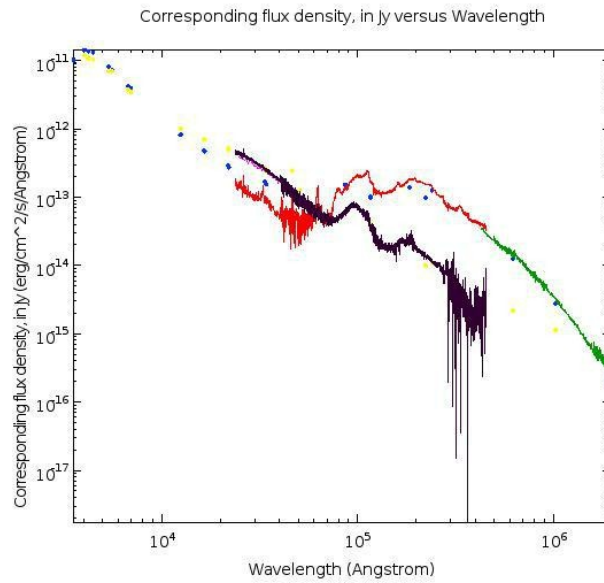


Classifying SEDs of Herbig Ae/Be Stars



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Abstract

Herbig Ae/Be stars are 2-8 solar mass, pre-main-sequence stars (that is, young objects with typical ages of < 10 Myr) of spectral types A or B. These stars are still embedded in gas-dust envelopes and are sometimes accompanied by circumstellar disks. They are in the gravitational contraction stage and approaching the main sequence (i.e. they are not burning hydrogen in their centre).

Herbig Ae/Be stars show Balmer emission lines in their stellar spectrum and infrared excess due to circumstellar dust. Sometimes Herbig Ae/Be stars show significant brightness variability associated to clumps (protoplanets and planetesimals) in the circumstellar disk. The SEDs of Herbig Ae/Be stars fall roughly into two groups: Group I sources have a relatively strong far-IR ux, which is energetically comparable with the ux in the near-IR showing an almost at spectral energy distribution. Group II sources show a similar near-IR excess as group I sources but their flux falls off strongly towards the far-IR. These were first classified by Meeus et al (2001, A&A, 365, 476). Examples of both groups are seen in the plot above. In this tutorial we will use VO tools and services to access observed photometric SEDs and spectra in the near and far infrared of different stellar objects to compare them and classified them into group one or group two.

Software: [SPLAT](#) Version 3.11, [Topcat](#) Version 4.5

1. Starting out

For this tutorial we need the VO tools Topcat and Splat-VO. You can find the most recent versions here:

TOPCAT: <http://www.star.bris.ac.uk/~mbt/topcat/>

Splat-VO: <http://www.g-vo.org/pmwiki/About/SPLAT>

2. SAMP and SSAP

The Virtual Observatory (VO) is all about interoperability of astronomical data. Within the different VO projects, services and client softwares are developed speaking common languages (protocols) which facilitates remote access to different data types like tables, images and spectra. In this tutorial we will make use of the VO standards Simple Application Messaging Protocol (SAMP) and Simple Spectral Access Protocol (SSAP). Don't be afraid, you will almost

not notice when we use either one of them, but will soon see how useful they are, to discover and access observational data of e.g. the Herbig Ae/Be stars HD100546 and HD163296.

3. Workflow

- **Search and download Photometry Points:** In this first step we will download photometry from Vizier and prepare the data in Topcat. In a later step we will load this data into Splat-VO. For now, start Topcat. Then open a Browser and access the Vizier Photometry Tool at: <http://vizier.u-strasbg.fr/vizier/sed/>. At Target enter HD100546 and at Radius enter 1. After a few seconds the service presents you the plot of the photometric data points of HD100546 (Figure 1). Below the plot you see a list of catalogues in Vizier that provide photometry. You can select and deselect whole catalogues or single data records to be plotted.

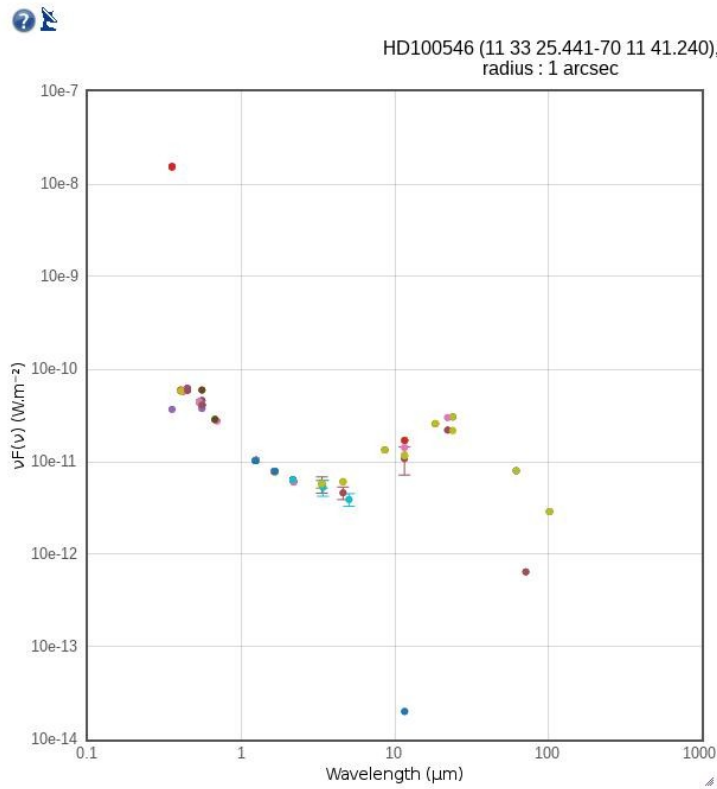


Figure 1: The Vizier Photometry Service

Now we want to obtain the data from the service and have a look at it. One way would be to click on download data, but it is more convenient to directly transfer the data to your desktop using a VO protocol called SAMP. To use it, spot the image of a radio dish right below the blue submit button (look at the upper left of Fig. 1 where to find it). Click on it once and a button broadcast will appear. Click on it, and a window will open that asks you if you want to accept the SAMP connection. SAMP is used to exchange data between different VO tools. In this case, your

browser will send the photometric catalogue data to Topcat. Click on Yes and change to the Topcat main window.

- **Make a table subset:** In Topcat in the **table list** you can see the entry [data from Vizier photometry viewer](#). Topcat also informs you that there are 130 rows in the table.

To produce a usable SED, we need to process this dataset a bit, in particular by filtering out obviously problematic records. To do that, go to [Views → Table Data](#) to have a look into the data. Sort by the column **_sed_filter**. For these particular objects (Herbig Ae/Be) we should pay particular attention to optical and infrared data; hence, select 1 record for each band from the following surveys (hold the control key and click on the rows): 2MASS , AKARI, Gaia, HIP, IRAS and WISE. Then go to [Subsets → Subset from Selected Rows](#). You will be asked to name the subset. Then, click [Add subset](#).

- **Send data to Splat-VO:** Our analysis will take place in Splat, so that's where we need to send the data to; again, we can use SAMP for that.

Open Splat-VO and then return to Topcat's main window. To make sure only our cleaned-up dataset is transferred to Splat, on the right side in **Current Table Properties**, at **Row Subset** select the subset we defined in the previous step.

Then, in TOPCAT, go to [Interop → Send Table to ... → splat](#). Going back to Splat-VO you will now see the table containing the photometry, as well as a open plot, which looks nothing like a SED; that's because Splat could not work out what columns contain the spectral and flux columns are (that's called an "interoperability problem" in the VO jargon and can count for a bug). To fix this, go to Splat-VO's main window and in **Properties of current spectra**. Under Columns select [sed freq](#) as Coordinates and [sed flux](#) as Data. In the Line type menu select [point](#). Play a little with the settings to get familiar with the various plot options.

- **Get infrared spectra:** The points we have aren't really enough to tell apart the two classes of Herbig Ae/Be stars. So, in this step we will search for spectra in the near and far infrared. To do that, we will use a VO standard called Simple Spectral Access Protocol (SSAP) that lets us search for spectra with all kinds of constraints and pull whatever we find into Splat-VO.

So, in the main SPLAT-VO window, go to [File → SSAP](#) to open a new window ("Query VO for spectra"). On the left side you find options that are related to the services, whereas on the right side you can set configurations concerning the object or position of interest. Let's start with the servers. We are interested in spectra in the infrared, so, at SSAP Servers, we select the [ISO ESA archive SSAP service](#). On the right side of the window we now make the settings for the object. At Object enter [HD100546](#) and then click lookup. This will resolve the object identifier to coordinates. The Radius with 10 arcminutes is a little too big (you'll get false matches); better set it to 1 arcminute. Finally, press Send Query.

The query results will show up. You'll see that there's quite a bit of metadata on each spectrum; this already lets you work out which spectra might be useful for your analysis. Unfortunately, at the time of this writing, not all metadata from the ISO service is in perfect order. If in doubt, just have a look at the spectrum itself. Anyway, the two spectra you want here are the last two spectra

in the list (ISO SWS01 and ISO LWS01). Select them by holding the control key and clicking on the rows. Press **Download Selected** to download the spectra. After a few seconds, the two spectra will appear on the left side of the main SPLAT window.

- **How not to get lost:** In Splat-VO's main window you will see the stack of spectra. Right now you should see the table containing the photometric points and two spectra, so keeping the overview here seems easy. The more data you download, the more difficult it gets to keep that overview. We suggest that whenever you want to keep a downloaded spectrum, you give it a more expressive name by changing the Short name entry. Do so now for the photometry points from VizieR and the (two) spectra from ISO. Below we will open spectra of different objects, so it is a good idea to also include some indication of the object name (HD 100546).
- **Unify units:** We will now merge the photometry with the spectra to a SED in a single plot. For this to work, we need to unify the units in the various pieces of data. To do this, in the SPLAT main window, go to **View** → **View/modify pectral coordinates**. You will recognise that the units of the spectra and the photometry table are different. Simply select all three entries in the **Global list of spectra** and then below, at Coordinate System, select Wavelength in vacuum and at units select Angstrom. Then click on **Convert** and, then, on **Close**.

The analogous step for the flux axis employs: **View** → **View/Modify data units**. Again, select the photometry table and the spectra in the **Global list of spectra**. At Units select $\text{erg/cm}^2/\text{s}/\text{Angstrom}$. Then click on **Convert** and, then, on **Close**.

These little magic trick show you how easy many things can become if people use proper standards and clients. (As an aside, when you have to use data without proper metadata, you can enter the proper units and hit the Set button in that dialogue).

- **Plotting:** Finally we can have a look at the SED plot: In the main window of Splat-VO select the photometry table and the two spectra and click on **View** → **Display/add to plot**.

Since we are spanning several orders of magnitude and flux, the default plot is not terribly informative. The physics here strongly suggests a log-log plot, so change the scale to logarithmic by checking log on both axes.

Fig. 2 shows the SED for HD100546, taken aside the colours, your SED should look similar.

- **Adding a second object:** As we stated in the abstract, Herbig Ae/Be stars fall into two groups, so we now will access data of a second object and then compare the plots. We do this by repeating the previous steps for the object **HD163296**. Note that during the spectra selection process you select the spectra ISO SWS 01 and ISO PHT40.

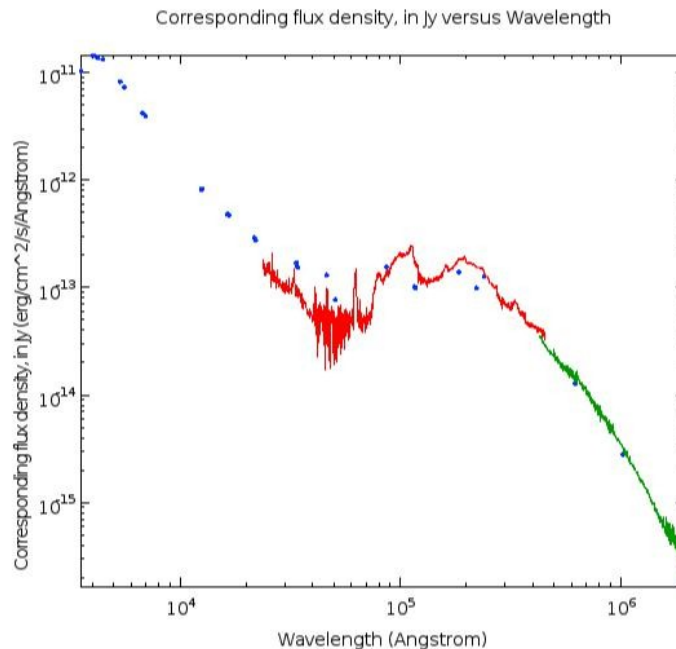


Figure 2: The plot of the SED of HD100546

- **What to do when Splat ignores the log check mark:** When trying to change the scale of the Y Axis to log you may notice that Splat sets the check mark but doesn't change the plot. This is due to a bug in the current version. If this isn't fixed in your version of Splat, try a quick workaround. The root of the problem is that when there are negative ux values (as in some ISO spectra), Splat catches the math exception but then does nothing useful (e.g., replacing it by a NULL or at least undo the check mark in log).

To still see something, select the spectrum in question in the Splat-VO main windows, then go to [View](#) → [View/modify spectra values](#). In the opening window, uncheck Read only, then click on [operations](#) → [Modify data column](#). In the newly opening window we can apply algebraic expressions to all data values of the spectra.

Since with ux calibrated data, negative values only make sense as the formal result of a (frequentist) error estimate, it doesn't really matter what we do to them for this analysis. A very quick hack that will let you do the log plot is replacing the flux values with absolute values; you can do that by entering `abs(data)` next to `y=` type (you should get fancier in less qualitative analyses). Then click **Apply** and **Close**.

- **Plot two objects:** We will now have a look at both objects in the same plot. You can do so from the Splat-VO main window by adding the SED and spectra of [HD163296](#) to the plots of [HD100546](#). You could also select the SED and spectra in the main window and click on [Views](#) → [Display/add to plot](#). The result should look similar to Fig. 3.

If you compare the two objects, you can easily see that HD100546 shows an excess in the near and far infrared, which the model says is due to the existence of dust surrounding the star and emitting in these bandpasses. Hence HD 100546 a Herbig Ae/Be star of group I, and HD 163296 Herbig Ae/Be star of group II.

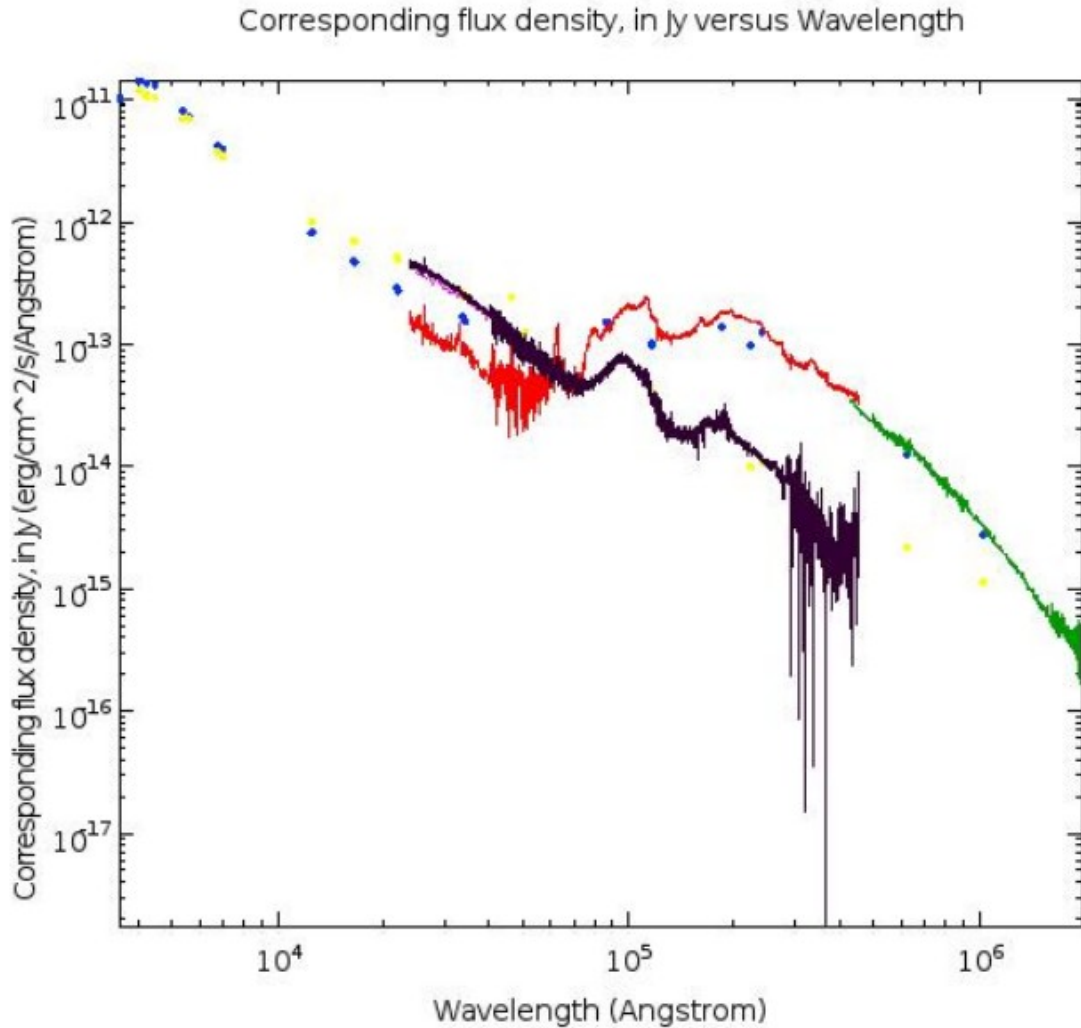


Figure 3: The SEDs of HD100546 and HD163296, as displayed by Splat-VO

4. Additional work

Repeat the above steps for AB Aurigae and categorise the star to one of the groups.

5. References

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