TA-DA

A Tool for Astrophysical Data Analysis

version 0.98

user manual

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Chapter 1

Introduction

1.1 What is TA-DA

TA-DA is a powerful, integrated tool for the analysis of stellar photometric data, aimed to significantly simplify the process of comparing stellar photometric data with theoretical models.

In the released version TA-DA allows to easily and reliably operate on synthetic photometry, creating theoretical spectral energy distributions (SEDs). The tool also supports analysis of photometry from different archives, SED model fitting, self-consistent prediction of stellar parameters based on multi-band photometry. TA-DA includes a comprehensive and updatable repository of throughputs of astronomical instruments and filters, stellar and synthetic spectra, and evolutionary models. Photometric and spectroscopic data can easily be imported from the Virtual Observatory as well as from user's own tables and models. Results are produced in tabular or graphic format, readily usable for publication.

TA-DA runs as an IDL widget application publicly available for download.

1.2 TA-DA functionalities

We summarize here the main functionalities of TA-DA:

1. Computation synthetic photometry of complete grids of evolutionary models, or part of them, or any arbitrary set of stellar parameters. Observed fluxes or magnitudes and colors are computed in a number of units. Dust extinction can be considered in the computation.

2. The results of synthetic photometry are plotted for visual inspection, and can be saved to file.

3. Tables with observed photometry can be imported in the program. The individual entries in the imported table can be sorted and selected. The data are plotted in comparison with the synthetic photometry.

4. A universal fitting algorithm is used to derive the best stellar parameters of individual sources, based on the their magnitudes or colors, and associated photometric errors, in an arbitrary number of simultaneous bands (up to 16).

1.3 Installation

The program is available as a pre-compiled IDL application. TA-DA can be obtained from the following URL:

`http://www.rssd.esa.int/SA-general/Projects/Staff/ndario/TADA/index.html`

as a compressed archive `tada.zip`. The archive content is the following:

- the file `tada.sav`: the pre-compiled IDL code.
- the directory `tada_data/`: contains the necessary data for the program to run; e.g., the synthetic spectra, the filter profiles, some family of theoretical isochrones.
- the directory `example_input_files/`: contains examples of input files that can be imported to data for testing.

To install TA-DA it is sufficient to decompress the archive, and run the program `tada.sav` from IDL:

```
IDL> cd,'/path/where/tada/is/located/'
IDL> tada
```

Note: the user may consider adding the directory where the program is located is added to the IDL path, although this is not necessary.

When TA-DA is started, it creates a widget-based interface. This is divided in 4 tabs, one for each main step of the analysis performed by the software: 1) The interpolation of evolutionary models; 2) the synthetic photometry, 3) the results of synthetic photometry, the plotting, and the uploading of the photometric data, and 4) the fitter engine.

1.4 Compatibility

TA-DA has been developed to work under IDL version 7.0 or higher, on all Windows, Linux, or Mac OS platforms. The widget-based graphical user interface, however, looks and behaves best under Windows systems. This is because IDL widgets allow more strict positioning and sizes under Windows.

Chapter 2

Using TA-DA

2.1 Panel 1 - Physical stellar parameters for the model

The first panel is dedicated to the preparation of the model stellar parameters for synthetic photometry. TA-DA allows two general approaches for this step, which can be switched from the top row of Panel 1 (see also Figure 2.1):

1. **Evolutionary models**: this approach considers evolutionary models (evolutionary tracks and isochrones). In this way the stellar parameters include, besides the effective temperature $T_{\rm eff}$, the stellar radius R, and the surface gravity $\log g$ (parameters necessary for synthetic photometry), also stellar masses M and stellar ages.

2. **Arbitrary**: this approach considers only the minimum parameters to perform synthetic photometry, i.e., $T_{\rm eff}$, R and $\log g$. Stellar masses and ages, which are model dependent quantities, will be undefined.

2.1.1 Evolutionary models

When selecting the evolutionary model approach, the panel shows additional widgets (see, e.g., Figures 2.1 and 2.2) where the parameters must be specified. Specifically, the user selects the family of evolutionary models; the available models are loaded automatically by TA-DA at startup, and additional families can be added (*see the appendix for details*). The user can then select among 5 options:

(a) **all isochrones:** TA-DA considers all isochrones from the selected family of models.

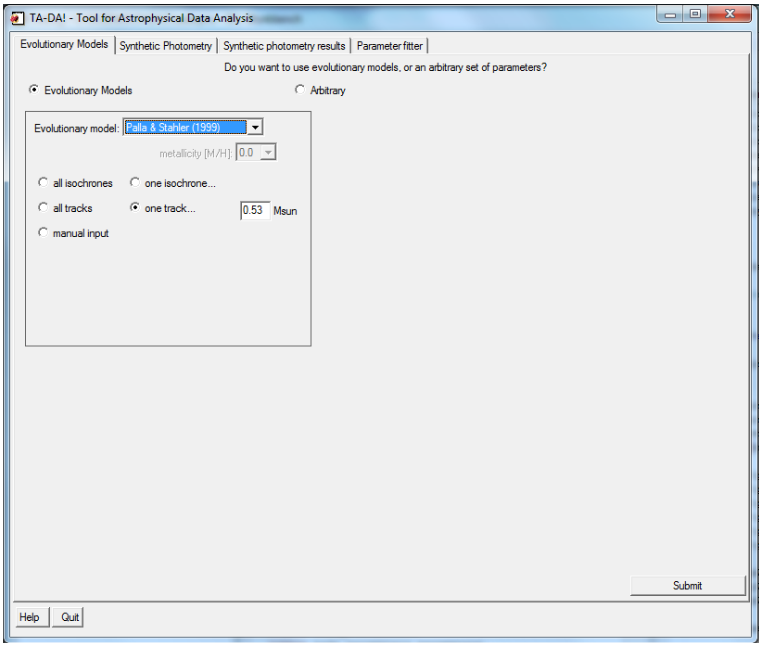


Figure 2.1: Selection of the evolutionary models to use for synthetic photometry.

(b) **one isochrones:** The user specifies one value of age, in Myr. TA-DA interpolates the evolutionary models to that value of age, if within the parameter range spanned by the models.

(c) **all tracks:** TA-DA considers all mass tracks from the selected family of models.

(d) **one track:** The user specifies one value of mass, in solar masses. TA-DA interpolates the evolutionary models to that value of mass, if within the parameter range spanned by the models.

(e) **manual input:** Selecting this option the user specifies an arbitrary set of stellar parameters; this is passed to the software through an ASCII text file, selected through a popup window. The ASCII file must contain 2 columns (or more, in which case only the two are considered) which contain any combination of the following parameters:

(a) *mass* ($M_\odot$)

(b) age (Myr)

(c) $\log T_{\rm eff}$ (K)

(d) $\log L_{\rm bol}$ ($L_\odot$)

(e) R ($R_\odot$)

The type of parameter described in each column must be manually specified through 2 drop lists in the widget GUI. The remaining 3 parameters (as well as the surface gravity $\log g$) are interpolated by the TA-DA from the considered evolutionary models. TA-DA also checks that the user provided parameter grid lies inside the parameter space covered by the evolutionary models. If this condition is not matched for a fraction of the points, an warning message is generated, and the software neglects these points. If all the specified points lie outside the evolutionary model grid, an error is generated and the user is asked to modify the input parameters. Finally, the user must specify wether the parameters provided through the ASCII file represent a 1-dimensional curve, or a 2-dimensional grid. In the latter case, the grid must be **rectilinear in the 2 parameters listed in the ASCII table**, i.e. a "cartesian grid" with arbitrary spacing between lines and columns, no "holes", and not necessarily complete at the edges. In Figure 2.3 some examples of allowed and not allowed configurations are shown for clarity. The distinction between a 1 or 2-dimensional inputs is relevant only when one runs the fitter within TA-DA, and is irrelevant for the computation of the synthetic photometry. In particular, if the parameters represent a 2D grid, the fitter will interpolate over the grid until the solution is found.

The options a) and c) are very similar, since they both load the entire parameter space covered by the models. Nevertheless, there are two main differences between them: First, the option *"all isochrones"* has a finer sampling in masses, whereas *"all tracks"* has a finer sampling in ages. Therefore, if the ultimate goal of the user is a precise estimate of stellar masses, selecting *"all isochrones"* is more appropriate, and viceversa. Second, when plotting the result of synthetic photometry, TA-DA will plot individual isochrones or tracks according to the choice done here.

2.1.2 No evolutionary models, defining only T_{eff}, $\log g$, R

TA-DA also allows to specify a more general set of stellar parameters which is independent on stellar evolutionary models. This method is activated selecting "*Arbitrary*" option on the upper-right part of the first panel. In this case (see Figure 2.4), the user must provide a 3-column ASCII table containing (in this order), values of T_{eff} (in K), $\log g$ (in cgs units) and stellar radii R (in units of $R_{\odot}$). These 3 parameters are sufficient to perform synthetic photometry (see Section 2) and compute absolute magnitudes (or fluxes); however, stellar masses and ages will not be defined.

Note: unlike magnitudes, stellar colors are independent on luminosity, therefore on stellar radius. If user aims only at the analysis of stellar colors, the values of stellar radii specified in

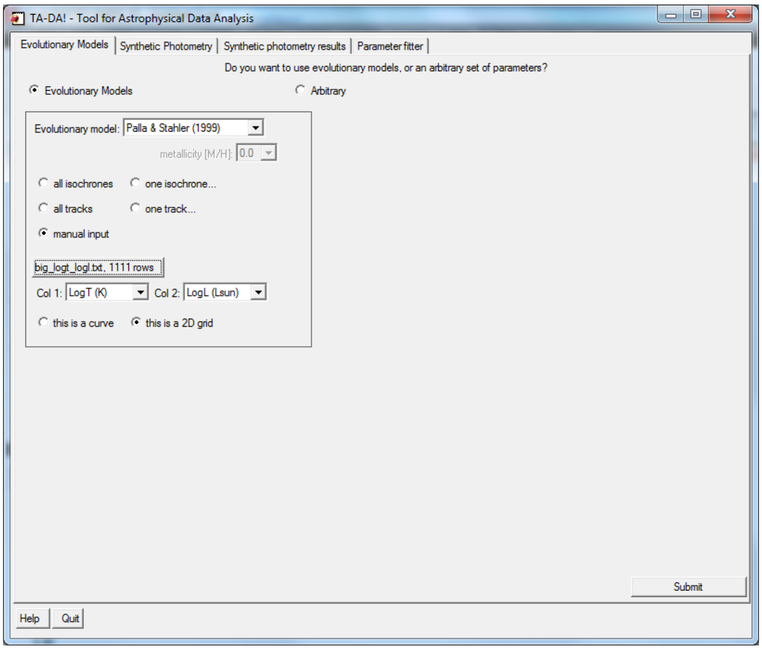


Figure 2.2: Importing an arbitrary table of 2 stellar parameters.

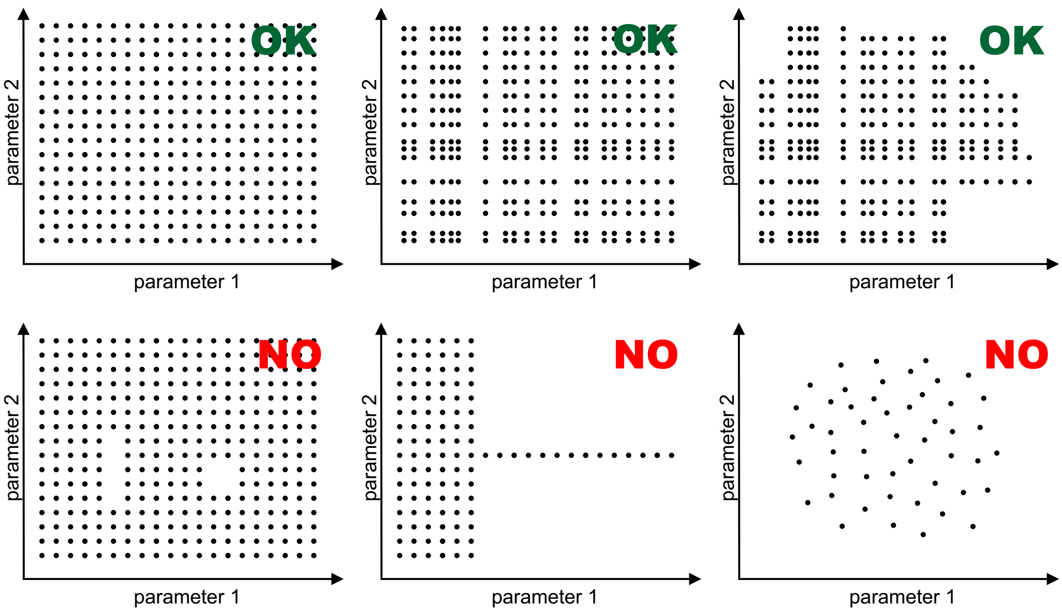


Figure 2.3: Examples of allowed (*top row*) and not allowed (*bottom row*) configurations for a user supplied 2-dimensional grid of stellar parameters.

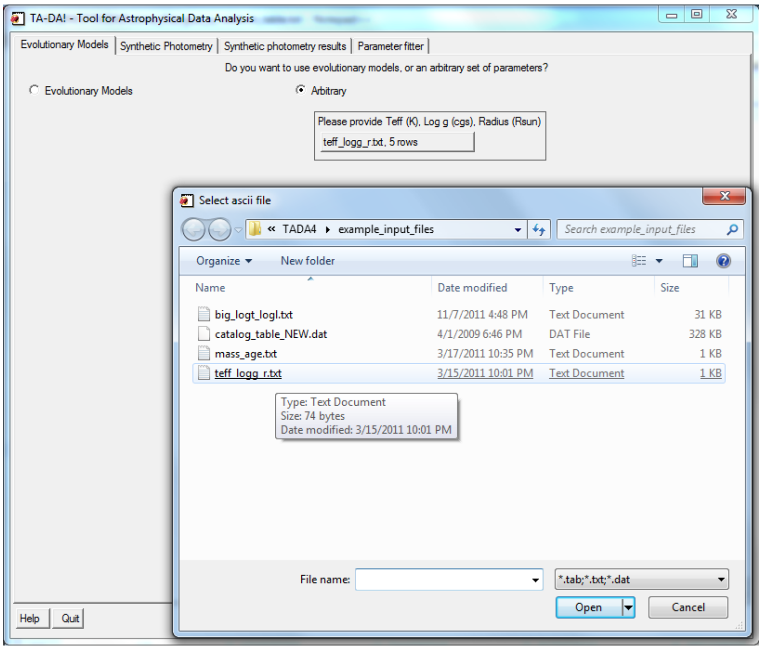


Figure 2.4: Importing a set of values of $T_{\rm eff}$, gravity and stellar radius.

the 3rd column of the ASCII file can be arbitrary, for example 1 $R_\odot$ for every model point.

In the first panel, clicking on the "Submit" button will lock in the input parameters. TA-DA organizes the set of stellar parameters, perform any interpolation if needed, checks the validity of the model points, and moves to the next panel.

Panel 2 - Synthetic Photometry

In the second panel of TA-DA the user can define all the necessary ingredients to perform synthetic photometry on the previously defined grid of grid of stellar models. An example of the layout of this panel is shown in Figure 2.5.

- **Selection of the synthetic model grid:** a drop-down menu lists the available grids of synthetic spectra. These are contained as fits table files in the subdirectory `tada_data/spectra/` within the TA-DA installation directory. When TA-DA is launched, the content of this directory is explored and the information on each data-cube of spectra is read. Thus, the user can add additional grids of atmosphere models, besides the defauld ones, provided that they are saved in the proper format and copied in the appropriate directory. Each grid can contain stellar spectra as a function of 3 parameters. The first two are $T_{\rm eff}$ and $\log g$; the third can be an arbitrary additional quantity, such as metallicity or any arbitrary parameter. The information on this parameter, as well as its range, are stored in the header

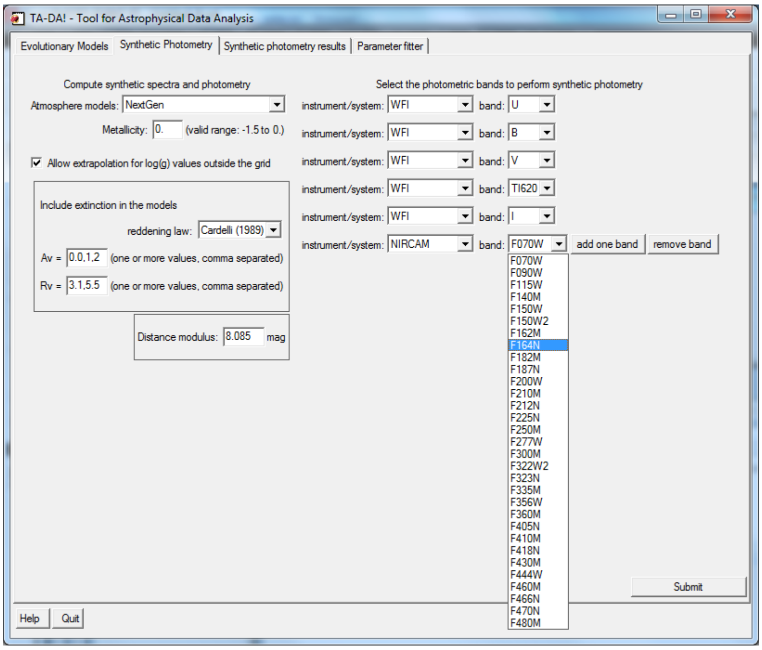


Figure 2.5: TA-DA second panel: input parameters for the synthetic photometry.

of the fits table and automatically considered by TA-DA. For additional instructions on the format of the synthetic spectra cubes, see the appendix at the end of this manual.

- **Extrapolation of** $\log g$**:** this option allows the user to choose how TA-DA should consider model points with a surface gravity $\log g$ outside the parameter range convered by the selected grid of atmosphere models. If the option is deactivated, any point of the stellar parameters defined in panel 1 with a $\log g$ value outside the range spanned by the spectra (for the $T_{\rm eff}$ of that point) is neglected in the computation of the synthetic photometry. If the option is activated, magnitudes and colors of parameter points with a $\log g$ out of range are extrapolated from synthetic photometry within the covered $\log g$ range. This extrapolation is useful when some model points correspond to $\log g$ values located just outside the grid. An example of such scenario is when the spectra from the AMES grid of Allard et al. (2000), defined for $\log g > 3.5$, is selected together with PMS evolutionary models, which predict $\log g > 3.2$ for the youngest ages in the very-low mass range. Since in general the computed magnitudes and colors depend only weakly on $\log g$, extrapolating the results to a small extent outside of the grid, still provides acceptable results. The users should however be careful in selecting this option, making sure they are aware of the parameter space covered by their stellar parameters and the grid of spectra.

- **Dust extinction:** extinction can be added directly to the synthetic spectra before the computation of the synthetic colors and magnitudes. TA-DA currently includes the Galactic Cardelli (1989) extinction law, as well as the the reddening curves for the Magellanic Clouds from Gordon et al. (2003, LMC average, LMC2 supershell, SMC bar). The user specifies one or more values of V-band extinctions A_V, and one or more values of the relative extinction parameter R_V (only if the Cardelli reddening law is selected). Synthetic photometry will be performed separately for each of these $n(A_V) \times n(R_V)$ values on every stellar parameter point provided in Panel 1. If the user wants to leave reddening as a free parameter to be fit to the observational data (last panel of TA-DA widget GUI, see next sections), it is mandatory to indicate at least 2 distinct values of A_V (e.g., 0 and 1) in this field.

- **Distance modulus:** a unique value for the distance modulus (in magnitudes) to be applied to the computed magnitudes or fluxes must be specified in this field.

- **Photometric bands:** the user specifies multiple (up to 16) photometric bands in which synthetic photometry has to be computed. These can be selected through drop-down menus, separately for the instrument (or photometric system) and the filter. The filter throughputs are stored as individual files in a TA-DA installation subdirectory `'/tada_data/throughputs/'`. The convention for the filenames is `instrument_filter.dat`, and they contain a 2-column ascii indicating wavelength (in $\mathring{A}$) and throughput (arbitrary relative units). TA-DA scans the content of this directory at start, so additional photometric systems or bands can be added by simply placing the relative files describing the filters profile in the appropriate directory. See the appendix for further details.

By clicking the "submit" button, the synthetic photometry code is started according to the selected parameters and options. Particularly large sets of model points may require some time (e.g. a full set of stellar masses and ages counting 100,000 model points, for 6 values of reddening and 6 photometric bands requires about 15 minutes of computing time on an average desktop computer). During the computation, the approximate progress (in percentage) is shown.

Panel 3 - Results of synthetic photometry and plots

After the synthetic photometry is computed, the software moves to the third panel (see Figure 2.6). Here a brief summary of the results is present. The synthetic photometry is natively

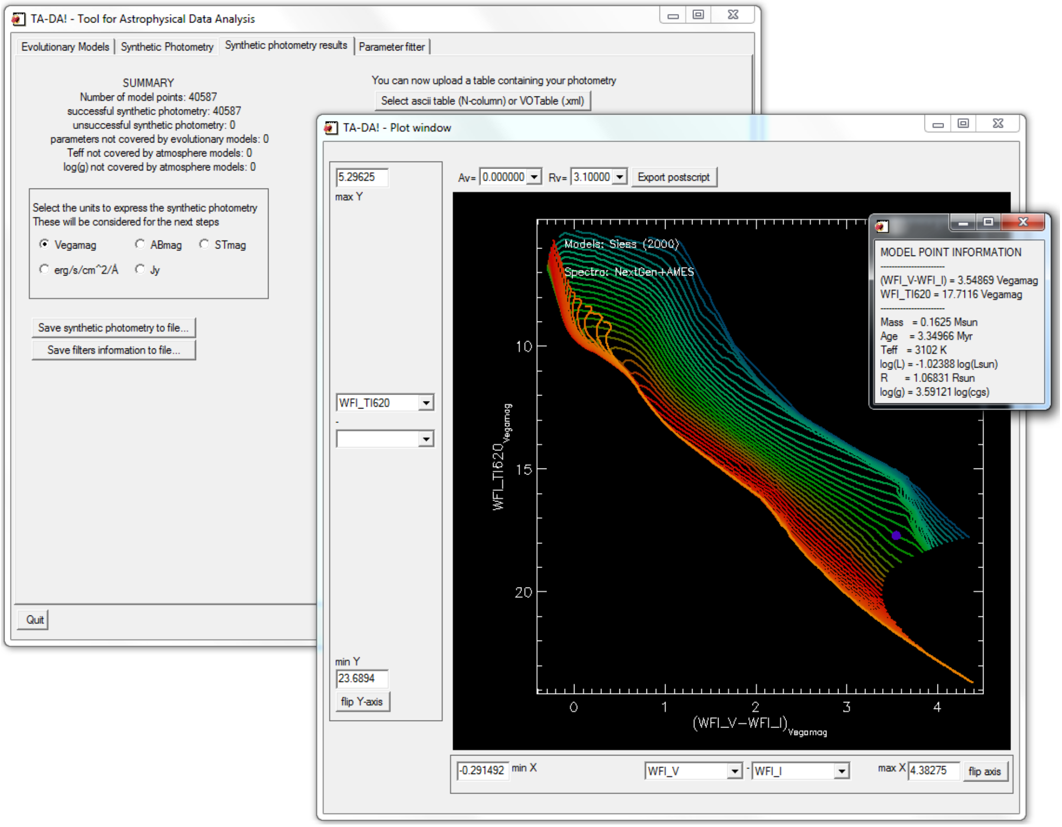


Figure 2.6: TA-DA panel with the results of synthetic photometry and plotting window. The small window on the top right corner is the model point information generated by right-clicking on a point of the plot (see below)

computed in units of VegaMag magnitudes, calibrated using a flux-calibrated spectrum of Vega (Bohlin et al 2007). However, the program derives all the conversions to express the results in units of ABmag or STmag magnitudes, as well as flux (either Jansky or erg/s/cm^2/Å). In the third panel it is possible to switch from one to another units. The results of synthetic photometry, in the chosen units, can be saved to a file through an apposite button. This will be an ASCII table, in which every row represents one model point. The columns report all the stellar physical parameters, as well as A_V and the magnitudes (or fluxes).

From panel 3 (with the button *"Save filters information to file"*)the saves a file with the information about the selected photometric bands. This includes effective wavelength, central wavelength, equivalent width, and the zero points in Jansky and erg/s/cm^2/Å. Such information may be useful when new filters are added providing solely the filter throughputs.

At the completion of the synthetic photometry computation, TA-DA also creates a plotting window showing the results (see Figure 2.6). One can select the quantities shown in the two axes, choosing either colors or magnitudes, and arbitrary ranges for each axis. The units for each axis in the plot are automatically updated when the user changes the defaults units in Panel 3. If the selected units represent a flux (i.e., Jansky or rg/s/cm^2/Å), the color terms will be the ratio (instead of the difference) between the fluxes in the 2 selected filters.

Panel 3 - Attaching photometric data

From the right hand part of panel 3, the user can attach a table containing observational data to TA-DA. This is expected to contain multiple rows, one for each star, and multiple columns, providing photometry or additional data relative to each source. This generates a new widget window, showing the content of the table as well as a number of widgets to explore and organize its content, select individual sources, etc. Supported formats are either ASCII table or XML VOtable. The format, as well as the number columns and rows of the attached table are automatically detected by TA-DA. Figure 2.7 and 2.8 show two examples of the result, respectively for an ASCII and a VOTable.

If the attached table is a VOtable, the original names of the fields (columns) are shown. In any case, the user must specify manually, through a drop-down menu for individual columns, if a particular column reports the observed photometry (or the associated photometric errors) in one of the bands for which synthetic photometry is computed. The software assumes the units are the same selected in Panel 3 of the main TA-DA window. The user table window also allows one to navigate through the table, sort columns and select individual rows (stars) for further analysis. The selection can be performed manually, by clicking to the left side of each row, or automatically, by selecting all the rows, or the first n-rows in a given page or the entire table, or through and IDL logical expression. En example of such expression could be the following:

```
johnson_v ge 10 and err_cousins_i lt 1 and col9 ne 'new'
```

meaning that the software will select all the rows for which the Johnson V magnitude is greater or equal than 10 mag, the photometric error associated to the Cousins I photometry is less than 1 mag and the 9th column, not associated any photometric band, is not equal to the string "new".

Note: the automatic selections at the bottom of the table window (selection by rows and by logical expression) are **additive**: stars that satisfy the input conditions are added to those previously selected. If you want to select only the stars that satisfy the last condition, you must deselect all the stars first, using the apposite button.

Note: unlike magnitudes, stellar colors are independent on luminosity, therefore on stellar radius. If user aims only at the analysis of stellar colors, the values of stellar radii specified in the 3rd column of the ASCII file can be arbitrary, for example 1 $R_\odot$ for every model point.

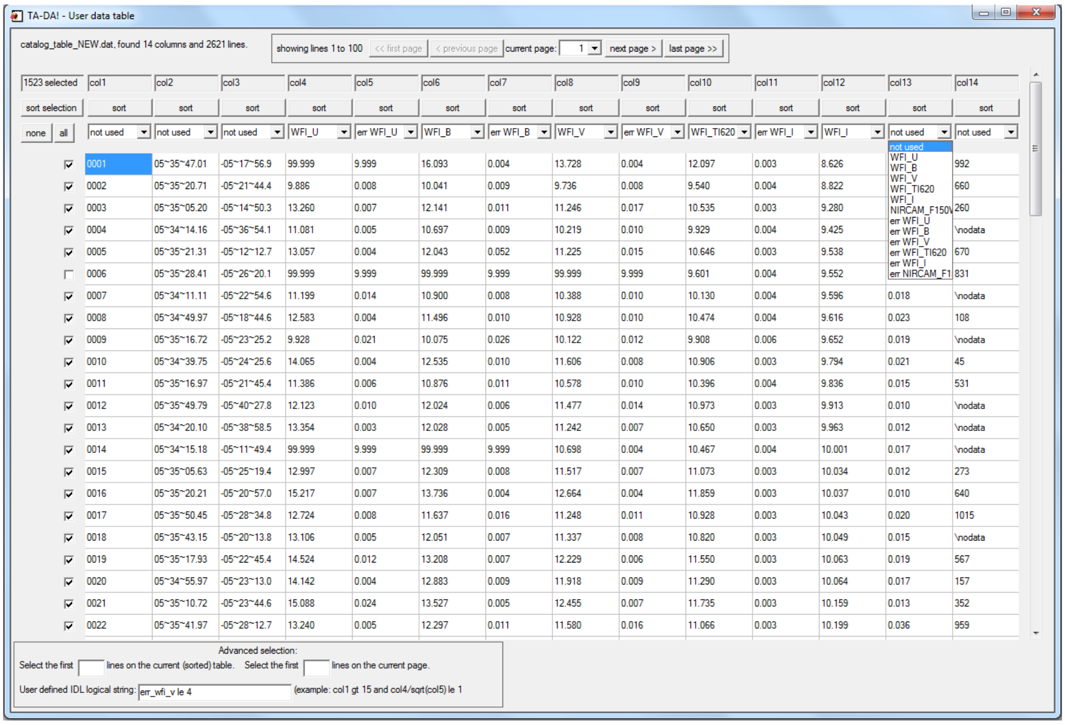
When the user defines which column is associated to any photometric band previously used for performing synthetic photometry, and some stars (rows) are selected in the table window, the plot window is automatically updated showing, together with the computed models, the observed photometry of the selected stars. An example of this is shown in Figure 8: in this example the plot window shows a 2 color diagram computed in the bands (WFI V, WFI I and WFI_Ti620), and the attached table provides photometry in these (and other) bands obtained in the Orion Nebula Cluster (Da Rio et al 2009). The models, indicate with different colors, represent the synthetic photometry in these bands for different Palla & Stahler isochrones.

When at least 2 photometric bands are specified in the table window, and at least one star is selected, in the TA-DA main window the button "go to the fitter" is activated. Clicking on this button produces a fourth panel in the TA-DA main window, with a list of options to perform the fit of the models on the attached data.

Clicking on the plot window

A mouse click on the plot window provides information on both stars and model points located in that point of the plot.

- A **left click** is for the closest selected star to the clicked point: a popup windows is created showing the stars' photometry, and the location of this star in the uploaded table.



TA-DA! - User data table

catalog_table_NEW.dat, found 14 columns and 2621 lines.

showing lines 1 to 100 | << first page | < previous page | current page: 1 | next page > | last page >>

1523 selected	col1	col2	col3	col4	col5	col6	col7	col8	col9	col10	col11	col12	col13	col14
sort selection	sort	sort	sort	sort	sort	sort	sort	sort	sort	sort	sort	sort	sort	sort
none / all	not used	not used	not used	WFI_U	err WFI_U	WFI_B	err WFI_B	WFI_V	err WFI_V	WFI_TI620	err WFI_I	WFI_I	not used	not used
☑	0001	05~35~47.01	-05~17~56.9	99.999	9.999	16.093	0.004	13.728	0.004	12.097	0.003	8.626		992
☑	0002	05~35~20.71	-05~21~44.4	9.886	0.008	10.041	0.009	9.736	0.008	9.540	0.004	8.822		660
☑	0003	05~35~05.20	-05~14~50.3	13.260	0.007	12.141	0.011	11.246	0.017	10.535	0.003	9.280		260
☑	0004	05~34~14.16	-05~36~54.1	11.081	0.005	10.697	0.009	10.219	0.010	9.929	0.004	9.425		\nodata
☑	0005	05~35~21.31	-05~12~12.7	13.057	0.004	12.043	0.052	11.225	0.015	10.646	0.003	9.538		670
☐	0006	05~35~28.41	-05~26~20.1	99.999	9.999	99.999	9.999	99.999	9.999	9.601	0.004	9.552		831
☑	0007	05~34~11.11	-05~22~54.6	11.199	0.014	10.900	0.008	10.388	0.010	10.130	0.004	9.596	0.018	\nodata
☑	0008	05~34~49.97	-05~18~44.6	12.583	0.004	11.496	0.010	10.928	0.010	10.474	0.004	9.616	0.023	108
☑	0009	05~35~16.72	-05~23~25.2	9.928	0.021	10.075	0.026	10.122	0.012	9.908	0.006	9.652	0.019	\nodata
☑	0010	05~34~39.75	-05~24~25.6	14.065	0.004	12.535	0.010	11.606	0.008	10.906	0.003	9.794	0.021	45
☑	0011	05~35~16.97	-05~21~45.4	11.386	0.006	10.876	0.011	10.578	0.010	10.396	0.004	9.836	0.015	531
☑	0012	05~35~49.79	-05~40~27.8	12.123	0.010	12.024	0.006	11.477	0.014	10.973	0.003	9.913	0.010	\nodata
☑	0013	05~34~20.10	-05~38~58.5	13.354	0.003	12.028	0.005	11.242	0.007	10.650	0.003	9.963	0.012	\nodata
☑	0014	05~34~15.18	-05~11~49.4	99.999	9.999	99.999	9.999	10.698	0.004	10.467	0.004	10.001	0.017	\nodata
☑	0015	05~35~05.63	-05~25~19.4	12.997	0.007	12.309	0.008	11.517	0.007	11.073	0.003	10.034	0.012	273
☑	0016	05~35~20.21	-05~20~57.0	15.217	0.007	13.736	0.004	12.664	0.004	11.859	0.003	10.037	0.010	640
☑	0017	05~35~50.45	-05~28~34.8	12.724	0.008	11.637	0.016	11.248	0.011	10.928	0.003	10.043	0.020	1015
☑	0018	05~35~43.15	-05~20~13.8	13.106	0.005	12.051	0.007	11.337	0.008	10.820	0.003	10.049	0.015	\nodata
☑	0019	05~35~17.93	-05~22~45.4	14.524	0.012	13.208	0.007	12.229	0.006	11.550	0.003	10.063	0.019	567
☑	0020	05~34~55.97	-05~23~13.0	14.142	0.004	12.883	0.009	11.918	0.009	11.290	0.003	10.064	0.017	157
☑	0021	05~35~10.72	-05~23~44.6	15.088	0.024	13.527	0.005	12.455	0.007	11.735	0.003	10.159	0.013	352
☑	0022	05~35~41.97	-05~28~12.7	13.240	0.005	12.297	0.011	11.580	0.016	11.066	0.003	10.199	0.036	959

Figure 2.7: Example of ASCII table imported to the TADA.

- A **right click** is for the closest model point to the clicked point: a popup windows is created showing the parameters associated to that point (e.g., mass, age, $\log T_{\rm eff}$, $\log L$, stellar radius, $\log g$, as well as the value of the quantities plotted in the two axes (e.g., color and magnitude).

Clearly, whereas the right click will in general always work (results of synthetic photometry always appear in the plot), the left click will work only if a table with the observed photometry is attached, the two quantities plotted are specified, and at least one star is selected from the table panel.

Adding labels to the plot

By default, the plot window shows a label, located in the top left corner, reporting the name of the used evolutionary models and synthetic spectra. It is possible to customize the label, remove it, displace it, or change the information reported. This can be done by editing the file `tada_data/tadaplot_additional_instructions.dat` within the TA-DA installation directory, where the actual IDL code lines which produce the label are declared. Further explanations on how to do this, as well as additional examples, are present in the file itself.

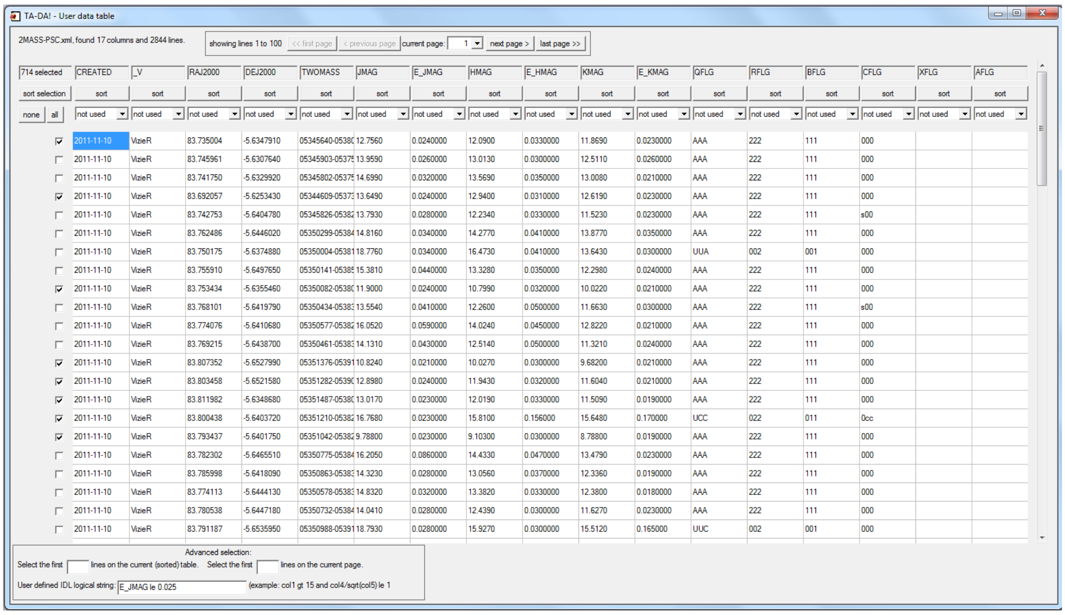


Figure 2.8: Example of user data table attached to TA-DA, originally in format of VOTable.

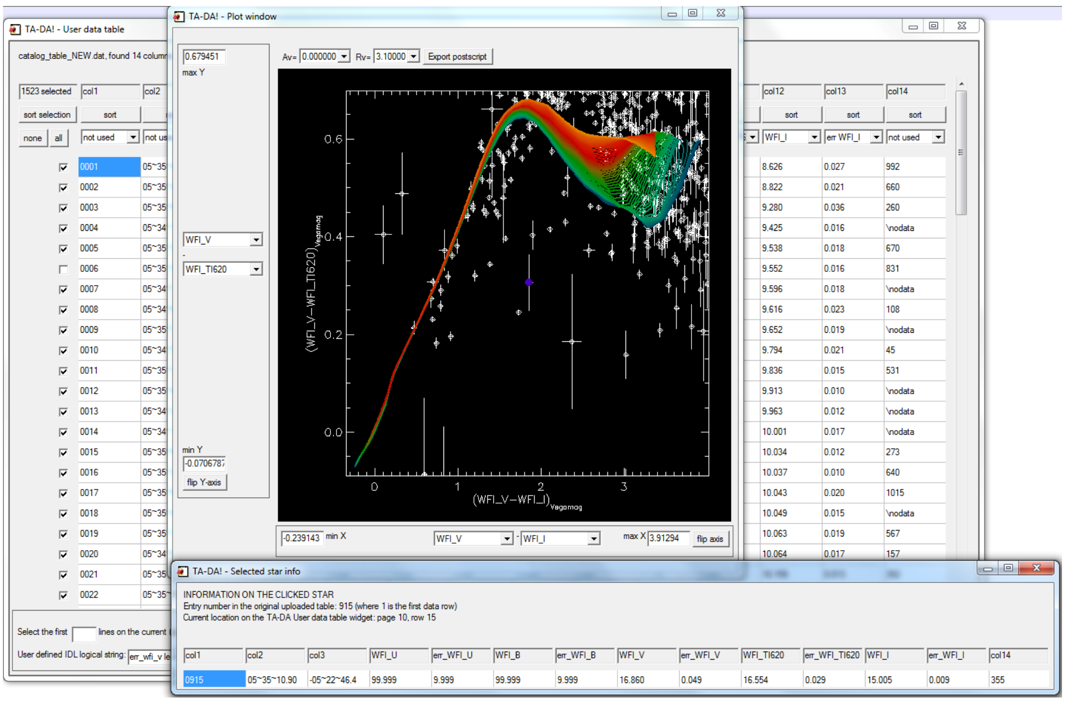


Figure 2.9: Example of the plotting window, showing both TADA computed models and the user photometry.

Panel 4 - The stellar parameter fitter

The photometry fitter included in TA-DA allows one to derive the stellar parameters of the individual stars selected in the attached table. This is a universal fitter and can be used in different scenarios, based on the type of models on which synthetic photometry is performed, the number of photometric bands of the measured photometry, and the options declared in the fitter panel. In general, we distinguish two cases:

1. **Interpolation of evolutionary models (and extinction):** if the number of free parameters is equal to the dimension of the measured photometry space, an exact solution can be obtained (potentially) of each source. Some examples are:

    (a) Interpolation in the CMD: the synthetic photometry is computed for a number of isochrones or tracks, the data include 2 photometric bands, and the extinction is a fixed parameter: the software will assign age and mass to the individual sources.

    (b) Dereddening onto one isochrone: the synthetic photometry is computed for a single isochrones, 2 observed magnitudes or colors are provided, the extinction is a free parameter: the software will determine the amount of reddening and the de-reddened position along the isochrone for each star.

    (c) Determination of 2 stellar parameters (e.g., mass and age, or $T_{\rm eff}$ and $\log L$) as well as extinction, for each star, based on 3 magnitudes or 3 colors.

2. **Probabilistic (SED) fitting:** if the number of measured magnitudes or colors exceeds that of the free parameters, the best fit solution for the parameters of each star is provided. This approach is analogous to a general spectral energy distribution (SED) fitting procedure, in which extinction can be either constrained of left as a free parameter, and the user can decide whether to consider only the shape of the SED, or also the actual luminosity (fitting photometric colors or photometric magnitudes).

Figure 9 shows an example of the fitter panel. From the top of the panel, the user selects which photometric bands to use for estimating the stellar parameters. The available bands are those for which synthetic photometry was previously computed. The user should keep in mind to select only bands for which the observed magnitudes or fluxes are provided, and declated in the table window. Clearly, at least 2 bands must be selected.

Next, the user can specify if the fit should be performed on the magnitudes (in a n-dimensional magnitude space) or on the colors (in a n-1 dimensional color space). The latter option is useful when the particular astrophysical problem the user is interested to solve requires the assessment of the stellar parameters in a luminosity (or distance) independent way.

If the uploaded photometry table includes also columns reporting the photometric errors in each band, it is possible to select weather the software should consider these errors in the fit or to neglect photometric errors and treat the photometry as a individual points for each star. Practically, not considering the photometric errors corresponds to assigning a constant identical error to every magnitude or color.

If the photometric errors are used, a further options allows to activated a Monte Carlo (MC) simulation to derive the errors in each derived stellar parameter for the individual sources. This step is quite time consuming; however it is needed to allow for a reliable estimate of the uncertainties, since, in general, the measured photometric errors lead to highly correlated and non-linear errors in the model parameter space.

Finally the user can select whether to fix a single value of A_V for every star, or to leave the reddening as a free parameter, to be derived by the fitter star by star. In this latter case, a range of extinction values and a first order resolution is specified. **Important note:** in order to leave reddening as a free parameters, at least 2 distinct values of A_V must have been specified earlier when the synthetic photometry was performed (Panel 2).

By clicking on the button "run fitter", the parameter fitting algorithm processes each **selected** star of the user data table.

Data outside the model predicted space

In both the cases introduced above (interpolation and exact solution, or probabilistic approach), it is possible that stars show observed magnitude or colors which are incompatible with the predictions from the synthetic photometry on the evolutionary models. As an example, one could consider a star located just below the main sequence on a CMD. In these cases, TA-DA still provides the most probable solution, which is the closest point to the observed fluxes and within the theoretical magnitude space in the direction of the photometric errors. This is illustrated in Figure 2.11. Along with the estimated parameters for each source, the results of the fitter provide the distance, in units of photometric error sigma, from the observed fluxes to the those of the most probable solution. The user can then use these values to discern among solutions to be kept or rejected.

Although this applies to both the case of interpolation of parameters and SED fitting, there is a significant conceptual difference between these two cases:

- in the interpolation case (number of free parameters = number of fitted observed quantities), if a star is located within the modeled grid, an exact solution is always found ($\chi^2 = 0$). Thus the fitter precisely distinguish between points inside or outside the grid, flags sources accordingly, and use the correct method to provide the best-fit parameters. Figure 10 schematizes the process for the two sub-cases a) and b), for a 2 dimensional magnitude space.

- in the actual SED fitting case (number of free parameters ¡ number of fitted observed quantities) an exact solution ($\chi^2 = 0$) is generally never found. Thus, TA-DA arbitrarily considers stars to be incompatible with the model grid when they lie at $> 3\sigma$ from the edge of the grid.

In any case, the results of the fitter include, for every star, two parameters that are useful to understand the goodness of the fit:

1. **"exact"**: is 1 if the observed star lies inside the parameter space covered by the model, 0 otherwise (see above)

2. **"distance in sigma"**: reports the distance, in units of the overall photometric error, from the observed magnitude, colors, or fluxes of the star to the closest (best-fit) point of the model grid.

The results of the fit can be saved to an ASCII table, either preserving the same row to row correspondence of the imported data table, or just limited to the selected source.

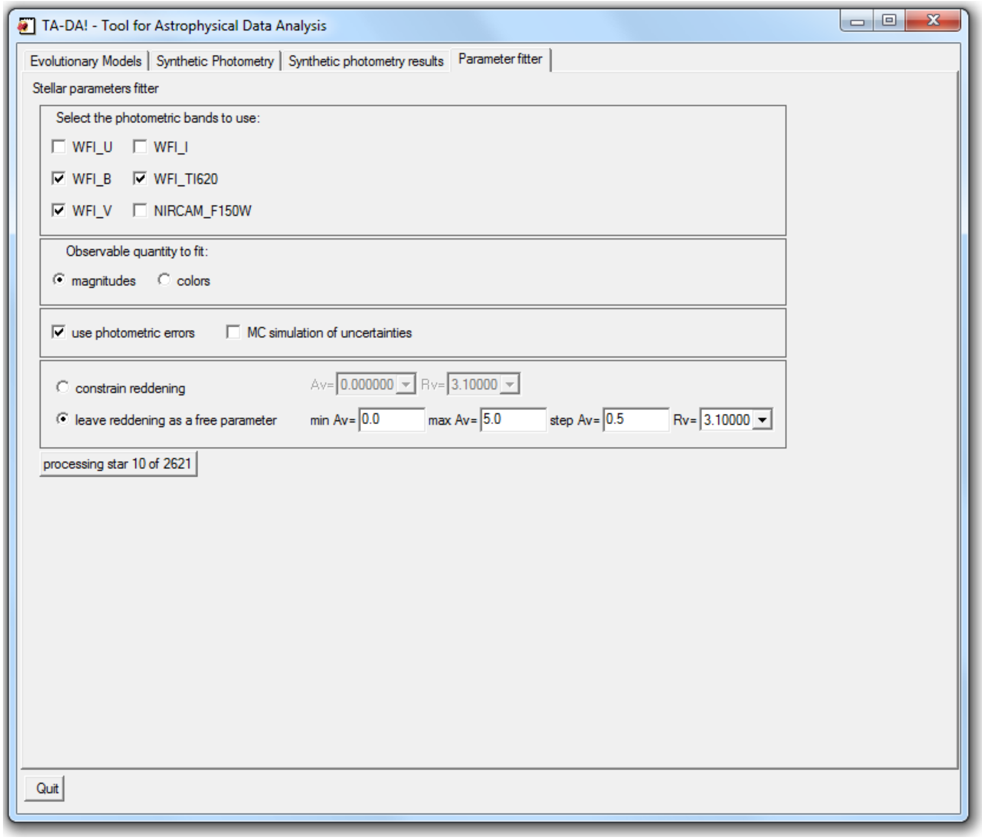


Figure 2.10: Example of the Parameters Fitter panel

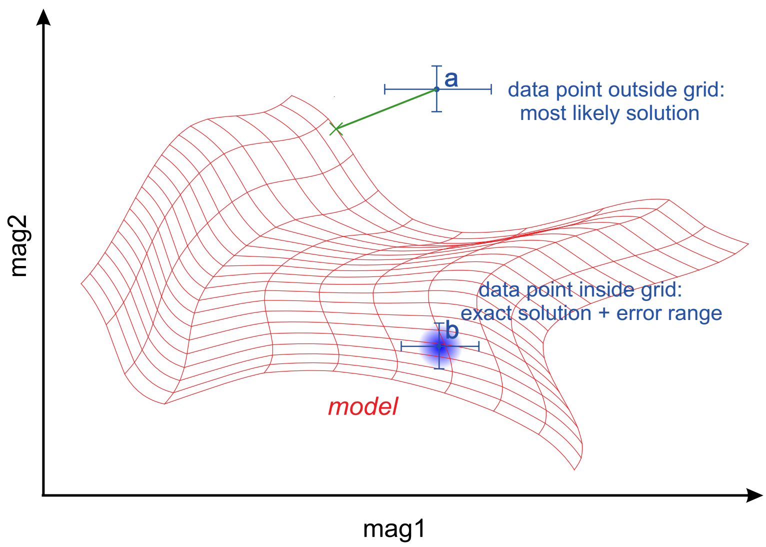


Figure 2.11: Schematic representation of the best-parameter fitting technique: a probabilistic approach when the observed data are outside the range spanned by the models (a) and an exact interpolation otherwise (b)

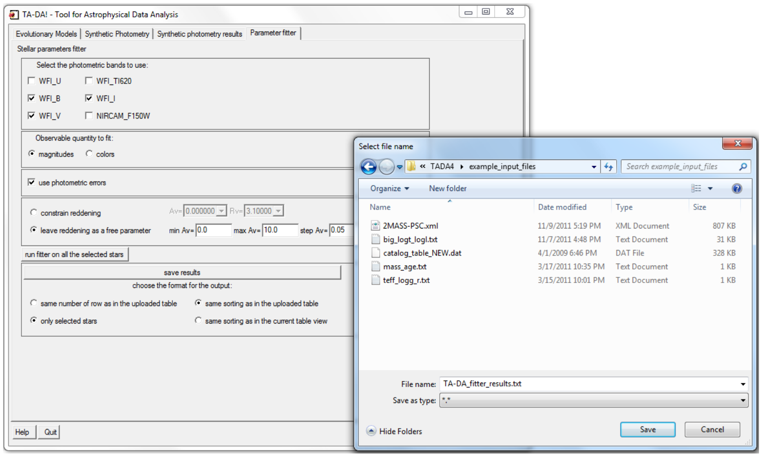


Figure 2.12: Interface to save the fitting results.

Appendix

Filter profiles

The current version of TA-DA includes the following filter profiles, located in the folder `tada_data/throughputs/`:

2MASS_H	COUSINS_R	NIRCAM_F410M	WFC3UVIS_F225W	WFC3UVIS_FQ619N
2MASS_J	GALEX_FUV	NIRCAM_F418N	WFC3UVIS_F275W	WFC3UVIS_FQ634N
2MASS_KS	GALEX_NUV	NIRCAM_F430M	WFC3UVIS_F280N	WFC3UVIS_FQ672N
ACSHRC_F220W	IRAC_I1	NIRCAM_F444W	WFC3UVIS_F300X	WFC3UVIS_FQ674N
ACSHRC_F250W	IRAC_I2	NIRCAM_F460M	WFC3UVIS_F336W	WFC3UVIS_FQ727N
ACSHRC_F330W	IRAC_I3	NIRCAM_F466N	WFC3UVIS_F343N	WFC3UVIS_FQ750N
ACSHRC_F344N	IRAC_I4	NIRCAM_F470N	WFC3UVIS_F350LP	WFC3UVIS_FQ889N
ACSHRC_F435W	ISAAC_F1215	NIRCAM_F480M	WFC3UVIS_F373N	WFC3UVIS_FQ906N
ACSHRC_F475W	ISAAC_F1710	SDSS_G	WFC3UVIS_F390M	WFC3UVIS_FQ924N
ACSHRC_F502N	ISAAC_F2090	SDSS_I	WFC3UVIS_F390W	WFC3UVIS_FQ937N
ACSHRC_F550M	ISAAC_F3280	SDSS_R	WFC3UVIS_F395N	WFI_571
ACSHRC_F555W	ISAAC_FL_BB	SDSS_U	WFC3UVIS_F410M	WFI_753
ACSHRC_F606W	JOHNSON_B	SDSS_Z	WFC3UVIS_F438W	WFI_770
ACSHRC_F625W	JOHNSON_U	STISCCD_50CCD	WFC3UVIS_F467M	WFI_851
ACSHRC_F658N	JOHNSON_V	STISCCD_F28X50LP	WFC3UVIS_F469N	WFI_852
ACSHRC_F660N	LANDOLT_B2	STISFUV_25MAMA	WFC3UVIS_F475W	WFI_853
ACSHRC_F775W	LANDOLT_B3	STISFUV_F25LYA	WFC3UVIS_F475X	WFI_870
ACSHRC_F814W	LANDOLT_U	STISFUV_F25QTZ	WFC3UVIS_F487N	WFI_B
ACSHRC_F850LP	LANDOLT_V	STISFUV_F25SRF2	WFC3UVIS_F502N	WFI_B842
ACSHRC_F892N	NICMOS_F110W	STISNUV_25MAMA	WFC3UVIS_F547M	WFI_FLAT
ACSSBC_F115LP	NICMOS_F160W	STISNUV_F25CIII	WFC3UVIS_F555W	WFI_HA
ACSSBC_F122M	NICMOS_F165M	STISNUV_F25CN182	WFC3UVIS_F600LP	WFI_I
ACSSBC_F125LP	NICMOS_F187W	STISNUV_F25CN270	WFC3UVIS_F606W	WFI_I879
ACSSBC_F140LP	NICMOS_F190N	STISNUV_F25MGII	WFC3UVIS_F621M	WFI_TI620
ACSSBC_F150LP	NICMOS_F205W	STISNUV_F25QTZ	WFC3UVIS_F625W	WFI_U
ACSSBC_F165LP	NICMOS_F207M	STISNUV_F25SRF2	WFC3UVIS_F631N	WFI_U841
ACSWFC_F435W	NICMOS_F222M	STROMGREN_B	WFC3UVIS_F645N	WFI_V
ACSWFC_F475W	NIRCAM_F070W	STROMGREN_OLD_U	WFC3UVIS_F656N	WFPC2_F170W
ACSWFC_F502N	NIRCAM_F090W	STROMGREN_U	WFC3UVIS_F657N	WFPC2_F255W
ACSWFC_F550M	NIRCAM_F115W	STROMGREN_V	WFC3UVIS_F658N	WFPC2_F300W
ACSWFC_F555W	NIRCAM_F140M	STROMGREN_Y	WFC3UVIS_F665N	WFPC2_F336W
ACSWFC_F606W	NIRCAM_F150W	TYCHO_B	WFC3UVIS_F673N	WFPC2_F380W
ACSWFC_F625W	NIRCAM_F150W2	TYCHO_V	WFC3UVIS_F680N	WFPC2_F439W
ACSWFC_F658N	NIRCAM_F162M	WFC3IR_F098M	WFC3UVIS_F689M	WFPC2_F450W
ACSWFC_F660N	NIRCAM_F164N	WFC3IR_F105W	WFC3UVIS_F763M	WFPC2_F467M
ACSWFC_F775W	NIRCAM_F182M	WFC3IR_F110W	WFC3UVIS_F775W	WFPC2_F502N
ACSWFC_F814W	NIRCAM_F187N	WFC3IR_F125W	WFC3UVIS_F814W	WFPC2_F547M
ACSWFC_F850LP	NIRCAM_F200W	WFC3IR_F126N	WFC3UVIS_F845M	WFPC2_F555W
BESSELL_B	NIRCAM_F210M	WFC3IR_F127M	WFC3UVIS_F850LP	WFPC2_F569W
BESSELL_BW	NIRCAM_F212N	WFC3IR_F128N	WFC3UVIS_F953N	WFPC2_F606W
BESSELL_I	NIRCAM_F225N	WFC3IR_F130N	WFC3UVIS_FQ232N	WFPC2_F631N
BESSELL_R	NIRCAM_F250M	WFC3IR_F132N	WFC3UVIS_FQ243N	WFPC2_F656N
BESSELL_U	NIRCAM_F277W	WFC3IR_F139M	WFC3UVIS_FQ378N	WFPC2_F673N
BESSELL_V	NIRCAM_F300M	WFC3IR_F140W	WFC3UVIS_FQ387N	WFPC2_F675W
CFHT_H	NIRCAM_F322W2	WFC3IR_F153M	WFC3UVIS_FQ422M	WFPC2_F702W
CFHT_I	NIRCAM_F323N	WFC3IR_F160W	WFC3UVIS_FQ436N	WFPC2_F785LP
CFHT_J	NIRCAM_F335M	WFC3IR_F164N	WFC3UVIS_FQ437N	WFPC2_F791W
CFHT_KS	NIRCAM_F356W	WFC3IR_F167N	WFC3UVIS_FQ492N	WFPC2_F814W
CFHT_Y	NIRCAM_F360M	WFC3UVIS_F200LP	WFC3UVIS_FQ508N	WFPC2_F850LP
COUSINS_I	NIRCAM_F405N	WFC3UVIS_F218W	WFC3UVIS_FQ575N	WHITE_WHITE

To add new filters, it is sufficient to put a file containing its profile in the same directory. This must be a 2-column ASCII file, with a name `instrumentname_bandname.dat`. The first column is the wavelength in Angstrom, the second is the associated filter throughput. The scaling units of the throughputs are absolutely irrelevant (e.g., the peak could be 1 or not).

In case of broad band filters, make sure that the profile you have includes also the other instrumental efficiencies, e.g., the transparency of the optics and most importantly the detector efficiency as a function of wavelength.

If your filter has a VegaMag zeropoint (which is the magnitude of Vega in that filter) different than zero (which is the case for some old photometric systems), this value should be added in the file `tada_data/zeropoints.dat`, following the format of the entries in the same file.

Evolutionary models

The present version of TA-DA includes already a number of evolutionary models namely:

- for evolved population (e.g, globular clusters):
  - Marigo et al. (2008) models
- for pre-main sequence populations:
  - Palla & Stahler (1999) models
  - Siess et al. (2000) models
  - Baraffe et al. (1998) models
  - D'Antona & Mazzitelli (1998) models
  - PISA/Franec models from Tognelli et al. (2011)

These are located, as fits table files, in the directory `tada_data/isochrones/`. The PISA/Franec grids include a large number of isochrones for several metallicities, mixing length parameter, helium abundance and deuterium abundance. For this reason, the original installation package of TA-DA (`tada.zip`, downloadable from the website) includes only the most used models for solar metalliticy. The rest of the grid can be downloaded, if needed, separately from the TA-DA website.

To add new family of models, one must put a properly formatted file containing them in this directory. Specifically, this must be a fits table must contain 4 columns, in this order:

1. mass (in units of $M_\odot$)
2. $\log age$ (in logarithm of years)

3. $\log T_{\rm eff}$ (in logarithm of K)

4. $\log L_{\rm bol}$ (in $L_\odot$)

The header of the fits table must also include the following additional keywords:

- `NAME` - the name of the family of models, e.g., "Siess (2000) oversh."
- `SHORTNAM` - a shorter (with no spaces) name, e.g., "siessover"
- `M/H` - the metallicity [M/H], e.g, '0.0' (float)
- `MTYPE` - the type of models, e.g, "PMS" (not used by TA-DA)
- `col1 - mass` (content of the first column, not actually used by TA-DA, so please do not change the order of the four)
- `col2 - logage` (content of the second column)
- `col3 - logt` (content of the third column)
- `col4 - logl` (content of the fourth column)

Here we have an example of how to produce a valid format fits table from IDL. I will assume you have already 4 IDL variables named `"mass"`, `"logage"`, `"logt"`, `"logl"` as one dimensional arrays of floating-point numbers containing this quantities.

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
fileout='/your/path/girardi_models.fits'

FXHMAKE,hdr,/EXTEND
FXWRITE,fileout,hdr

FXBHMAKE,newhdr,1
FXBADDCOL,c1,newhdr,[[mass]]
FXBADDCOL,c2,newhdr,[[logage]]
FXBADDCOL,c3,newhdr,[[logt]]
FXBADDCOL,c4,newhdr,[[logl]]

FXADDPAR,newhdr,'NAME','Girardi et al. (2000)'
FXADDPAR,newhdr,'SHORTNAM','girardi'
FXADDPAR,newhdr,'MTYPE','postMS'
FXADDPAR,newhdr,'M/H',0.0
FXADDPAR,newhdr,'col1','mass'
FXADDPAR,newhdr,'col2','logage'
FXADDPAR,newhdr,'col3','logt'
FXADDPAR,newhdr,'col4','logl'

FXBCREATE,unit,fileout,newhdr
FXBWRITE,unit,mass,c1,1
```

```
FXBWRITE,unit,logage,c2,1
FXBWRITE,unit,logt,c3,1
FXBWRITE,unit,logl,c4,1
FXBFINISH,unit
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
```

Important note: the grid of evolutionary models must be already *densely interpolated* (with a resolution in the parameter space not much worse than the precision you aim to achieve in fitting your data with TA-DA), and *rectilinear* in mass and log age (see Figure 2.3 for what this means).

Synthetic spectra

The current version of TA-DA includes a number of grids of synthetic spectra, used to perform synthetic photometry. These are:

- The BT-Settle grid of Allard et al. (2010), defined for 2000 K< T_{eff} <70,000 K, -0.5< $\log g$ <5.5, -1< $[M/H]$ <0.3
- The NextGen grid of Hauschildt et al. (1997), defined for 2500 K< T_{eff} <50,000 K, 2< $\log g$ <5.5, -1.5< $[M/H]$ <0
- The NextGen grid of Hauschildt et al. (1997) complemented with the AMES-MT grid of Allard et al. (2001) for the low T_{eff}, defined for 2000 K< T_{eff} <50,000 K, 3< $\log g$ <5.5, $[M/H] = 0$
- The AMES-Settle grid of Allard et al. (2002), defined for 1100 K< T_{eff} <2300 K, 4.5< $\log g$ <5.5, -1< $[M/H]$ <0

One can add additional grids, by placing them in a proper format in the same directory. The grid of spectra must include a spectrum as a function of 3 parameters: the first 2 must be T_{eff} (in Kelvin) and $\log g$ (in logarithm of cm s^{-2}); the third parameter is typically metallicity [M/H], but can be any other arbitrary quantity.

The grids of spectra must be stored as a 5-column fits table, where the columns are:

1. **wavelength** - in Angstrom (1-dimensional, *nlambda* elements)
2. T_{eff} - in Kelvin (1-dimensional, *nmodels* elements)
3. $\log g$ - in log of cm s^{-2} (1-dimensional, *nmodels* elements)

4. **third parameter** - whatever units, e.g., metallicity in [M/H] (1-dimensional, *nmodels* elements)

5. **the actual spectra** - in erg s^{-1} cm^{-2} $Å^{-1}$ (2-dimensional, *nmodels*$\times$*nlambda* elements)

The fits tables must also include these additional keywords in their headers:

```
NAME    = 'Ames Settle 2002'   /name of the grid
PARN    =                    3 /number of model parameters
WAVN    =                 1221 /number of wavelength points
WAVUNIT = 'Angstrom'           /units of wavelength scale
PARNAME1=                    T /name of first parameter
PARNAML1= 'Temperature'        /name of first parameter (long)
PARUNIT1= 'K       '           /units of first parameter
PARMIN1 =              1100.00 /minimum value of first parameter
PARMAX1 =              2300.00 /maximum value of first parameter
PARNAME2= 'logg    '           /name of second parameter
PARNAML2= 'Surface gravity'    /name of second parameter (long)
PARUNIT2= 'log(cgs)'           /units of second parameter
PARMIN2 =              4.50000 /minimum value of second parameter
PARMAX2 =              5.50000 /maximum value of second parameter
PARNAME3= '[M/H]   '           /name of third parameter
PARNAML3= 'Metallicity'        /name of third parameter (long)
PARUNIT3= 'log(ratio)'         /units of third parameter
PARMIN3 =             -1.00000 /minimum value of third parameter
PARMAX3 =             0.000000 /maximum value of third parameter
MODN    =                   52 /number of model spectra
```

Here I present an example of IDL code to produce a model grid. It is assumed that the 5 variables `lambda`, `teff`, `logg`, `metallicity` and `spectra` are already stored in IDL as arrays:

```
filename='/your/path/synthetic_grid.fits'

FXHMAKE,hdr,/EXTEND
FXWRITE,filename,hdr

FXBHMAKE,newhdr,1
FXBADDCOL,c1,newhdr,[[lambda]]
FXBADDCOL,c2,newhdr,[[teff]]
FXBADDCOL,c3,newhdr,[[logg]]
FXBADDCOL,c4,newhdr,[[metallicity]]
FXBADDCOL,c5,newhdr,[[spectra]]

FXADDPAR,newhdr,'NAME','The name of my grid'
FXADDPAR,newhdr,'MODTYPE','Star'
FXADDPAR,newhdr,'PARN',3
FXADDPAR,newhdr,'WAVN',(size(lambda))[1]
FXADDPAR,newhdr,'WAVUNIT','Angstrom'
FXADDPAR,newhdr,'PARNAME1','T'
FXADDPAR,newhdr,'PARNAML1','Temperature'
FXADDPAR,newhdr,'PARUNIT1','K'
FXADDPAR,newhdr,'PARLOG1',0
```

```
FXADDPAR,newhdr,'PARMIN1',min(teff)
FXADDPAR,newhdr,'PARMAX1',max(teff)
FXADDPAR,newhdr,'PARNAME2','logg'
FXADDPAR,newhdr,'PARNAML2','Surface gravity'
FXADDPAR,newhdr,'PARUNIT2','log(cgs)'
FXADDPAR,newhdr,'PARLOG2',1
FXADDPAR,newhdr,'PARMIN2',min(logg)
FXADDPAR,newhdr,'PARMAX2',max(logg)
FXADDPAR,newhdr,'PARNAME3','[M/H]'
FXADDPAR,newhdr,'PARNAML3','Metallicity'
FXADDPAR,newhdr,'PARUNIT3','log(ratio)'
FXADDPAR,newhdr,'PARLOG3',1
FXADDPAR,newhdr,'PARMIN3',min(metallicity)
FXADDPAR,newhdr,'PARMAX3',max(metallicity)
FXADDPAR,newhdr,'MODN',(n_elements(teff))

FXBCREATE,unit,'filename,newhdr
FXBWRITE,unit,lambda,c1,1
FXBWRITE,unit,teff,c2,1
FXBWRITE,unit,logg,c3,1
FXBWRITE,unit,metallicity,c4,1
FXBWRITE,unit,spectra,c5,1
FXBFINISH,unit
```

Contents