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ExoplAn3T: a new way of exploring large exoplanetary databases and its applications to astrobiology

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Abstract. ExoplAn3T is the SSDC scientific webtool providing access to several on-line exoplanet catalogues, including observational information, and is designed and optimized for the study of exoplanetary systems as a whole, rather than to extract information on single planets.
To achieve this goal, the tool applies a two step procedure: the first step is to find all the exoplanets with user-defined characteristics; then, in the second step, all the planets belonging to systems including the exoplanets selected in the first query are listed.
One of the applications of such a web tool is, for instance, to accurately investigate the habitability conditions.
In addition to the planetary parameters, the tool's features would make more straightforward to take into account orbital excitation and probability of impacts, providing information on the history and evolution of the system. This functionality will be available in forthcoming versions of the tool.
These features, together with the possibility of looking for systems with characteristics similar to those of the Solar System, makes ExoplAn3T a very interesting tool for all the researchers whose work is focused in finding exoplanetary systems where at least one planet could have been developed an habitable environment.

Key words. exoplanets – exoplanetary systems – database – 3D visualization – data access

1. Introduction

Since the discovery of the first planet orbiting a main-sequence star different from the Sun (Mayor & Queloz 1995) interest and techniques devoted to exoplanetology steadily grew until today, with more than 4300 exoplanets and 3200 exosystems confirmed [1] [2], most of which ascribed to results obtained by means of NASA's Kepler/K2 data (Christensen-Dalsgaard et al. 2009, Beichman

[1] http://exoplanet.eu/catalog/
[2] https://exoplanetarchive.ipac.caltech.edu/docs/counts_detail.html

et al. 2013, Howell et al. 2014).
Recently launched missions, as well as future ones, will be no longer limited to the discovery of new planets, but will aim to characterize them and their exosystems as a whole (e.g., Tinetti et al. 2018, Turrini et al. 2018), with the ultimate goal to find a general classification of planetary systems capable of including the solar system as one of the possible outcome of exosystems evolution patterns.
In order to fulfill this task it is critical to compare and to easily group together exosystems with similar characteristics, even following the "peas in the pod" effect outlined by Weiss and Petigura (2020). However the differences in terms of data structures, interfaces and service provided by the existing exoplanetary databases, makes it difficult for the users to take full advantage of their potential.
In this context the Space Science Data Center of the Italian Space Agency (SSDC – ASI) developed ExoplAn3T (Exoplanetary Analysis and 3D visualization Tool – https://tools.ssdc.asi.it/exoplanet/), a scientific webtool capable to search inside several different datasets (NASA Exoplanetary Archive – Akeson et al. 2013 –, The Extrasolar Planet Encyclopedia – Schneider et al. 2011 – and ExoMerCat – Alei et al. 2020) and, starting from queries on specific planetary characteristics, to extract information about the exosystems including the planets selected with the initial the query. This allows to promptly find similarities between exosystems and to identify characteristics that can be connected to similar formation and evolution pathways.
By means of this tool it is also possible to visualize the selected systems in a three-dimensional view directly within a browser window. This can be fruitfully exploited to visually compare the exosystems found, allowing to infer additional useful information on the system.
All these characteristics make ExoplAn3T an ideal tool also for astrobiologists looking for planetary systems having physical parameters similar to those of the Solar System and, hence, likely candidate to host planets with life-supporting conditions.
In this paper we will provide an outline of the ExoplAn3T tool, describing its software architecture (Section 2), showing a noteworthy use case (Section 3) and finally drawing the conclusions in Section 4.

2. Software architecture

The approach followed in the development of the main ExoplAn3T search capability is different with respect to that of common exoplanetary queries to online catalogues: up to now it has been common practice to search for planetary features, retrieving as output a list of individual exoplanets sharing some characteristics. On the contrary, ExoplAn3T offers the possibility to easily search for exosystems including similar planets.
This capability could be valuable in studies pointing at finding a classification of exosystems (e.g., Zinzi & Turrini 2017, Turrini et al. 2020) and is achieved passing by two different steps: the first one is the "planetary query", aimed at finding exoplanets having the characteristics required by the user; the second one is made up of a series of "system queries" (one query for every exosystem found in the first step) looking for all the planets belonging to each exosystem in which the exoplanets of the "planetary query" are found.
Indeed, in the very next releases of the tool the possibility of computing the NAMD (Normalized Angular Momentum Deficit) parameter described by Turrini et al. (2020) will be added.

2.1. Web interface

The module has been designed to produce different outputs (i.e., query, 3D visualization, 2D plot) and is initialized by the web interface presented to the users when accessing the tool. This interface is designed to allow for intuitively building complex queries in a transparent way and without any prior knowledge of the specific details and behaviour of each queried database.
The parameter values selected through the web interface (Fig. 1) are passed to the module according to the user requests and, finally, the

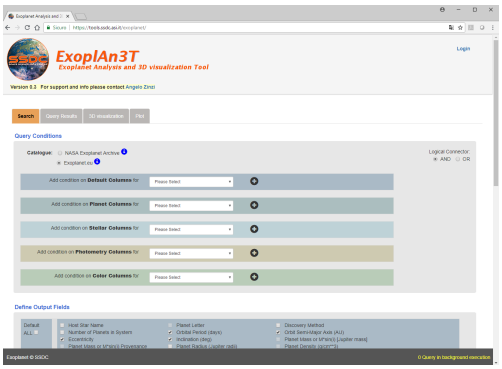

Fig. 1. The main page of ExoplAn3T with the dropdown menus to build the query.

outputs are shown.

The "Query Results" tab contains a table listing all the exosystems found, and directly show some of their main parameters and the relative query written at the top of the tab, to allow for its future re-use and for inclusion in other tools or software. The entire set of data requested by the user for all the planets in the system can be visualized expanding any single row and, when available, measurements are automatically accompanied by corresponding uncertainties.

Exosystems with all the parameters needed for the 3D visualization are also accompanied by a "3D" icon: clicking on it will give access to the third tab ("3D visualization") with the interactive visualization of the system.

Both of these features are very uncommon as compared to other online tools, but it is also possible to generate plots of two variables. This functionality is similar to those available in the online databases queried by ExoplAn3T, but here the advantage is the possibility to quickly compare the plots obtained from data by different catalogues.

The final results are shown in an interactive scatterplot from which data in textual and graphic (i.e., PNG, JPEG, PDF and SVG) format can be downloaded.

3. Illustrative use case

In order to better show the capabilities of the ExoplAn3T tool we selected a use case related to the characterization of exosystems around

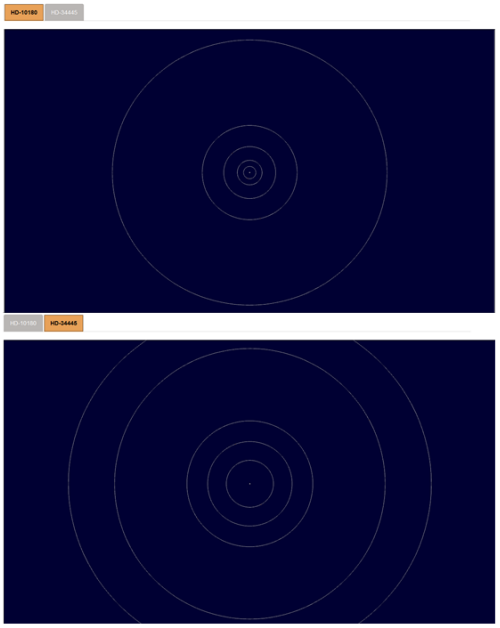

Fig. 2. The two exosystems considered in the use case. Here they are shown only up to the habitable-zone planet (i.e., HD-10180 e and HD-34445 d) to highlight the similarities among their architectures.

solar type stars with at least one planet in the habitable zone.

We used the definition of "Conservative Habitable Zone" as found in Kane et al. (2016): therefore we used ExoplAn3T to submit a query to the NASA Exoplanet Archive imposing stellar effective temperature between 5500 and 6000 K, semi-major axis between 0.75 and 1.8 au and requiring a system with at least 3 planets.

Among the 6 systems found, 2 (HD-34445 and HD-10180) have 6 planets, thus allowing a quick visual comparison between their structures: by taking into consideration their sizes (i.e., semi-major axis of the farthest planet), these appear to be rather different, as the first one is almost a factor of two larger than the second one (6.36 and 3.38 au, respectively).

However, without any claim of physical explanation, some similarities immediately emerge from a visual comparison (Fig. 2). In both

cases the habitable planets are located in the outer region of the system, but they are not the farthest planet. Another interesting similarity is represented by the fact that both systems host another inner planet just out of the habitable zone semi-axis range.
HD-10180 has its habitable planet (the fifth from the star) at 1.43 au, with the fourth one at 0.5 au; HD-34445 has the habitable planet (the fourth from the star) at 1.5 au and another planet at 0.72 au, just out of the range selected for the habitable zone in this case.

4. Conclusions

The number of known exoplanets increased by a factor of 5 since 2009 and more discoveries are expected, thanks to missions just launched or to be launched in the near future. Catalogues continuously updated with measurements from various discovery methods have shown the need for data comparison, in particular with the goal to investigate exosystems characteristics and to confirm the reliability of the measurements.
Our ExoplAn3T tool is designed to explore exosystems data rather than only exoplanet ones, and it is proposed to the exoplanetary and astrobiology community as a new tool open to further development, thus allowing researchers to shift their attention from the individual exoplanets to the exosystems seen as global entities.
Thanks to its architecture, coupling together a user-friendly web interface and a software able to perform a complex series of queries to external resources, it provides an easy way of exploring exoplanetary data and exosystem characteristics, even when the user is not familiar with database interrogation and advanced data visualization issues.
Alongside this ease of usage, ExoplAn3T is the only tool up-to-date exploiting the peculiar strengths of multiple databases, thus providing a powerful tool for comparative studies. This characteristic is intended to be further enhanced with the addition of the NAMD computation in the forthcoming versions of the tool.
No other publicly available online resource currently offers all these features. ExoplAn3T is now fully available to the scientific community and we showed in this paper some noteworthy applications of this tool, such as the comparison between catalogues and the visual inspection of exosystems hosting similar planets.

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