The Exoplanet Explorer - September 2022 prototype guide

Emma Broman, emma.broman@liu.se
2022-09-21

This is a how-to-use and explaining guide for the September 2022 prototype of the ExoplanetExplorer research tool, created using OpenSpace. This guide briefly explains the menus and visualizations in the tool, as well as the external webpage and how the data was processed.

Note that the tool is currently a research prototype, and will be subject to improvements and future work. For that reason, the guide includes multiple caveats sections that explain things that might not work quite as expected. I recommend reading these in particular if you come across any problems.

Feel free to contact me if you have any questions. Also, any feedback, ideas or suggestions on future work and improvements are warmly welcomed.

// Emma

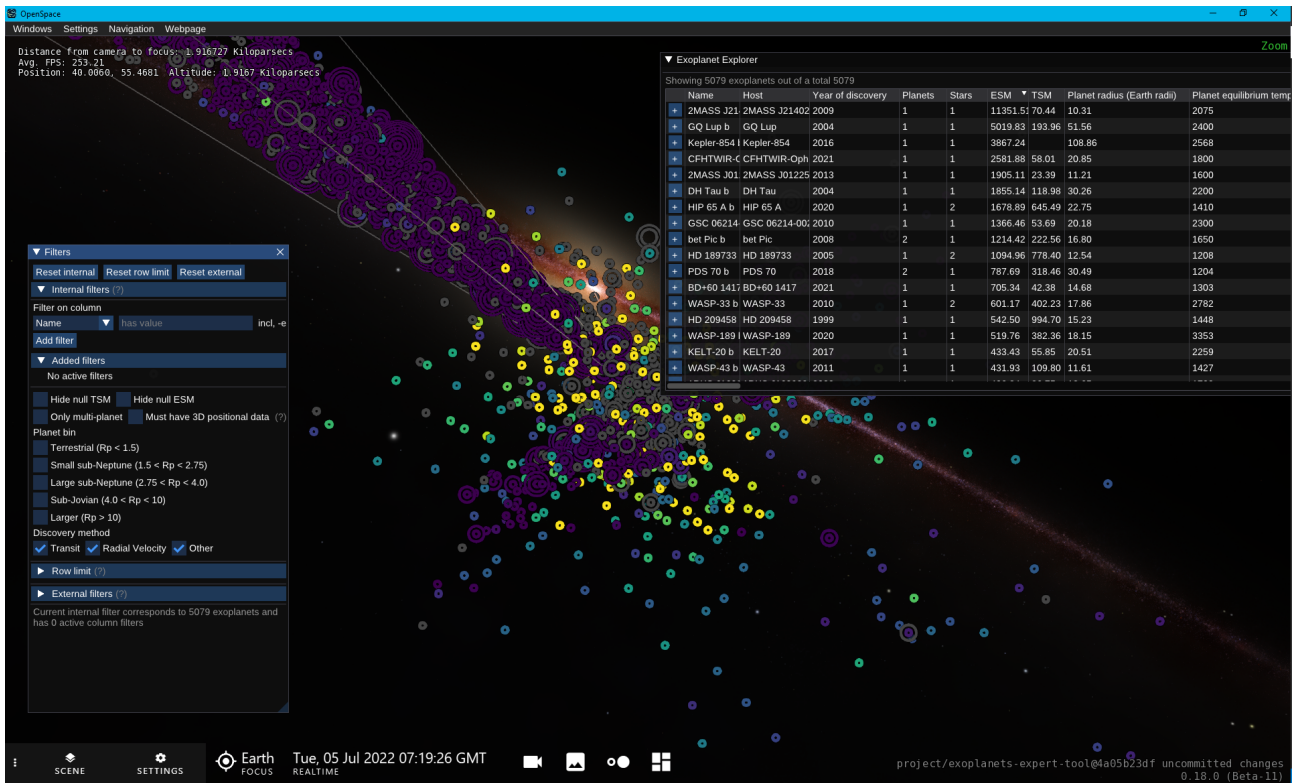**OpenSpace**

1. Start-up and installation

1. Download the *OpenSpace_ExoExplorer.zip* file from [this location](#) and unzip it in an optional location.

2. You will also need to install Microsoft Visual C++ Redistributable, which you can [download here](#). If you experience the error *"VCRUNTIME140_1.dll was not found"* when starting OpenSpace, the Redistributable installation will fix this.

3. Start OpenSpace using the OpenSpace.exe file in the bin folder

4. In the launcher, choose your desired window option in the bottom dropdown menu and then click START. The default is one single window, but it is also possible to open the application in two windows: one with the GUI and one with the rendering.

   Next page shows examples of how the setup can look like in single VS multi-window setup.

   Note: A benefit of the two window setup is that one avoids problems with the UI menus occluding the rendering view. I often go with the "two_window.json" option, and resize the windows to how I like them. For example as shown below. There are also a few different predefined two-window setups with different resolutions available.

5. OBS! The first time you start the application, OpenSpace will ask for permission to access the internet which causes a Windows popup window. Allow this access (needed for some features in the software to work).

Single-window setup

Two-window setup (Left: menus, Right: rendering)
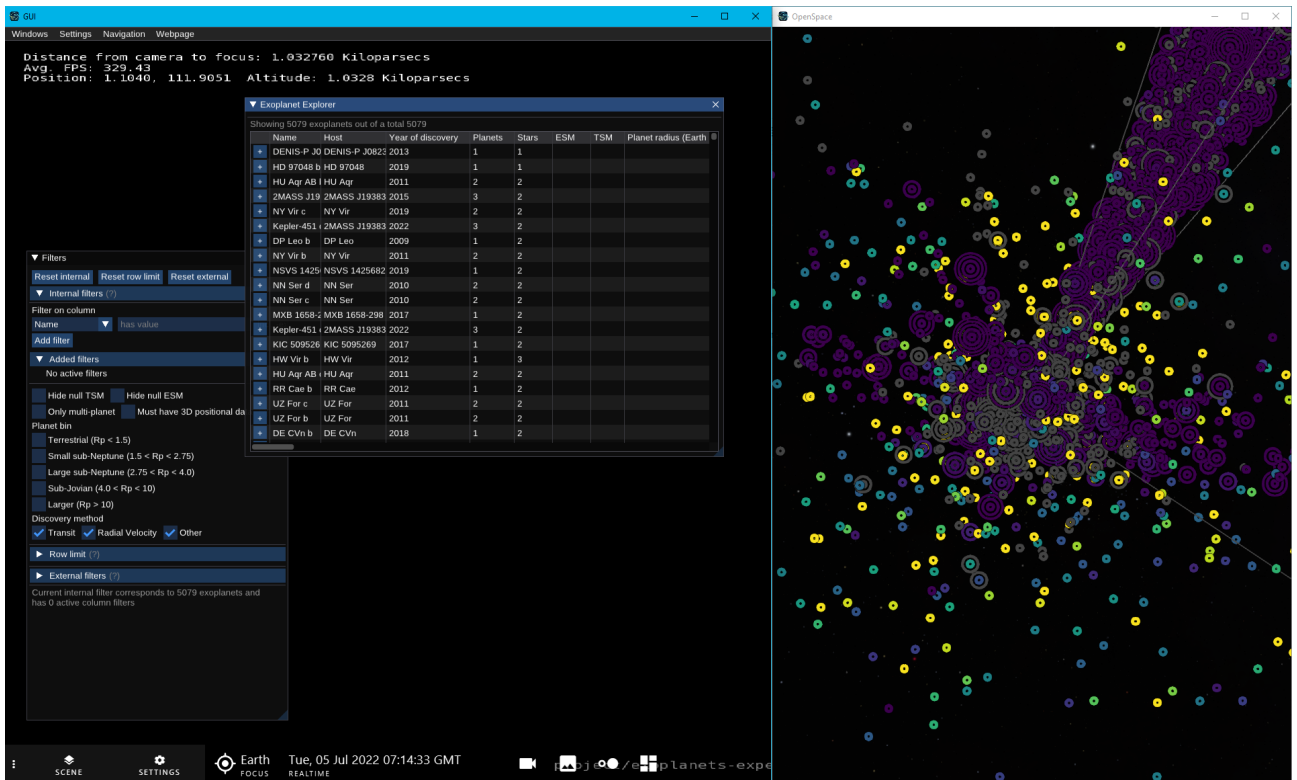
2. Basic navigation

You can rotate the OpenSpace view using the mouse, by holding down the left mouse button. Holding down the CTRL key while doing this will allow you to move the focus point. Also try doing the same motion, but click the scroll wheel instead. This will rotate the view.

At startup, the camera is located at about 0.8 Parsec from Earth. You can move further away by holding the right mouse button and dragging along the y-axis of the screen. Holding down the Z key while doing this makes it go faster.

In summary:
- Left mouse button: Rotate around focus point
- CTRL + left mouse: Move focus point on screen
- Scroll-wheel: Rotate view
- Right mouse button: Zoom in/out

There are also some predefined navigation options available in the "Navigation" menu in the top menu bar (see image to the right). These can be used to reset the view.
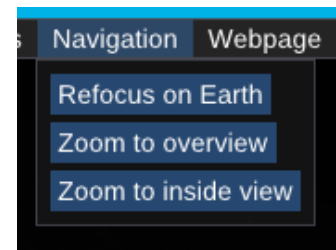
3. Visuals

At the heart of the start-up view is a rendering where each exoplanet system is rendered in its position in the galaxy by a set of rings; one per detected planet in the system. The rings are centered around the position of the host star, and their radius corresponds to the planet component. That is, the "b" planet is rendered in the center, then the "c" planet, then "d" and so on. We refer to these rings as the *exoplanet glyphs*.

The rings' color is mapped to a data value of choice. On startup, it is mapped to an ESM value in the range [0, 100], where zero is purple and 100 is yellow. The image to the right shows an example of a system with 5 planets (each ring is here colored by its mass uncertainty, given in percentage).

3.1. Settings

Per default, the width of the rings decrease with the radius, to give all the planets similar "visual weight". In the Setting menu at the top bar there is however an option to render all the rings using the same width, if desired. There is also an option to change the size glyph, using the "Glyph scale".

In addition to the glyph cloud with the exoplanet rings, the initial view contains a few visual cues: A representation of the Kepler Field of View and a line to the Milky Way center. These can also be toggled on/off through the settings menu.
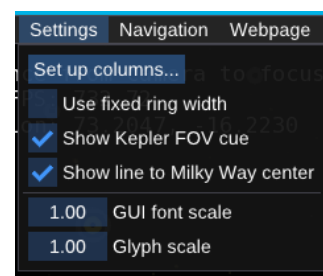
There is also a setting to change the font size in the GUI, which might be useful to set the text size to something suitable for your monitor.

3.2. 3D visualization of exoplanet systems

In addition to the glyph view, with the colored rings, the tools include a 3D rendered view of the exoplanet systems that can be explored by interacting with the tool. This view includes visuals for:

- The host star, with correct radius, BV color and a "glare" effect that scales with the luminosity of the star

- The planet bodies, if there is a value for the radius of the planet

- Orbital parameters of the planets, with a "blurry" disk around the orbit that shows the uncertainty of the semi-major axis.
  - Note: Default values are used for some parameters to render the orbit if no value exists in the database. These are
    - Eccentricity: 0
    - Inclination: 90 degrees
    - Longitude of ascending node: 180 degrees

- - ■ Argument of periastron: 90 degrees

- ● The habitable zone of the star with boundaries from [Kopparapu et al. (2014)](#) showing conservative boundaries in green and optimistic boundaries in red/blue. The coefficients selected are those corresponding to a planet of 1 Earth mass.

An example is shown below.
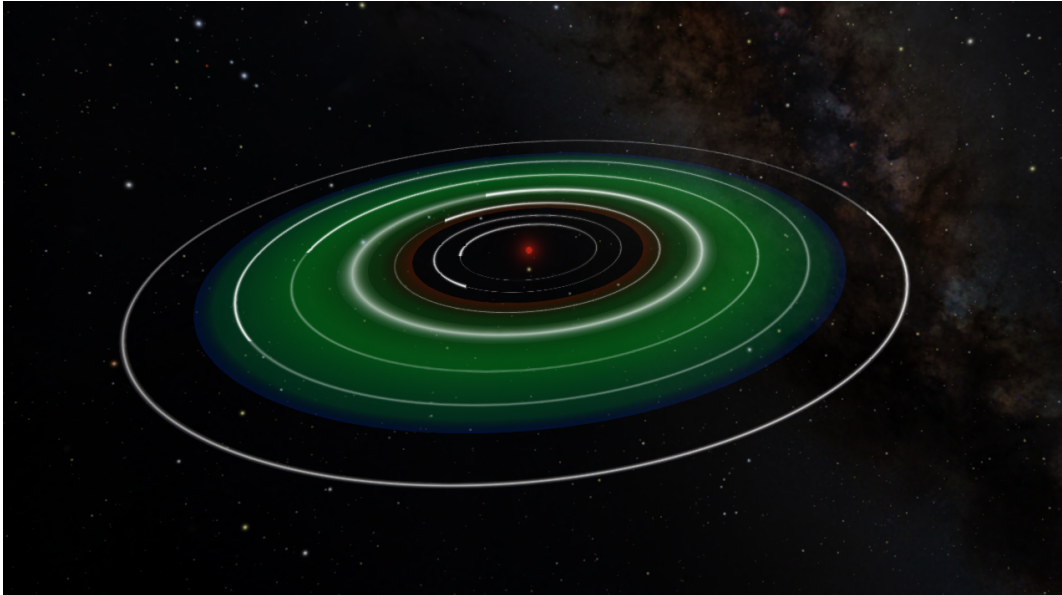
3D view of the Trappist-1 system

Additionally, it is possible to toggle a few visual ques that provide further information about the direction, orientation, and size of the system:

- ● A ring with a radius of 1 AU
- ● An arrow pointing in the direction of Earth
- ● A grid/plane, showing the 90 degrees inclination plane
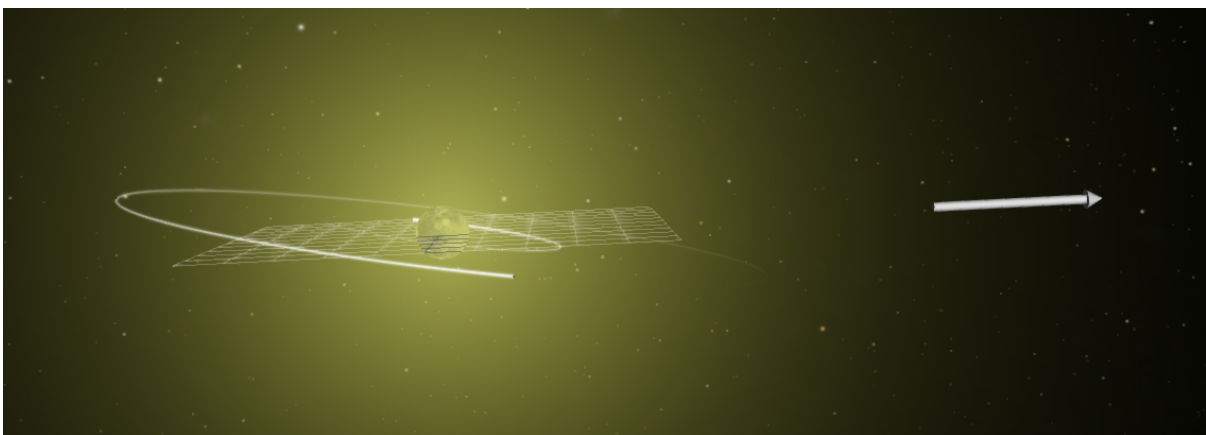
The CoRoT-7 system, with 90-degree inclination planet and arrow pointing towards Earth

4. Menus

All the menus are accessible from the "Windows" menu in the top menu bar. The windows can be opened/closed on demand, either using the Windows menu or the little "x" at the top right of each window. A checkbox means that the window is opened

The three top windows in the menu are most useful:
- **Table**: A sortable table of the currently selected planet data
- **Filters:** Where the current selection of planets can be customized and filtered
- **Color mapping**: Here the rendered planet glyphs can be colored based on chosen features
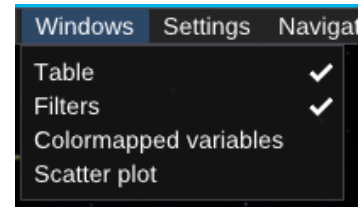
The last one, the "Scatter plot", shows a RA DEC plot of the current selection of planets.

Note that the windows "remember" their last position, as long as the application window (OpenSpace) is not minimized. If a window shows as open in the Windows menu but you can't see it, try to make the application window fullscreen. It might be that the window is located in a position that's not visible with your current application window size.

All the windows can also be resized by click-and-dragging the blue little triangle in the bottom right corner.

4.1. Table window

This view just shows a regular table with values for the different columns in the dataset. The columns shown can be changed in the settings menu (see setting sections in "About the Data" below).

The table is scrollable both horizontally and vertically, and sortable. It also includes some interaction options, as explained below. The leftmost column, the planet name, will always be visible even if scrolling horizontally.

Table window
Controls in the top part of the window: 1) Open the list of pinned planets (see section 4.1.1). 2) Number of planets passing current filter settings, compared to the full dataset. 3) Search the list of planets. 4) Table header (interactive, left-click to sort and right-click to access settings)

4.1.1. Table interaction

The **table header** includes the following interaction options:
- Click a table header to sort the table in ascending order based on that value, and click again for descending.
- Click and drag left to right to move/reorder columns
- Right-click to get some option about resizing or hiding certain columns

It is also possible to **select planets** by clicking a row in the table. The table row will be marked in blue, and some white markers will appear in the rendering to highlight which planet ring is the selected one See image →

The **planet name column** also has some interaction built into it to add a 3D representation of the system or focus on a specific planet. The current status is shown in the leftmost column:

1. If a "+" button is shown, clicking it adds the system to the rendering.
2. Once a system is added the button changes to a "->". It can then be used to focus a certain planet and fly there by navigating with the mouse. If the button is green, it means that planet is the current focus (it should also show as Focus in the bottom bar).
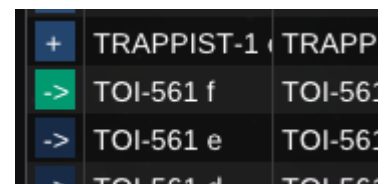
Both of the actions above can be performed by double-clicking the planet name as well. Doing so also opens the system view for the clicked planet (see section 4.4.). In addition, a focused system can be flown to, to show a 3D visualization of the planet and its system. See 3.2 for more details about this visualization mode.

In addition, **right-clicking a planet row** opens a context menu with 3 buttons (see →):
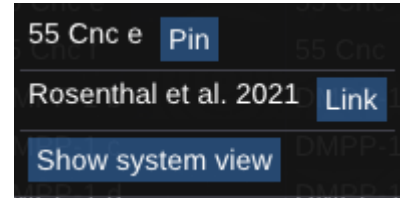
1. "Pin" is used to pin a planet to the top part of the table window. Makes it easier to compare planets, and the pinned list is also not affected by filtering.
2. Link to the reference for the planetary parameters for the exoplanet data entry (opens in your default browser)
3. A "Show system view" button, which opens a system view window for the system the planet is part of (see section 4.4. for more details).

4.1.2. Caveats:

- **Mismatching star positions?**
  Note that the planet system view is built using the existing exoplanets visualization in OpenSpace (more info on that here). This visualization uses a slightly different dataset for the star position compared to the glyphs in this tool, which means that the position of the focused planet and the visual ring representation might not always fully match.
- **Not all systems can be added**
  The 3D visualization of the exoplanet system uses a separate dataset that is not updated as frequently as the dataset used for the rest of the tool. Consequently, a 3D view cannot be added for the most recent planets. If a system cannot be added, an error will appear in the OpenSpace log.

4.2. Filters window

The filter window consists of three parts:

1. **Internal filters**: Filter the data collection inside of OpenSpace

2. **Row limits**: Limit the number of table rows to show, based on which have the maximum TSM or ESM value.

3. **External filters**: With the option to apply filtering/selection coming from the external webpage (see later chapter)

All the filters affect which planets are being
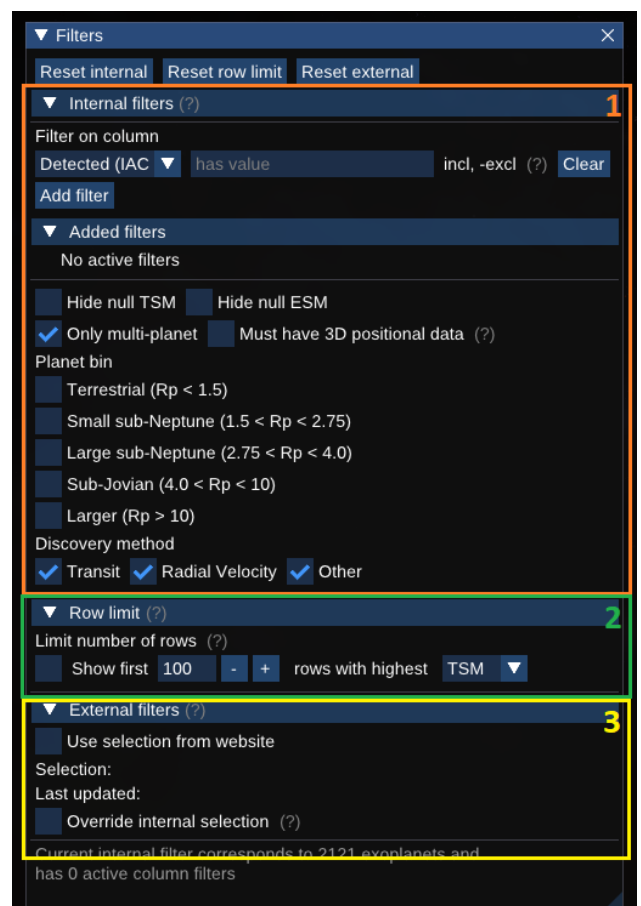
rendered. Each filter category can be reset with the buttons at the top of the window.

The planets shown in the table and the rendering will be the ones **matching all the currently selected filters**. That is, the intersection of the chosen filter set.

4.2.1. Internal filters

This is where the majority of the filtering is done. The menu consists of two parts: one with a custom column-based filtering and one with checkboxes for some predefined filters.

The **column-based filtering** uses a text query to filter. Numeric columns can be queried using operators such as >, >=, =, etc., while text-based columns can be queried either using inclusive or exclusive checks. See the hint in the menu for more information. An empty query per default means to filter based on whether it has a value or not.

The **predefined filters** can be used to quickly toggle certain common filterings. For example, planets from all the discovery methods are enabled by default, but to select only Transit planets you can uncheck "Radial Velocity" and "Other" in the menu.

The **"planet bin" filter** is a little special. If no option is selected, all planets are shown. But if any checkbox is selected, only planets from that bin will be visible. This can be used to quickly select all the terrestrial planets (with Earth radii under 1.5). Also note that the units of the radius values are only in Earth radii, for now. The plan is to add an option to toggle between Jupiter/Earth units in the future.

4.2.2. Row limit

This filter acts as a shortcut to always show the X matching planets with the highest ESM or TSM value, out of the result from the internal filter.

4.2.3. External filters

The external filters are disabled by default, but can be used to crossmatch the internal filter with a selection of planets from the external webpage. To do so, send a selection from the website to OpenSpace and check the "Use selection from website" checkbox.

Some hints are shown in the menu, telling how big the external selection is and when it was last updated. There is also a checkbox that makes it possible to show only the external selection in the tool ("Override internal selection").

4.3. Color mapping window

The rendered glyphs can be colored based on one or multiple selected variables through the color mapping window.

For each variable, it's possible to set the column, choice of colormap and min and max values for the colormap range. The min/max value can be changed by clicking and dragging

left-to-right, or by double-clicking and typing in an exact value. In addition, there are a few buttons to quickly set the min and max values:

- *Set from current table data* - based on the minimum and maximum value in the data currently shown in the table, i.e. the filtered data
- *Set from full data* - use the min and max values from the full dataset, excluding any filtering

In the example below, The planet radius has been mapped to the Viridis colormap, where a more yellowish color implies a larger planet.

Clicking the "+ Add variable" button adds another variable to use for color mapping. With multiple variables selected, the rings split up into "pie pieces" based on the number of variables chosen. For example, in the image below, the rightmost half of the rings are mapped to the planet radius, while the leftmost part is mapped to the orbital period.
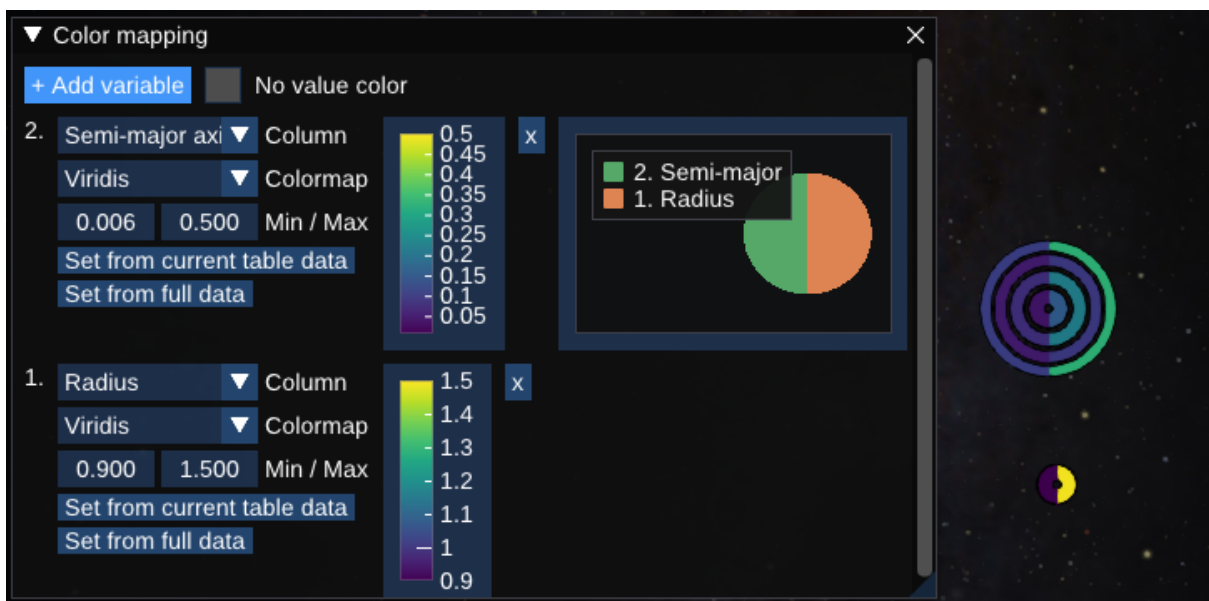
4.3.1. Caveats:

Note that with multiple parameters it quickly becomes difficult to interpret the visual representation, especially when looking at multiple planets at once. We hence recommend only looking at one or a couple of variables at once using this method, and limiting the number of planets looked at simultaneously when color mapping by multiple variables.

4.4. System view

A system view, showing the details of planets in a specific system, can be opened by right-clicking a planet in the table and selecting "Show system view". Or, if a planet is currently targeted, the system view of that planet can also be accessed through the top menu bar. For example, in the image below a planet in the 55 Cnc is selected.
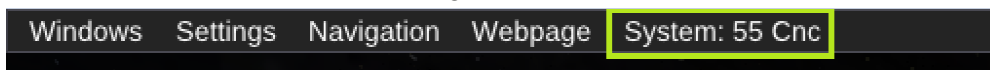
and clicking that button gives us the following menu and options:

1. Buttons to focus or fly/zoom to the star, and a 3D view of the system.

2. Toggle specific visuals in the 3D visualization.

3. A table showing the data for all planets in the system. This table has the same controls as the big main table in the table window.

4. An option to color the orbits in the 3D visualization. Clicking the checkbox opens the controls for the coloring (see next section).
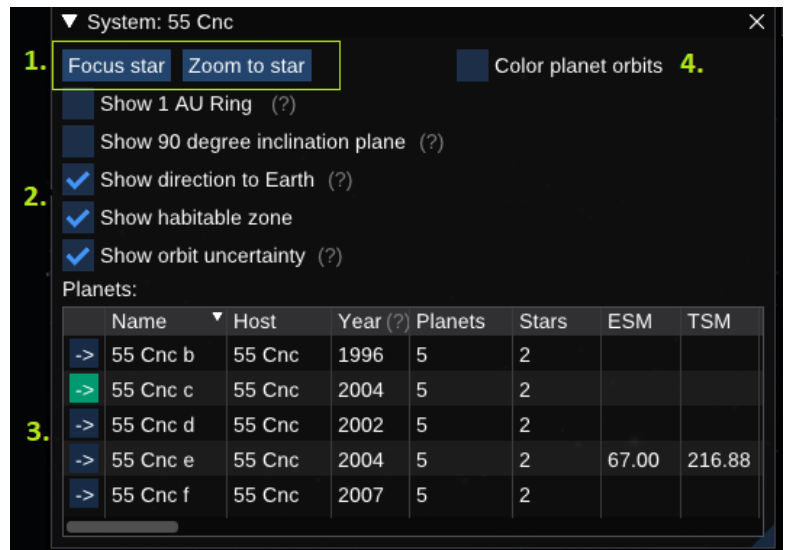
Note that options 1, 2, and 4 are only available if the system is added to the view. If not, an "Add system" button will be shown at the top of the window.

4.4.1. Coloring orbits

Checking the "Color planet orbits" checkbox opens an edit similar to the one in the color mapping window, that allows coloring each of the planet orbits by a value. Just as for the other color mapping, it is possible to set the column, colormap, and min/max range. In addition, this panel includes a quick-access button to set the min/max range from just the planets in this system.

The image below shows the Trappist-1 system with orbits colored by the radius of the planets. The range is set from the planets in the system.
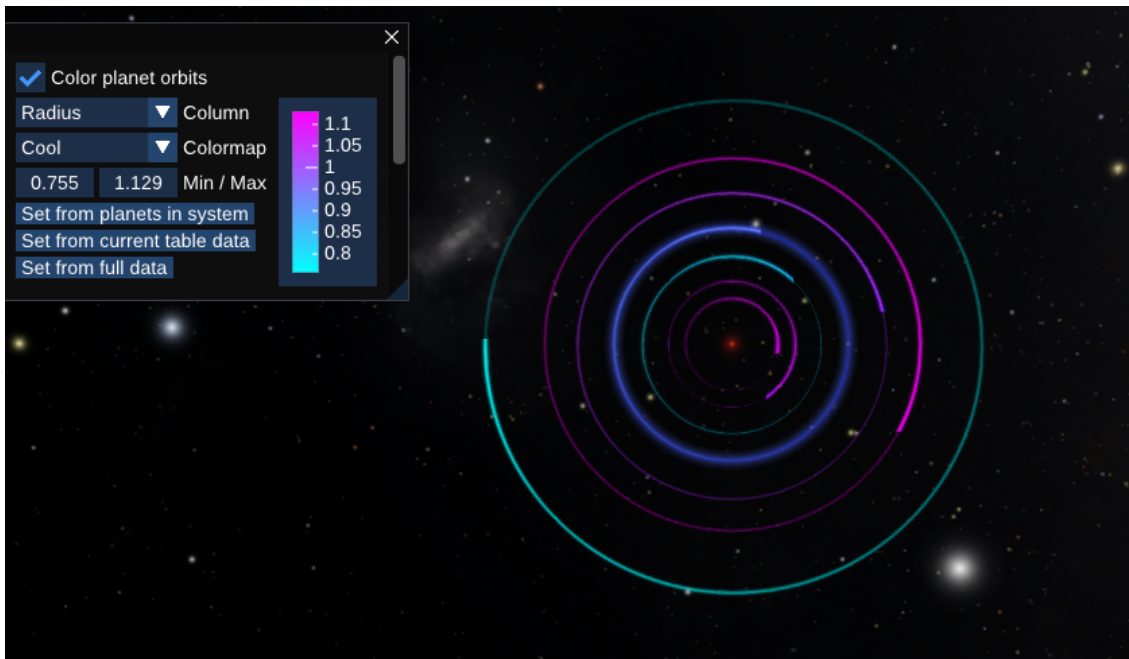
4.4.2. Caveats:

When opening a new system view window, but without the orbits actually being colored. This may happen if the checkbox was checked in a previous system view when opening a new view. To get around the problem, just click the checkbox again until the software shows the desired outcome.

5. About the data

The dataset is prepared through the python script *datapreparation.py* that is available in the *modules/exoplanetexperttool/scripts* folder. Running this file will update the data with the most recent data from:

- The NASA Exoplanet Archive: link
- The IAC community database on Exoplanet Atmosphere Molecule detection - ExoAtmos: link
- Emission and Transmission Signal-to-noise Metrics (ESM and TSM), from Kempton et al. (2018) paper
- Data on the chemical abundance of the star (see below)
- Some other parameters that have been computed for the research project

The second dataset, the detected molecules, has been added as one column per detection level: The "Detected" molecules, the "Upper limit" ones and the one with "No detection" (but which should have been detected if they were there). There is also an extra column numeric column that just includes a flag for water detection (H_2O).

Chemical abundances
The dataset also includes some columns on chemical abundances of the host stars from GALAH and APOGEE. The APOGEE+GALAH dataset has been created by matching the datasets with the host stars in the exoplanet archive using their Gaia DR2 ID.

Note that the chemical abundance values are provided as is, and since GALAH and APOGEE use slightly different units this results in one column per dataset, for the same abundance ratio. **Note that the chemical abundance data is a subject of future work, and not all data that might be relevant has been included**. One thought is to use data from Gaia DR3 in the future.

GALAH file used: GALAH_DR3_main_allstar_v2   (Data model, X_fe columns)
APOGEE file used: APOGEE_allStarLite-r12-l33   (Data model, also mainly the _FE
                                                                          and ALPHA_FE col, for now)

Please refer to the *datapreparation.py* file to see which columns come from which dataset, or feel free to email/message me to discuss.

6. Setting up data columns in OpenSpace

The Settings menu also contains a button that opens a modal where you can select up to 64 columns to show simultaneously in the OpenSpace part of the tool. See image below
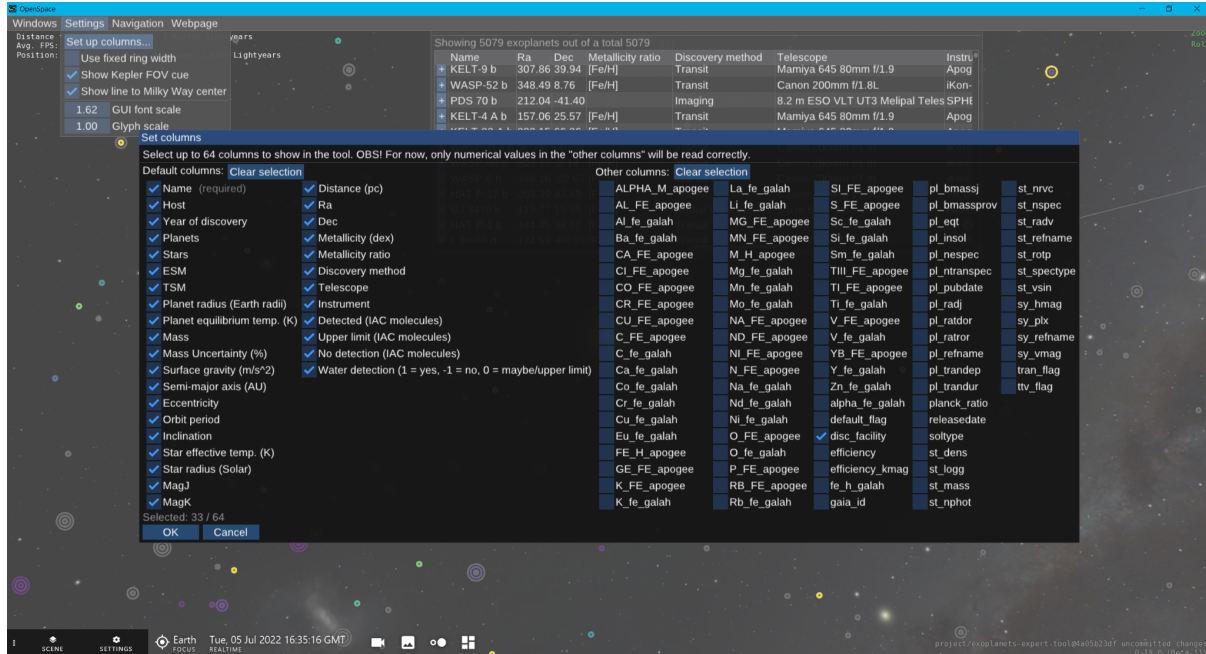

The leftmost part are some columns that the tool always reads from the data, and the rightmost part shows any other columns that are available in the CSV file generated from the *datapreparation.py* script.

7. The external webpage/visualization tool

Another way to visually analyze multiple parameters is to use the external webpage that comes with the tool. This can be opened in your browser of choice (Chrome or Firefox) through the "Webpage" menu in the top bar.
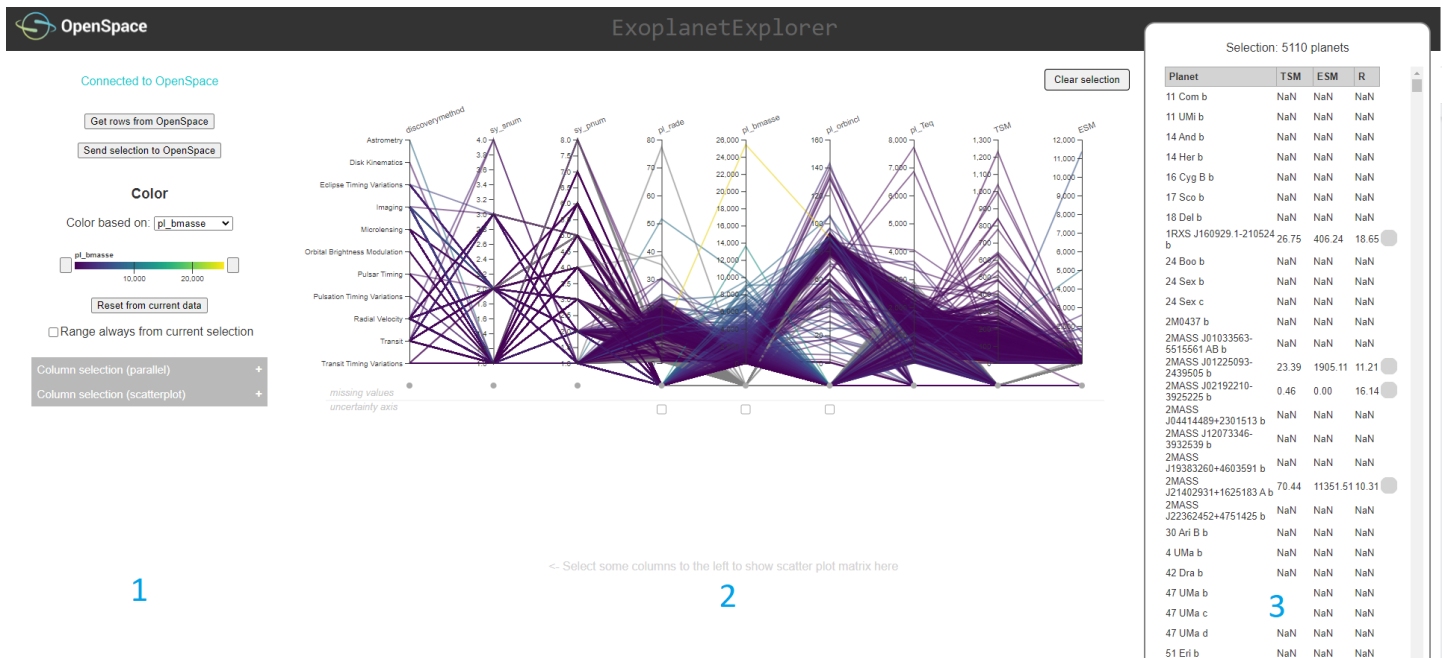
This page consists of three parts:

1. Left - a settings panel with options for color and what data parameters (columns) to show in the visualizations. Here it's also possible to send or fetch a data selection to/from OpenSpace, or control the connection in case it is lost.

2. Center - An interactive visualization view, which initially shows a parallel coordinate plot of the currently selected data (see separate document for a guide on how to read parallel coordinates). Each line corresponds to a planet in the dataset. Use the "Column selection" in the leftmost panel to decide what columns should show in the visualizations.

   Note that some lines are redirected to a point below the actual axes. These represent **missing values** in the data, and a line that passes through one of these points hence has no value for that specific column.

3. Right - An interactive and sortable list/table showing the currently selected planets

The center view (2) can also show a **scatterplot matrix** (a.k.a. **corner plot**) with some selected columns. To make that show, select some columns in the "Column selection (scatterplot)" part of the menu to the left.

7.1. OpenSpace connection and sending/getting data selection

When connected to OpenSpace, the upper part of the left panel (1) contains two buttons:

Connected to OpenSpace

Get rows from OpenSpace

Send selection to OpenSpace

- *Get rows from OpenSpace* - Clicking this button gets the currently selected data rows from the OpenSpace application and loads those planets into the webpage.

- *Send selection to OpenSpace* - Sends the current selection from the webpage (see "Interaction/filtering" below) to OpenSpace. The Filters->External filters in OpenSpace can then be used to show that selection in OpenSpace. That menu will also be updated to show the number of planets coming from the web page selection and the time the selection was last updated (see image below)

▼ External filters (?)

Use selection from website   Delete

Selection: 135 items
Last updated: 11:06:41.193

Override internal selection (?)
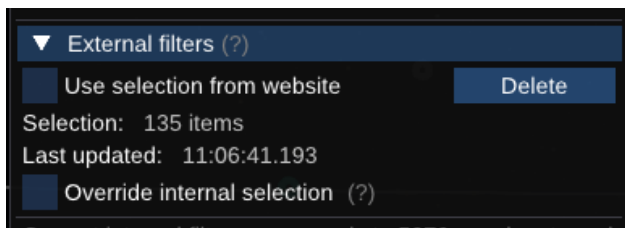
If the connection to OpenSpace is lost for some reason, a "Connect" button appears as well. This can be used to re-connect to OpenSpace.

7.2. Color mapping

Color

Below the buttons for getting/sending data is a part that controls the color of the lines and points rendered on the webpage. This includes a few settings:

Color based on: pl_bmasse   ⌄   **1.**

pl_bmasse

5,000   10,000   15,000   20,000   **2.**

Reset from current data   **3.**

☐ Range always from current selection **4.**

1. A dropdown menu where you can select what column to color based on

2. A legend that shows the current color mapping. For numeric columns, this also includes handles to increase/decrease the min/max range. Click the button and drag left-to-right to change the values.

3. A button to reset the min/max range based min and max value of on the current data on the page (does not account for the current filtering/selection)
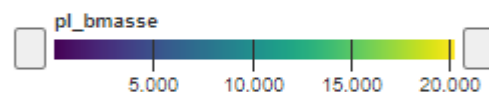
4. A checkbox that can be used to always update the color mapping based on the current selection. The min/max values will then be dynamically updated as you filter the data values in the parallel coordinates plot.

7.3. Interaction

The web page includes a few different methods of interaction:

- **Hovering** any line in the parallel coordinates, point in the scatter plot matrix, or row in the table will show what planet that represents and also highlight the same planet in all the other views.

- The **table can be sorted** based on any of the columns. Click a table header to sort decreasingly based on that value, and click again to sort decreasingly

- The axes of the parallel coordinate plot can be reordered. Click and drag on an axis header left-to-right to move the axes around. (This can be useful to show relations between values in different data columns)

- You can also double-click a header in the parallel coordinates or scatter plot matrix to quickly set the color mapping to use that data column.

In addition, the parallel coordinates plot includes interaction that can be used to filter the data on the page. The filtering feature is explained further in the next section.

7.4. Filtering - parallel coordinates

Finally, one of the main features of the web page is that the data can be filtered per axis in the parallel coordinates plot. If you hover over an axis, the mouse will change to a crosshair. That's when you can use the mouse to start filtering the data. On filtering, the other views (table + scatter plot matrix) will be updated to match the current selection.

To add a filter for an axis, click on the axis at the value where you want the filter to start, and hold and drag the mouse to where you want the range to end. This creates a box on the axis, and the data will be filtered so that only planets that have values within that value range are shown. The box can also be moved and resized to change the filtering. See demo here.

To remove a filter for an axis, click anywhere on the axis outside the box. It is also possible to use the "Clear selection" button to remove all filters for all axes at once.

It is also possible to control if **missing values** should be included or not, by clicking the circle below the axis that represents a missing value in the dataset. Click multiple times to change the behavior. The color of the circle is a cue on the current filtering for that axis:

Red	Filter out missing values, i.e. do not include planets that have missing values for this column

| Green	Only include planets that have missing values for this column (alternative interpretation: the lines must pass through this point to be included)
Gray	No missing value filtering applied

The effect of each stage is illustrated in this GIF. Also, note that a red/blocking filter is automatically created when adding an axis filter. Click the circle again to change the filtering behavior for the missing values.

Finally, the filters over all axes are combined to yield the resulting selection of planets. Meaning, that a planet will only be part of the selection if it passes all filters. See example in this GIF.

7.5. Uncertainty - parallel coordinates

The parallel coordinates plot includes some representations of the uncertainty values for the axes that have error columns. If a column has error information, a checkbox is rendered below the axis in the section, below the point representing missing values. The uncertainty information can then be presented visually in two ways:

1. Hovering over a planet in any of the plots will show an area around the line. This area shows the min and max extent of the error, as given in the Exoplanet Archive. See an example in the image below.

2. Clicking a checkbox beneath an axis makes another axis show up next to it. This shows the full range of the uncertainty given in a relative measure, as percentage of the corresponding value. This axis can then be used to filter the data the same way as any other axis in the plot, based on the percentual uncertainty.
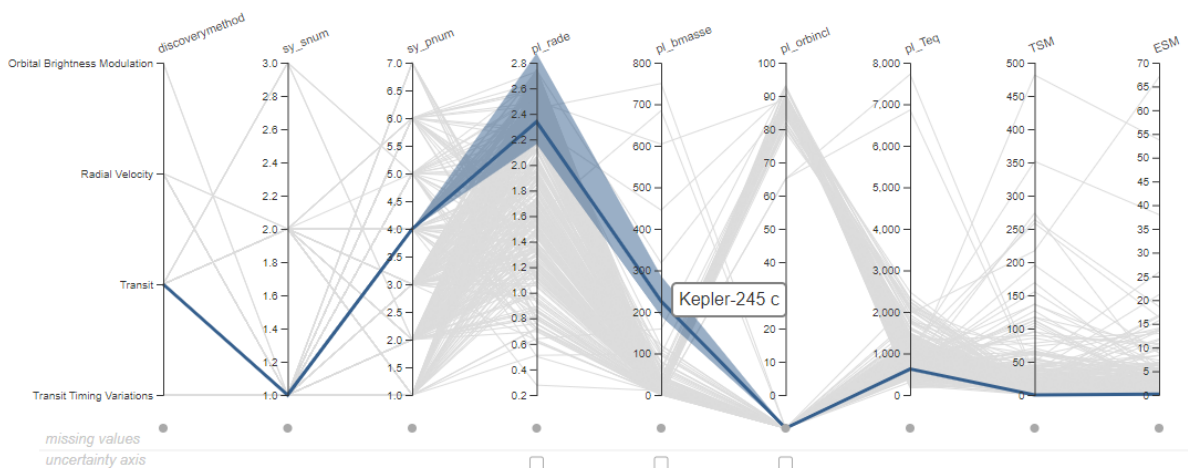
Example of uncertainty area around parallel coordinates line for Kepler-245 c

7.6. Scatter plot matrix/corner plot

Finally, the webpage includes a feature to pairwise investigate correlations between data variables using a scatter plot matrix (also known as a corner plot). To show this, select some columns in the "Column selection (scatterplot)" menu to the left on the page. This is essentially a collection of regular 2D scatterplots, structured in a grid so that multiple plots can share the same axis. An example with three columns is shown below.
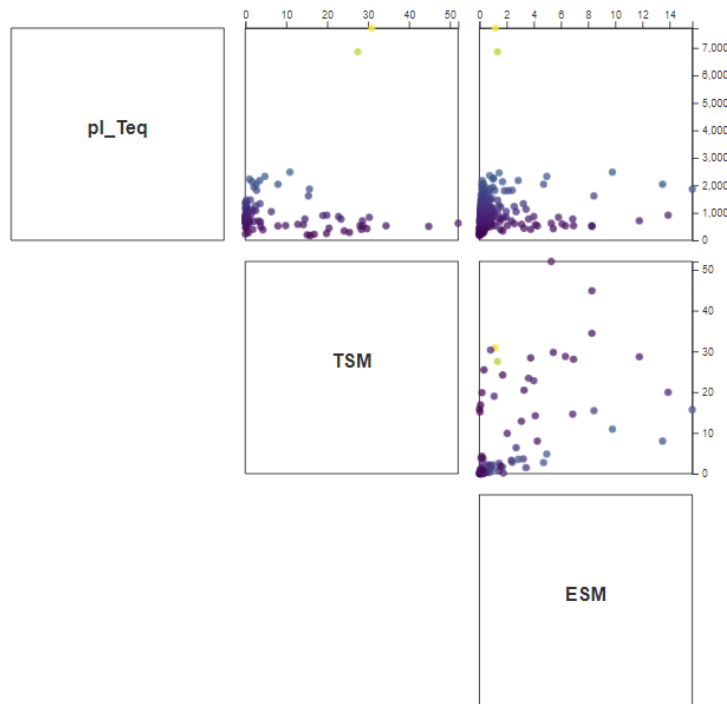
Scatter plot matrix / Corner plot with three columns.
The scale for the pl_Teq *column goes from 0 to about 7000 (top row),* TSM *from 0 to about 50 (second row and column) and* ESM *from 0 to about 16 (rightmost column).*

7.7. Caveats

- The webpage struggles from poor performance when all exoplanets are included. Thus, for now, we recommend that you start by making a limited selection in OpenSpace and fetch those data rows before interacting with the webpage. Up to about 1000 planets should work decently.

- The current filtering is sometimes cleared, for example when selecting new columns or when getting rows from OpenSpace.

- Sometimes buttons on the web page have to be pressed multiple times before the desired effect takes place.

- In general, if you encounter any weird behavior, try reloading the page