox"/>	l/355/paramsup	(c) Additional parameters from the Apsis processing chain, compared to the main table astrophysical parameters, from modules that produce more than one result for a parameter (473020612 sources) (astrophysical_parameters,supp) (original column names in green) (473020612 rows)			
<input type="checkbox"/>	l/355/tgextmap	Total Galactic Extinction (TGE) map for extinction parameters A0 (original column names in green) (4177920 rows)			
<input type="checkbox"/>	l/355/tgextopt	Optimum version of the Total Galactic Extinction Map, derived from the table tgextmap.dat (total_galactic_extinction_map) at a single HELPix level 9 (3145728 rows)			
<input type="checkbox"/>	l/355/oainfo	Content of a Self-Organized Map calculated from a dataset composed by outliers by the Apsis module OA (oa_neuron_information) (original column names in green) (900 rows)			

- In the **Target Name** (resolved by Sesame) or **Position** box on top left, write the coordinates of the object: 151.31404 +19.18553. Then change the target dimension to 5 arcsec and click the **Submit** button.

Simple Target | List Of Targets Fast Xmatch with large catalogs or Simbad

Target Name (resolved by Sesame) or Position:

NB: The epoch used for the query is the original epoch of the table(s) Radius Box size

I/355 [acknowledge and cite Gaia DR3](#) [Post annotation](#) [Similar Catalogs](#) [2022yCat.1355...0G](#) [ReadMe+ftp](#)

l.l/355/gaiadr3 Gaia data release 3 (Gaia DR3). (original column names in green) [timeSerie] (1811709771 rows) [spectrum](#)

Simple Constraint | List Of Constraints

Query by Constraints [?](#) applied on Columns (Output Order: + -)

Standard Original

Show	Sort	Column	Clear	Constraint	Explain (UCD)
<input type="checkbox"/>	<input type="radio"/>	DR3Name	<input type="text"/>	(char)	Unique source designation (unique across all Data Releases) (designation) (meta.id)
<input checked="" type="checkbox"/>	<input type="radio"/>	RA_ICRS	<input type="text"/>	deg	(i) Right ascension (ICRS) at Ep=2016.0 (ra) (pos.eq.ra:meta.main)
<input checked="" type="checkbox"/>	<input type="radio"/>	DE_ICRS	<input type="text"/>	deg	(i) Declination (ICRS) at Ep=2016.0 (dec) (pos.eq.dec:meta.main)
<input type="checkbox"/>	<input type="radio"/>	SolID	<input type="text"/>		Solution Identifier (solution_id) (meta.version)
<input checked="" type="checkbox"/>	<input type="radio"/>	Source	<input type="text"/>		(i) Unique source identifier (unique within a particular Data Release) (source_id) (meta.id:meta.main)
<input type="checkbox"/>	<input type="radio"/>	RandomI	<input type="text"/>		Random index for use when selecting subsets (random_index) (meta.code)
<input checked="" type="checkbox"/>	<input type="radio"/>	e_RA_ICRS	<input type="text"/>	mas	Standard error of right ascension (ra_error) (stat.error:pos.eq.ra)
<input checked="" type="checkbox"/>	<input type="radio"/>	e_DE_ICRS	<input type="text"/>	mas	Standard error of declination (dec_error) (stat.error:pos.eq.dec)
<input checked="" type="checkbox"/>	<input type="radio"/>	Pix	<input type="text"/>	mas	(n)(i) Parallax (parallax) (pos.parallax.trjg)

- Launch TOPCAT: If you downloaded the Jar file, open a terminal and type: java - jar topcat-full.jar & ; if you have the MacOS installation, open the TOPCAT application.
- Back to Vizier, on the top right corner of the results' page, you will see the text **Send to VO tools**. Click on the antenna icon below the text. A SAMP Hub Security window will pop-up. Click on Yes to authorize the connection. Then click on **Broadcast** button near the antenna in the Vizier window. A table named "gaiadr3" will be loaded in TOPCAT.

Portal Simbad VizieR Aladin X-Match Other Help

VizieR

Show the target form
Show constraint information

The 2 columns in *color* are computed by VizieR, and are *not part of the original data*.

I/355/gaiadr3 Gaia DR3 Part 1. Main source (Gaia Collaboration, 2022) 2022yCat.1355...0G ReadMe:ftp
Post annotation Gaia data release 3 (Gaia DR3). (original column names in green) (1811709771 rows) spectrum timeSerie

start AladinLite plot the output query using TAP:SQL

Full	RA ICRS	DE ICRS	Source	e RA ICRS	e DE ICRS	Plx	e _{plx}	PM	pmRA	e _{pmRA}	pmDE	e _{pmDE}	RUWE	FG
	deg	deg		mas	mas	mas	mas	mas/yr	mas/yr	(μ)	mas/yr	(μ)		c/s
	151.31405347582	+19.18551111348	626719772406892288	0.1326	0.1415	2.9292	0.1693	13.378	-13.344	0.151	-0.962	0.133	1.025	1068.85368

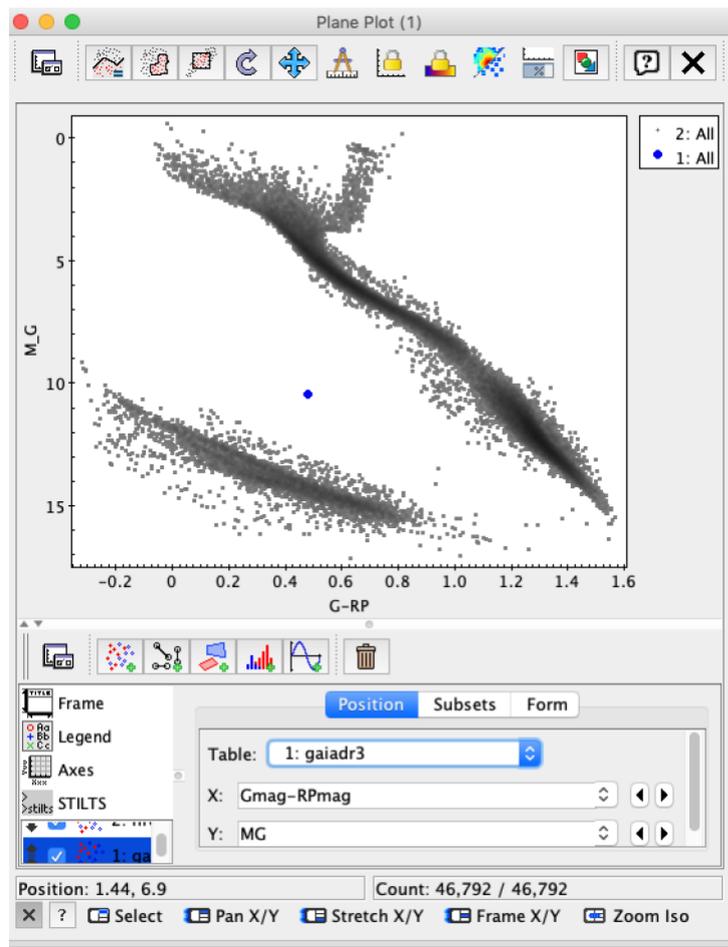
plot the output query using TAP:SQL

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- Download the file "[hrdiagram_dr3.xml](#)". It contains the astrometric solution for more than 46000 Gaia sources with good parallaxes and colours. We will use it as a reference for the HRD.

● Exploring the data:

- In TOPCAT, load the file "hrdiagram_dr3.xml": *File* → *Load table* → *Filestore Browser*. Select the file and click OK. You will see the table loaded in the *Table List* box, to the left. By double clicking on it you can open the table to make a visual inspection of its content.
- To plot the HRD: *Graphics* → *Plane Plot* (or click on the 11th icon starting from the left). A new window will pop up.
 - Select your table "hrdiagram_dr3.xml"
 - X axis will be (G-RP) (difference in magnitude in the Gaia G and RP bands)
 - Y axis: M_G (absolute magnitude in the G band).
- On the left panel of this window, go to **Axes** → **Coords** and select *Y Flip*.
- The color of the sources can be changed in the *Plane Plot* window by clicking on the name of the plane (hrdiagram_dr3.xml; it should be highlighted in blue), then click on **Subsets** (the tag in between *Position* and *Form*) and change the red color to, for instance, light gray.
- In order to overplot in this HRD the gaiadr3 source we need first to create a new column with the absolute magnitude in the G band. For this, we will proceed as follows:
 - Click on *gaiadr3* in the Table List box of the TOPCAT main window (it should be highlighted in blue).
 - Views* → *Column info* (or click on the 6th icon starting from the left). A new window (Table columns) will pop up. Click on the first icon starting from the left (a green cross). A new window (define synthetic column) will pop up. Name it **MG** and write in the *Expression* box:
$$\text{Gmag}-5*\log_{10}(1000./\text{plx})+5$$
 - Click OK
- In the same Plane Plot window: *Layers* → *Add Position Control*. A new line will appear below the left box. In the frame to the right, select the table "gaiadr3" and plot (Gmag-RPmag) on the X axis and MG on the Y axis. The source lies between the main sequence and the white dwarf locus, as expected for a cataclysmic variable star.



2. **Spectral Energy Distribution (SED)**. Close binary stars of different effective temperature will present two differentiated distributions, one per each component in the system. We will now build the SED of our target using VOSA (VO SED Analyzer).
 - Open your web browser and go to: <http://svo2.cab.inta-csic.es/theory/vosa> Log in with your user and password if you already have an account. Complete the registration process, otherwise. To do that, click on *Register* and fill in the fields (e- mail address, name and password).
 - Create a single object data file typing the coordinates of the object in the RA and DEC boxes to the right. You can write the name of the object in the description box ("Gaia19fdn"). Click on the *Create* button.
 - RA: 151.31404
 - DEC: +19.18553



- Click the *Continue* link to keep going. You will be redirected to the initial page with this data file selected.
- Go to [Objects](#) → [Distances](#) tab to obtain the distance to the target. Keep the search radius at 5 arcsec. Click on *Search for Obj. Distances*. Distances from different catalogs will be shown. To make the Gaia DR3 distances the final ones, select them using the radio button on the right and click *Save Obj. Distances*. The distance and its error should appear boldfaced under the *Final* column.

GAIA DR3 (viz)

Δ (arcsec)	RA (deg)	DEC (deg)	Plx (mas)	Δ Plx (mas)	D (pc)	Δ Dis (pc)	<input type="radio"/>
0.0828	151.31405347582	+19.18551111348	2.9292	0.1693	341.390	19.731	<input type="radio"/>

- Move to [Build SEDs](#) → [VO photometry](#). Here we will be able to look for photometric information of our objects in different VO archives and services. In order not to slow down too much the tutorial, click on *unmark All* and select only 2MASS, WISE, Gaia DR3 (CDS), Pan-Starrs PS1 DR2, and GALEX GR6+7. Then, click *Query selected services* at the bottom of the page. Once this is done, a summary table with the VO photometry (in flux units) will appear.
- Go to [Build SEDs](#) → [SED edit/visualize](#). This tag gives us the possibility of visualizing/modifying the SED before the model fitting. VOSA gathers from VO services not only the photometric information but also different metadata of interest (Object name, observing date and information on quality). In particular, VOSA uses the information on quality to automatically identify bad photometric points and remove them from the fitting (see next step). Upper limits are treated in a similar way. The user can manually override this selection of photometric points by ticking/unticking the appropriate boxes. For this use case, do not make any change in the SED edit/visualize section.

Files	Objects	Build SEDs	Analyse SEDs	HR Diag.	Results	Help
Stars and brown dwarfs (Change)			File: Gaia19fdn (info) (Change)			

VO Photometry SED edit/visualize

Object data

See object: excess See all

obj_151.31404_+19.18553

Position: (151.31404,+19.18553) Distance: 341.390 pc

Data for this object:

Filter	λ_{med}	Observed		Dereddened		$\Delta F/F$	In SED	Point Opts				Source
		Obs.Flux	Δ Obs.Flux	Flux	Δ Flux			NoFit	Uplim	Bad	Ignore	
GALEX/GALEX.FUV	1548.85	1.524e-15	1.321e-16	1.524e-15	1.321e-16	8.67e-2	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	GALEX-GR6+7
GALEX/GALEX.NUV	2303.37	7.337e-16	4.180e-17	7.337e-16	4.180e-17	5.70e-2	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	GALEX-GR6+7
PAN-STARRS/PS1.g	4810.16	2.081e-16	4.396e-18	2.081e-16	4.396e-18	2.11e-2	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Pan-Starrs PS1 DR2
GAIA/GAIA3.Gbp	5035.75	2.035e-16	8.578e-18	2.035e-16	8.578e-18	4.22e-2	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Gaia DR3 (CDS)
GAIA/GAIA3.G	5822.39	1.421e-16	2.077e-18	1.421e-16	2.077e-18	1.46e-2	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Gaia DR3 (CDS)
PAN-STARRS/PS1.r	6155.47	1.291e-16	1.151e-18	1.291e-16	1.151e-18	8.91e-3	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Pan-Starrs PS1 DR2
PAN-STARRS/PS1.i	7503.03	1.172e-16	5.181e-18	1.172e-16	5.181e-18	4.42e-2	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Pan-Starrs PS1 DR2
GAIA/GAIA3.Grp	7619.96	1.121e-16	7.816e-18	1.121e-16	7.816e-18	6.97e-2	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Gaia DR3 (CDS)
PAN-STARRS/PS1.z	8668.36	1.026e-16	5.785e-18	1.026e-16	5.785e-18	5.64e-2	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Pan-Starrs PS1 DR2
PAN-STARRS/PS1.y	9613.60	1.159e-16	7.436e-18	1.159e-16	7.436e-18	6.42e-2	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	Pan-Starrs PS1 DR2
2MASS/2MASS.J	12350.00	7.802e-17	1.028e-17	7.802e-17	1.028e-17	1.32e-1	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	2MASS
2MASS/2MASS.H	16620.00	6.215e-17	0.000e+00	6.215e-17	0.000e+00	0.00e+0	✓	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	2MASS
2MASS/2MASS.Ks	21590.00	2.914e-17	5.234e-18	2.914e-17	5.234e-18	1.80e-1	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	2MASS
WISE/WISE.W1	33526.00	5.434e-18	2.152e-19	5.434e-18	2.152e-19	3.96e-2	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	WISE
WISE/WISE.W2	46028.00	2.190e-18	1.856e-19	2.190e-18	1.856e-19	8.47e-2	✓	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	WISE
WISE/WISE.W3	115608.00	9.654e-19	0.000e+00	9.654e-19	0.000e+00	0.00e+0	✓	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	WISE
WISE/WISE.W4	220883.00	1.763e-18	0.000e+00	1.763e-18	0.000e+00	0.00e+0	✓	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	WISE

Apply changes

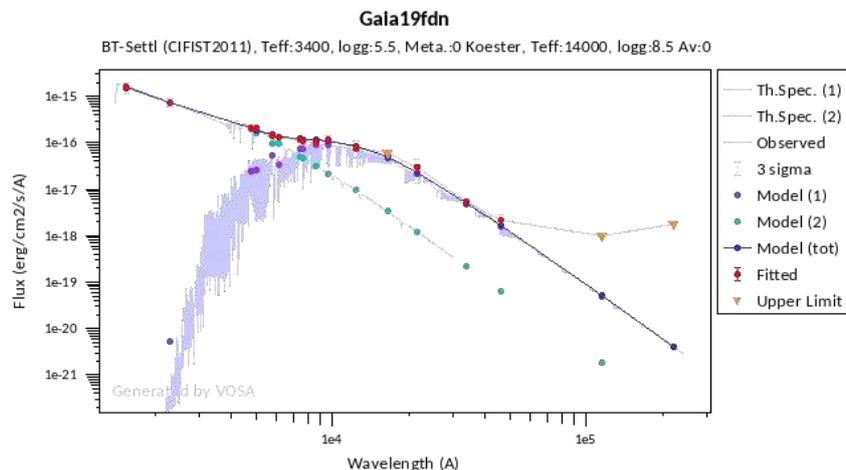
(Add a new point)

- Move to *Analyse SEDs* → *Binary Fit*. Different grids of theoretical models covering different ranges of physical parameters are displayed. For this tutorial select the “Koester WD models” and “BT-Settl (CIFIST)” for fitting the white dwarf and the main sequence components of the system, respectively.

At the bottom of the page, in **Options for this fit**, select “*Include model spectrum in fit plots?* (The fit process will be slower, because getting the spectra from the VO can take some time)”. Click on *Next: Select model params* at the bottom of the page.

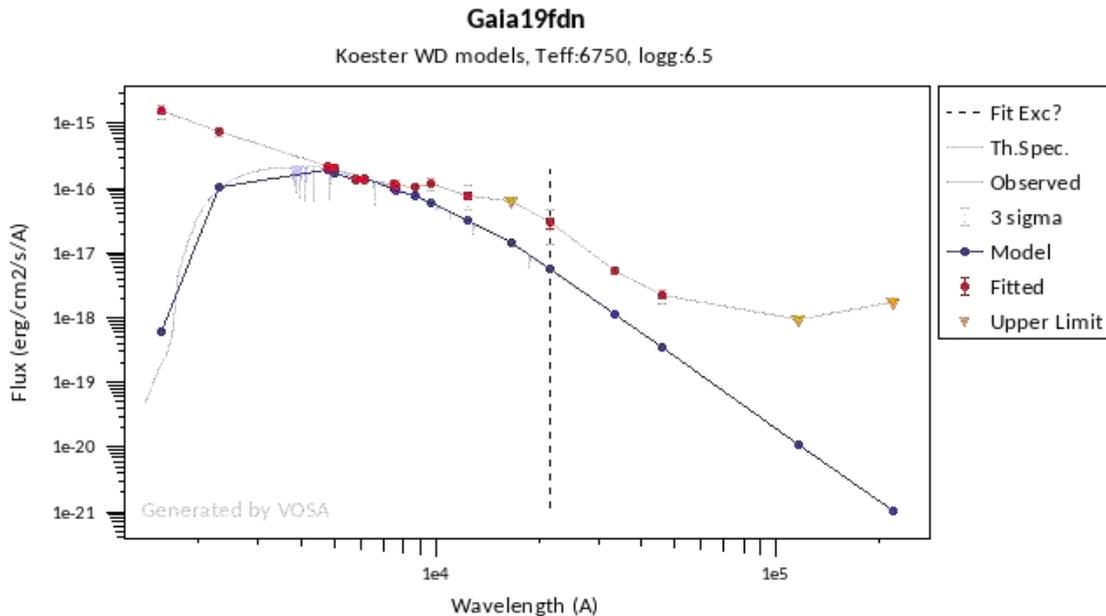
- To save time, for BT-Settl set the logg range to 4.5 – 5.5. For Koester set the temperatures range to 5000 – 15000 K. Click on *Next: Make the fit*.

A summary table will appear. Click on the *Show graphs* button above the table to see the SEDs plot.



Both components of the systems have been fitted with temperatures of 14000 K and 3400 K for the white dwarf and the low-mass star secondary, respectively.

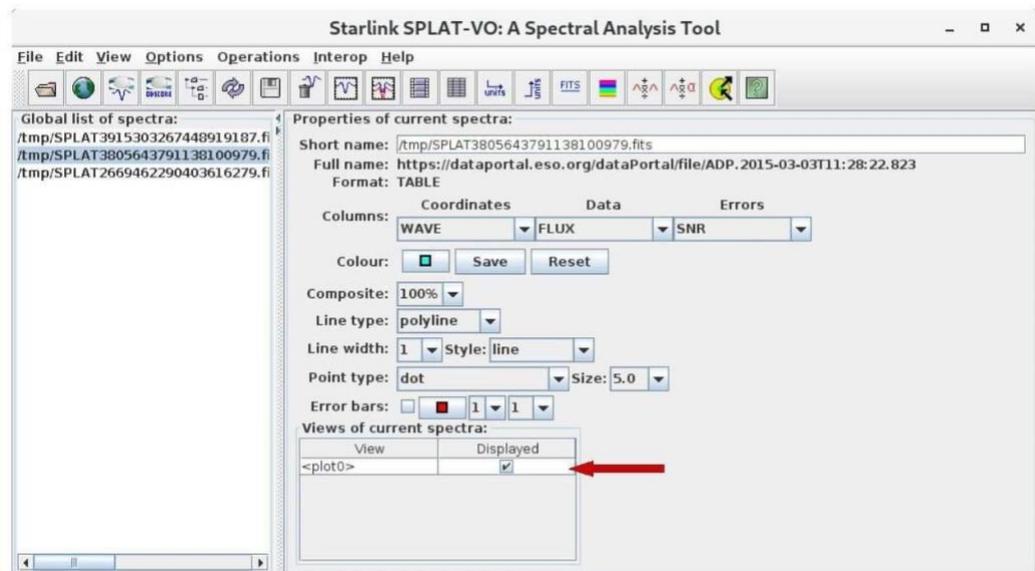
- To see the importance of the binary fitting, try yourself by fitting only the white dwarf component. For this, move to the tab *Analyse SEDs → Chi-square Fit* instead and select the “Koester WD models” with the same parameter restrictions. The observational SED shows an infrared excess compared to the models due to the presence of the cool component and the estimated effective temperature (6750 K) comes from a poor SED fitting and does not represent the real temperature of the white dwarf.



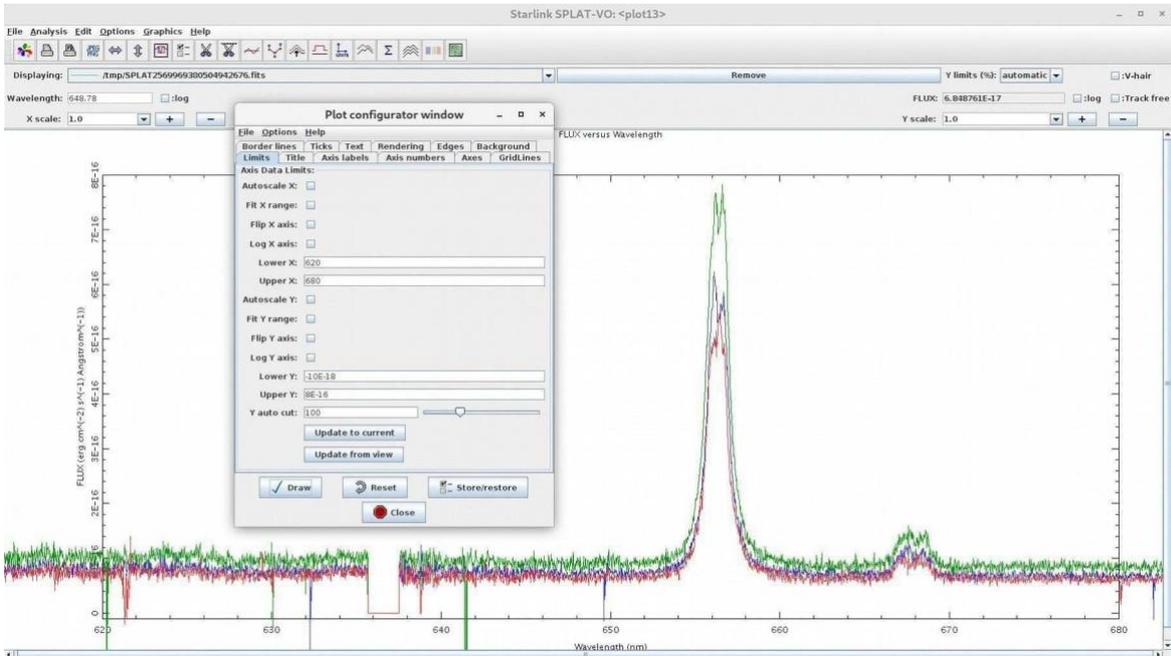
3. **Search for spectroscopic information.** Cataclysmic variables show H α emission due to accretion. Let's look for spectra of our source in VO archives to see if this feature is present.

- Open your web browser and go to: <http://sdc.cab.inta-csic.es/SVODiscoveryTool/>. The SVO Discovery Tool will help you getting basic information like physical parameters and photometry in the VizieR service, as well as images and spectra in all the Virtual Observatory.
- Copy the coordinates of the object in the *List of object coordinates* box: 151.31404 +19.18553. Select the *Spectra* mark box under **VO Services** to obtain all available spectra of the target. Click on *Submit Query* at the bottom. A summary table shows that there are 27 spectra from the ESO spectra service. On the bottom table, click on the number 27 to list the spectra. They were taken with the X-Shooter instrument. You can download them by ticking them and clicking on *Download selected*. They will be saved in a zip file. But you can also keep the window open and launch SPLAT-VO.

- Repeat the same steps to load these two spectra: ADP.2015-03-03T11:28:22.823 and ADP.2015-03-03T11:28:24.993. When you are done, if you wish, you can close the auxiliary window “Starlink SPLAT-VO: Query for VO spectra”.
- In the SPLAT-VO main window, select the first spectrum and open it: *View* → *Display in new plots* (or double click on the name of the spectrum). A new window will pop-up with the spectrum.
- Again in the SPLAT-VO main window, select the second spectrum. In the right side of the window, at the bottom, you will see a table that lists the active plots. Tick the box under *Displayed* to display it together with the previous spectrum. Do the same with the third spectrum. You can change the colour of the displayed spectrum in this same panel, under the selection of columns to be displayed.



- Go to the plot window. Go to *File* → *Configure* (or click on the 8th icon from the left). A new window will pop-up. Untick the *Autoscale X* and *Autoscale Y* boxes and change the wavelength and flux ranges. Then click on the *Draw* button.
 - Lower X = 620
 - Upper X = 680
 - Lower Y = -10E-18
 - Upper Y = 8E-16



This is the H α emission line at 656.28 nm, which shows strong variability associated to the accreting process typical of cataclysmic variables.