

- **Title:** Determination of stellar physical parameters using VOSA.
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- **VO-Tools:** VOSA, TOPCAT
- **Scientific background:**

This science case comes from a recently published paper (“*Accurate, empirical radii and masses of planets with Gaia parallaxes*”, Stassun et al., 2017AJ....153..136S). The paper focuses on the determination of radii and masses of extrasolar planets in an empirical way (i.e. in a model- independent way).

Estimates of masses and radii can provide important insights into the physics of planetary atmospheres, their interiors as well as on planet formation and evolution theories. For instance, the origin of “inflated hot Jupiters” (planets in the range 0.1-2 Jupiter masses whose radii is much larger than that predicted from models) is still a matter of debate. It is widely accepted that the intense radiation received from the star combined with internal heating help to inflate the atmosphere. This effect is not so significant in more massive planets because the gravity is strong enough to keep the planet at roughly the Jupiter's size. Having a good determination of the planet radius will allow looking into other correlations with physical parameters like age, magnetic fields or winds.

Accurate radius can also provide constraints on the heavy element content and, therefore, on the existence of a solid core which would favour the core accretion theory versus the gravitational instability scenario.

As we can deduce from (1) and (2), an accurate knowledge of the radius and mass of an extrasolar planet requires a very good determination of the mass and radius of the hosting star.

$$M_p = \frac{K_{RV} \sqrt{1 - e^2}}{\sin i} \left( \frac{P}{2\pi G} \right)^{1/3} M_\star^{2/3} \quad (1)$$

$$\Delta F = \left( \frac{R_{planet}}{R_{star}} \right)^2 \quad (2)$$

where  $K_{RV}$  is the velocity semi-amplitude and  $P$ ,  $e$ , and  $i$  are period, eccentricity, and inclination of the planet's orbit, respectively.  $M_p$  is the mass of the planet and  $M_\star$  is the mass of the star.

A key aspect in the methodology used in this paper is that radii and masses are empirically determined. And this is possible because most of the flux comes from photometry covering a large wavelength range, limiting the flux contribution from models just to the edges of the Spectral Energy Distribution (SED) where the flux is not significant. Knowing the empirical bolometric flux it is possible to compute luminosities using Gaia/TGAS distances in a largely empirical manner.

- **Goal of the tutorial:** Estimation of radii and masses of star-hosting planets using [VOSA](#).

- **Workflow:**

- Step 1.- Go to <http://svo2.cab.inta-csic.es/theory/vosa/>
- Step 2.- To use VOSA you need to be registered. Click on “Register” and fill in the fields (email, name and passwd).
- Step 3.- Copy to your laptop the file “vosa\_usecase\_final.txt” available at: <https://cloud.cab.inta-csic.es/index.php/s/YdtuvoBfyB63KS1>

- Tag "Files"

- Step 4.- Upload the file in VOSA (*File to upload / Browse*). Give a description (free text). And then, click **Upload** (do not bother about the File type). The message “*your- file-name has been succesfully uploaded!*” will appear. Click **Continue**. If the message does not appear, go to **Your files** section and click **Select**.

- Tag "Objects"

- Step 5.- Place the cursor on the **Objects** tag and then click **Coordinates**. The message “*There are objects in your file without coordinates. Please, try to find them using Sesame*”, will appear. Click **Search for Obj. coordinates**.
- Step 6.- Once Sesame has been used to find the coordinates of our objects we have to make them the “final” coordinates. To do so, we have to click **Make all changes** in the left panel (the one labelled as *Actions for all the objects in the file*). The Sesame coordinates will appear in bold in the *Final* column.
- Step 7.- Place the cursor on the **Objects** tag and then click **Distances**. Set the search radius to 10arcsec. Click **Search for Obj. Distances**. To make the Gaia DR2 distances the “final” distances, do the following: Go to the *Actions for all the objects in the file* panel, tick **Select values by ranking** and choose Gaia2 in the first place. Click **Make all changes**. The Gaia DR2 coordinates will appear in bold in the *Final* column.

- Tag “Build SEDs”

- Step 8.- Place the cursor on the **Build SEDs tag** and then click **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 **unmark All** and select only 2MASS, DENIS, WISE, Tycho-2, Gaia DR2 and Galex. 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.
- Step 9.- Place the cursor on the **Build SEDs tag** and then click **SED edit/visualize**. This tag gives us the possibility of visualising/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.

- Tag “Analyse SEDs”

- Step 10: Place the cursor on the **Analyse SEDs tag** and then click **Chi-square fit**. Different grids of theoretical models covering different ranges of physical parameters are displayed. For this tutorial select only the “BT-Settl-CIFIST”. Click **Next: Select model params**.
- Step 11.- In this window, we can limit the range of physical parameters that will be used for the fit. To save time we will make the following assumptions:
  - Teff: 4000-7000K
  - logg: 4.5-4.5 dex. Then, click **Make the fit**.
- Step 12.- We will see now a summary table with the best fit results. Click on **Show graphs** to have a look at the graphics. The effective temperatures obtained after the fitting are:
  - TYC\_5273: Teff: 5600K
  - TYC\_9023: Teff: 5900K
  - TYC\_9083: Teff: 4800K
  - TYC\_9241: Teff: 5500K
  - TYC\_9437: Teff: 5100K

To get information on the radii and masses derived from VOSA, click **Click here to configure what fields to show** and tick all the parameters in the *Masses and radiuses* section. Click **Save config**. Radii and masses obtained using two different approaches will now appear in the summary table. More information on how VOSA calculates masses and radii can be found at:

<http://svo2.cab.inta-csic.es/theory/vosa/helpw4.php?otype=star&action=help&what=fit#fit:radius>

- Tag “HR Diag.”

- Step 13.- This tag allows the estimation of masses and ages using theoretical models. Click on **HR diagram**. The BHAC15 collection of isochrones and evolutionary tracks (Baraffe et al. 2015) will be selected. Do not modify the range of masses/ages. Click **Make the HR diagram**. A table including the luminosities, masses and ages as well as the HR diagram will be shown. Click on **Data range** (below the HR diagram) for a more clear view of it.