

# Exo-MerCat

a merged  
exoplanet catalog

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Groningen, the Netherlands





# Overview

- Online exoplanet catalogs: state of the art
- Raw statistics with the current datasets
- Known Issues: updates, errors, selection criteria
- Exo-MerCat: aims, description, efficiency
- Update workflow and VO resource
- Data Model for Exoplanets

# Catalogs Comparison

NASA EXOPLANET ARCHIVE

A SERVICE OF NASA EXOPLANET SCIENCE INSTITUTE

Home

About Us

Data

Tools

Support

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3,949

Confirmed Planets

05/02/2019

→

11

TESS Confirmed Planets

04/25/2019

→

564

TESS Project Candidates

04/23/2019

→

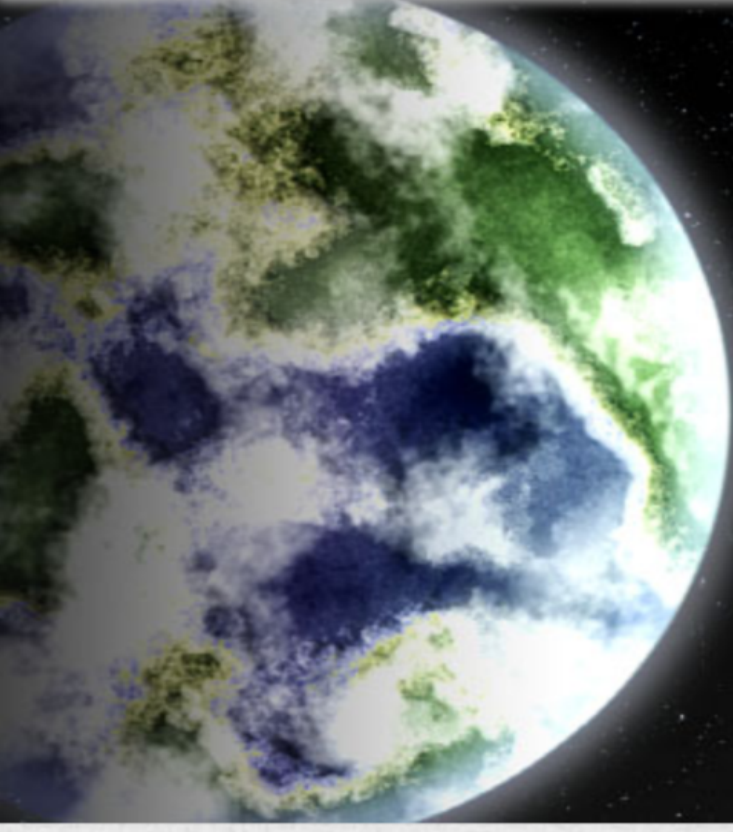
exoplanets.org


Exoplanets Data Explorer

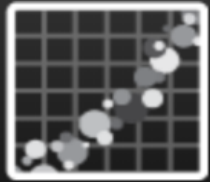
Methodology and FAQ


Exoplanets Links

California Planet Survey



Table

Plots

Search BETA

3237

EOD Planets

Planets with good orbits listed in the Exoplanet Orbit Database

26

Other Planets

Including microlensing and imaged planets

3263

Total Confirmed Planets

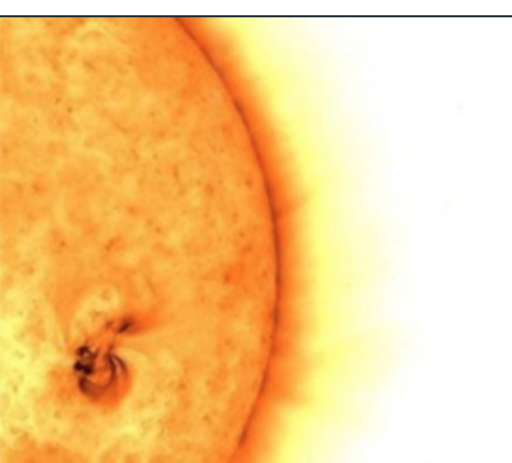
2485

Unconfirmed Kepler Candidates

5748

Total Planets

Confirmed planets + Kepler Candidates



Open Exoplanet Catalogue

an open source database of all discovered extrasolar planets

Fork me on GitHub

Catalogue

All extrasolar planets

Habitable zone planets

Planets in binary systems

Plots

Correlations plots

Statistics

Number of confirmed exoplanets	3504
Total number of planets (including Solar System objects and unconfirmed exoplanets)	3791
Number of planetary systems	2657


The Extrasolar Planets Encyclopaedia

Established in February 1995

Developed and maintained by the [exoplanet TEAM](#)

update : May 6, 2019 (4065 planets)

Please report any problems to [vo.exoplanet@obspm.fr](mailto:vo.exoplanet@obspm.fr)




All Catalogs

Filter, sort, export — arbitrary data manipulations with the Extrasolar Planets Encyclopaedia

3



Table 1. Features of the available catalogs.

Catalog	Features
NASA Exoplanet Archive (NASA) (Akeson et al. 2013)	<ul style="list-style-type: none"> <li>• Confirmed planets</li> <li>• Overview page for every confirmed planetary system</li> <li>• Data values sorted by reference</li> <li>• <math>\text{Mass} &lt; 30 M_J</math></li> <li>• Only peer-reviewed publications</li> <li>• No name change if confirmed</li> <li>• Provides pre-made histograms and graphs</li> </ul>
Exoplanet Orbit Database (ORG) (Wright et al. 2011; Han et al. 2014)	<ul style="list-style-type: none"> <li>• Confirmed and candidate planets</li> <li>• <math>M_P/M_\star &lt; 0.024</math></li> <li>• Peer-reviewed publications</li> <li>• High quality datasets</li> <li>• Focus on orbital measurements</li> <li>• Name changes if confirmation happens</li> </ul>
 No longer maintained	
Open Exoplanet Catalogue (OEC) (Rein 2012)	<ul style="list-style-type: none"> <li>• Open-source</li> <li>• XML-based, better visualization of systems</li> </ul>
Exoplanet Encyclopaedia (EU) (Schneider et al. 2011)	<ul style="list-style-type: none"> <li>• <math>\text{Mass or } M_{\text{Jini}} &lt; 60 M_J + 1 \text{ sigma}</math></li> <li>• Published, submitted, and announced references</li> <li>• Provides histograms and graphs tools, VO services</li> </ul>

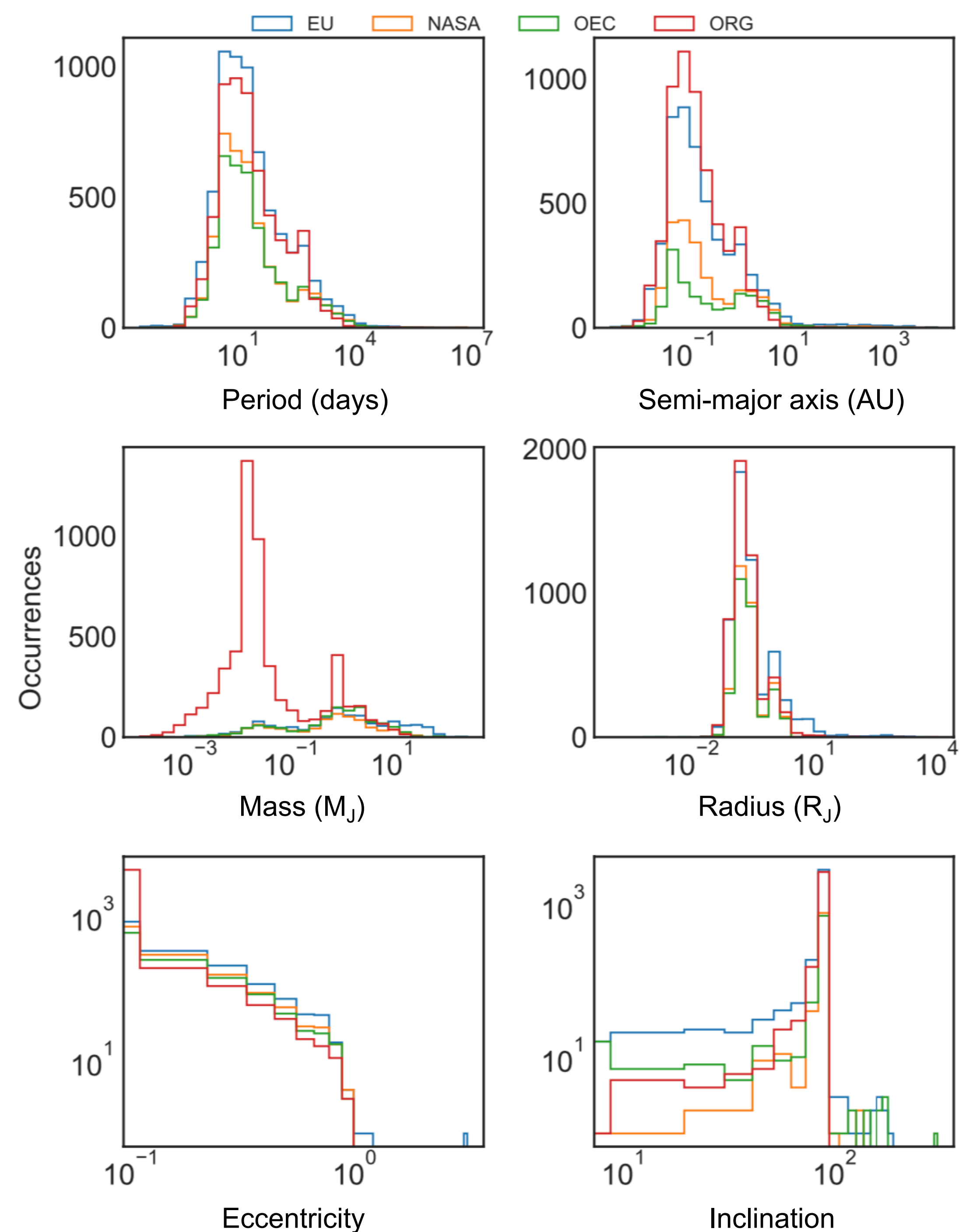
## Some issues appear!

- Nature of the reference source
- Status of the target
- Selection criteria
- Treatment of data

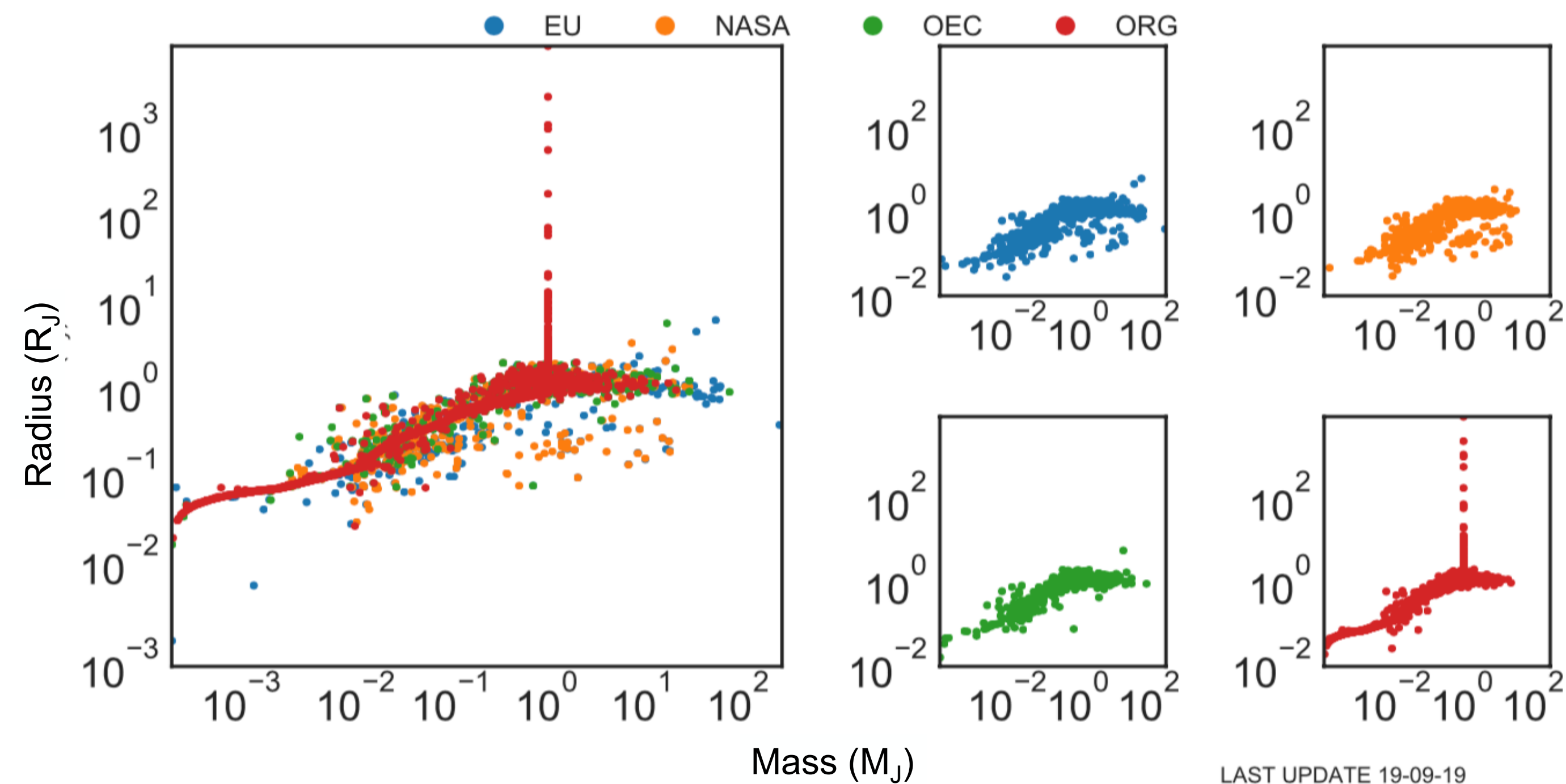


Differences in the available data. For example:

- **ORG: Theoretical mass values**
- **NASA: Dataset chosen from the same reference paper → less data**
- **OEC: Weird inclination values**
- **EU: Interstellar objects/comets ( $e > 1$ )**





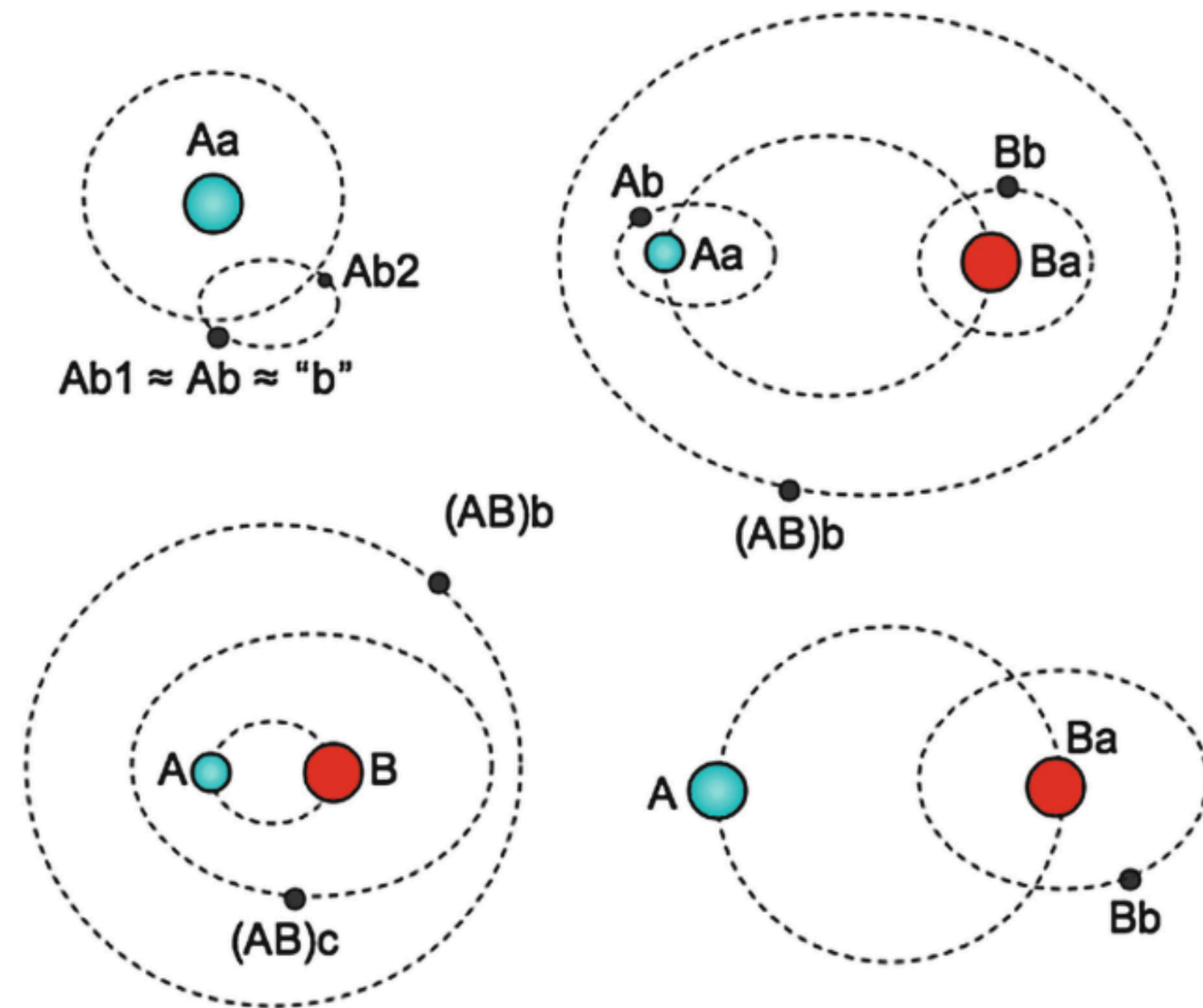


Query	NASA	ORG	OEC	EU
All planets	4055	5747	3793	6759
Confirmed	4055	3236	3674	4069
Candidates	0	2511	108	2681
False Positives	0	0	11	9
With radius	3142	4999	2917	5393
With mass	877	456	1120	1161
With minimum mass	769	29	273	1017
With period	3941	5733	3678	6517
With mass or minimum mass	1613	480	1393	2047
With mass and minimum mass	33	5	0	131
With mass and minimum mass and radius	10	2	0	43
With mass or minimum mass and radius	717	420	537	783
With mass or minimum mass, and radius and period	707	420	525	763
All systems	3027	4715	2795	5458

Yikes!



# Naming of Exoplanets

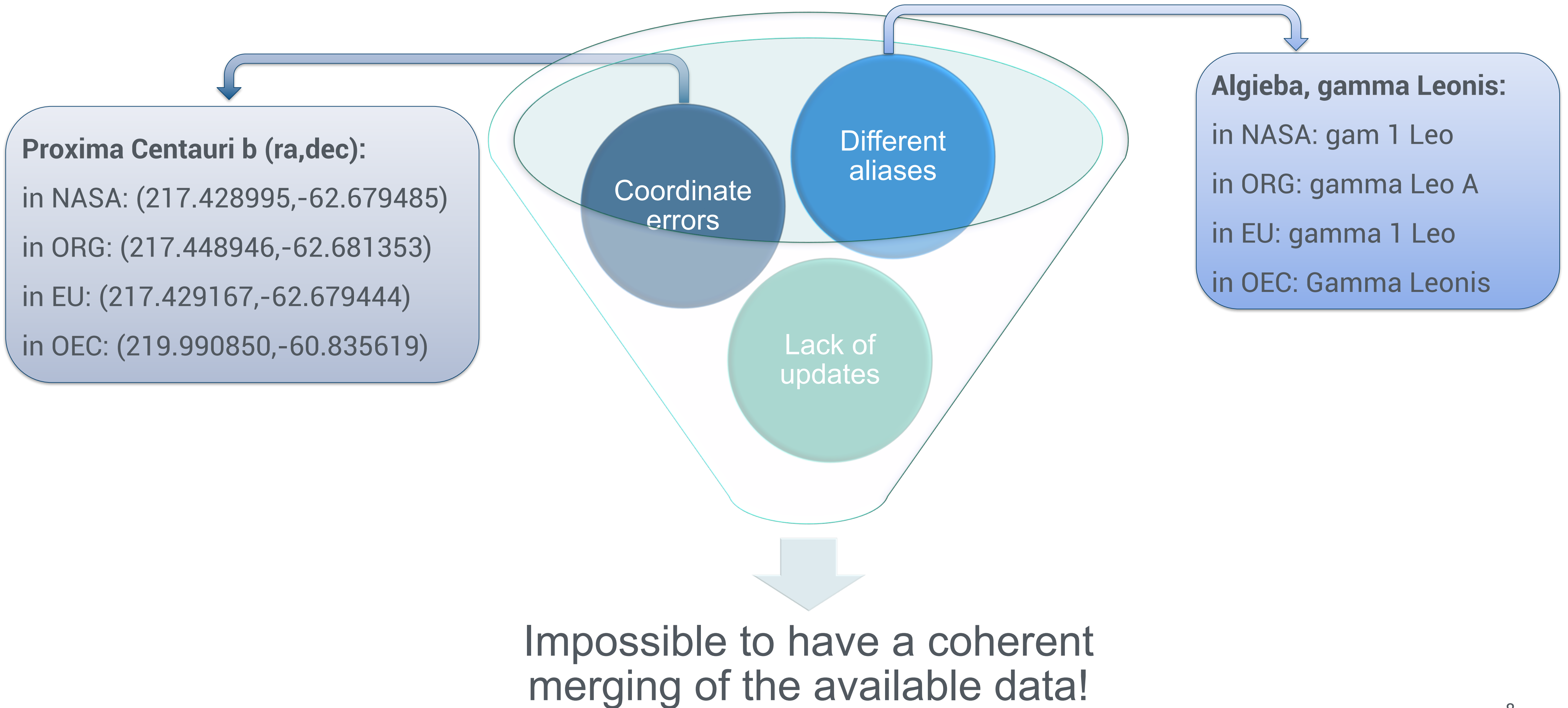


Examples of different exoplanet name suffixes in single and binary systems [ibid.]. *Top left:* a single exoplanet around a single star (e.g., 51 Peg) plus a moon. *Top right:* double star, each with a planet (e.g. HD 41004), plus a circumbinary planet. *Bottom left:* two circumbinary planets (e.g., NN Ser). *Bottom right:* a planet around the secondary star in a binary (e.g., HD 178911).

- Romans, Greeks, Arabs gave deity names to constellations, stars, and planets.
- **Johannes Bayer** (1572-1625) used Greek letters based on the relative brightness within a constellation.
- Later, stars known with the name that reflected their position within the survey catalog. **Different surveys** = the very same star could have different names depending on the catalog number of each survey.
- **Eclipsing binaries** = uppercase Roman letter. **Spectroscopic binaries (and planets)** = lowercase Roman letter.
- But sometimes known stars are later discovered to be gravitationally bound → **problems in the notation.**



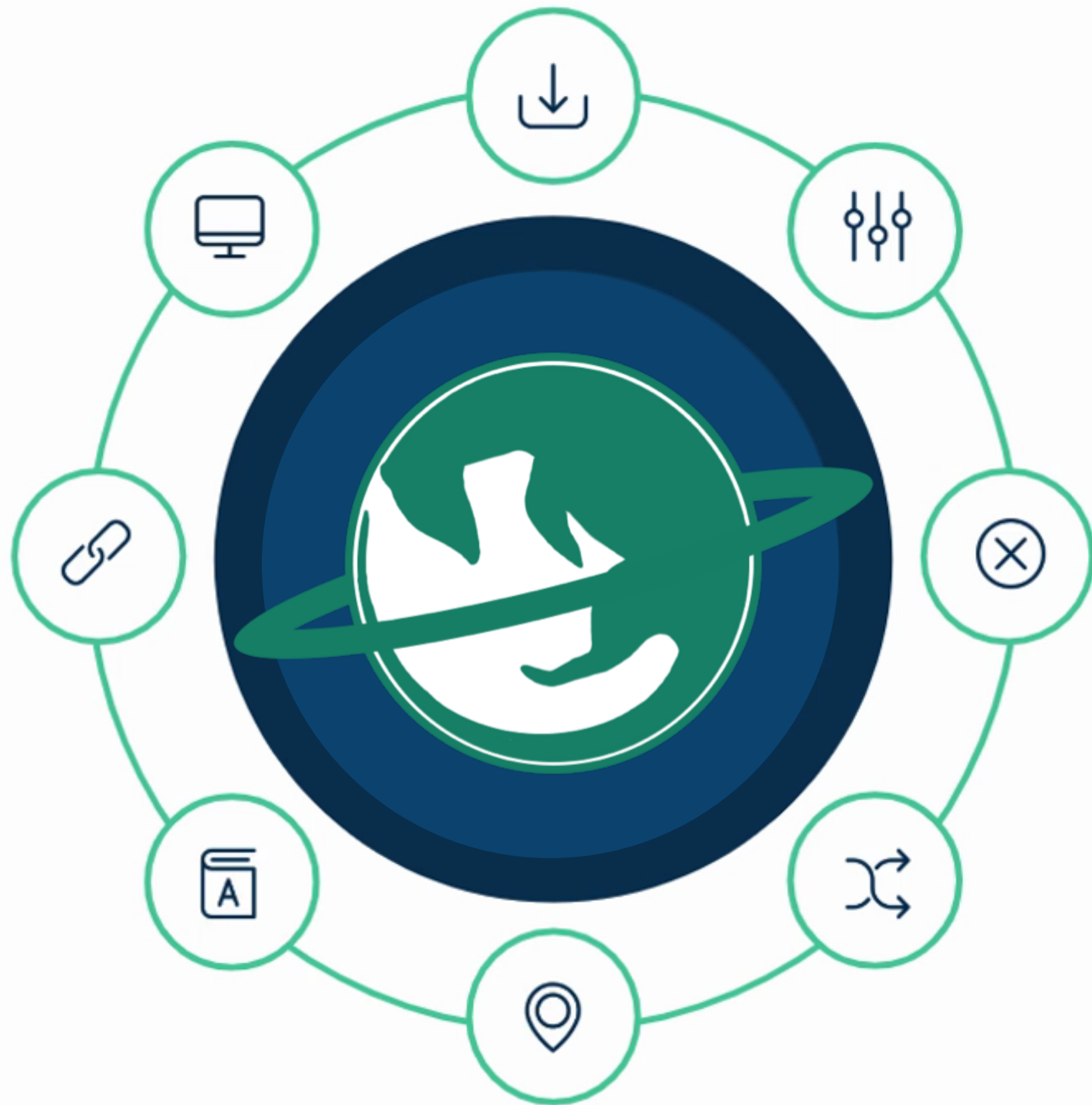
# Other issues





# Aims

- To provide **greater uniformity** among the databases;
- More effective **associations** among the datasets;
- To identify and **correct errors**, to warn the catalog maintainers;
- To provide a direct **link** with most **stellar sources** archives;
- To provide the user with an intuitive **Graphical Interface** to download and filter data.





# Initialization

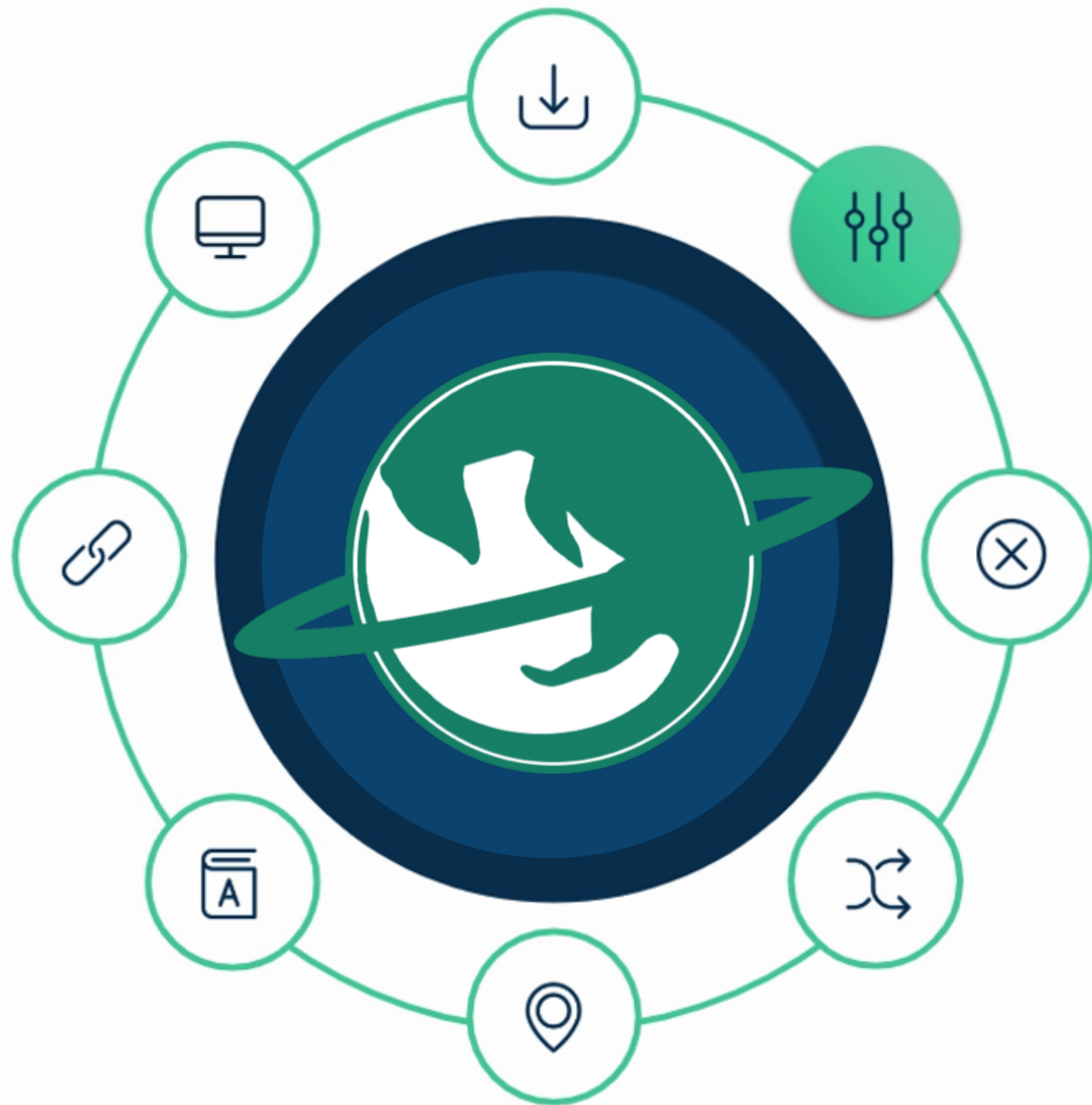
- Create a nested folder to contain all useful files;
- Use various **Virtual Observatory** tools to download raw datasets;
- `wget` command to access NASA/ORG database;
- `git` commands and an `*.xml` reader to access the OEC database;
- VO TAP service for the EU database.





# Homogenization

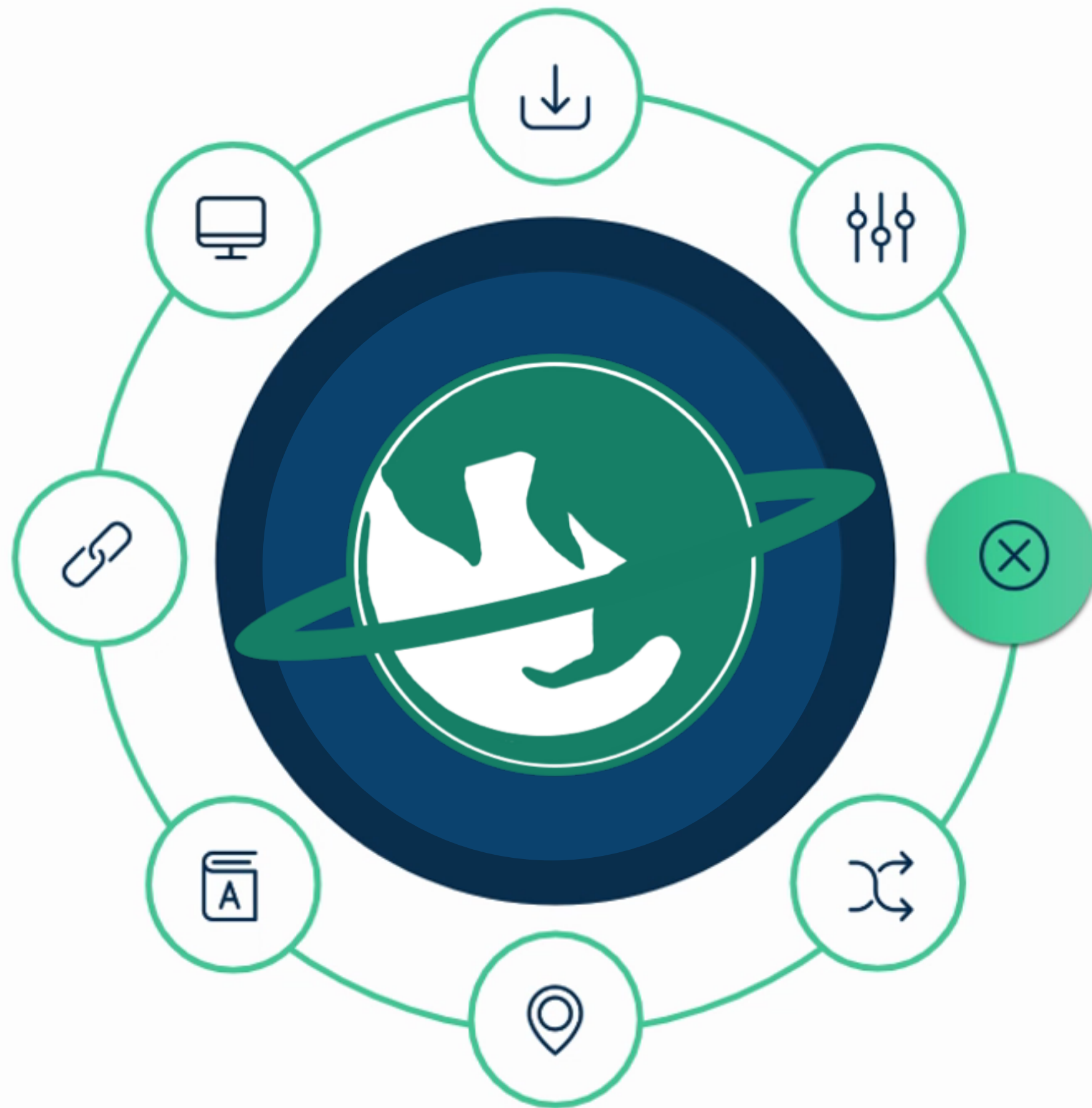
- Select specific, useful columns;
- Group stored **aliases**;
- **Remove of whitespaces** and homogenize name strings, following known notations and conventions;
- **Planet name = Host star name + Letter**. These values are stored separately;
- In the end... all four datasets looked very similar!





# Status check

- Download the **Kepler-K2 Objects of Interest** list with updated statuses from NASA Archive and Mikulski Archive for Space Telescopes (MAST);
- Compare the various entries and **update** if necessary the **status** of each planet (whether CONFIRMED, CANDIDATE, FALSE POSITIVE);
- If confirmed, **update names with default ones**.



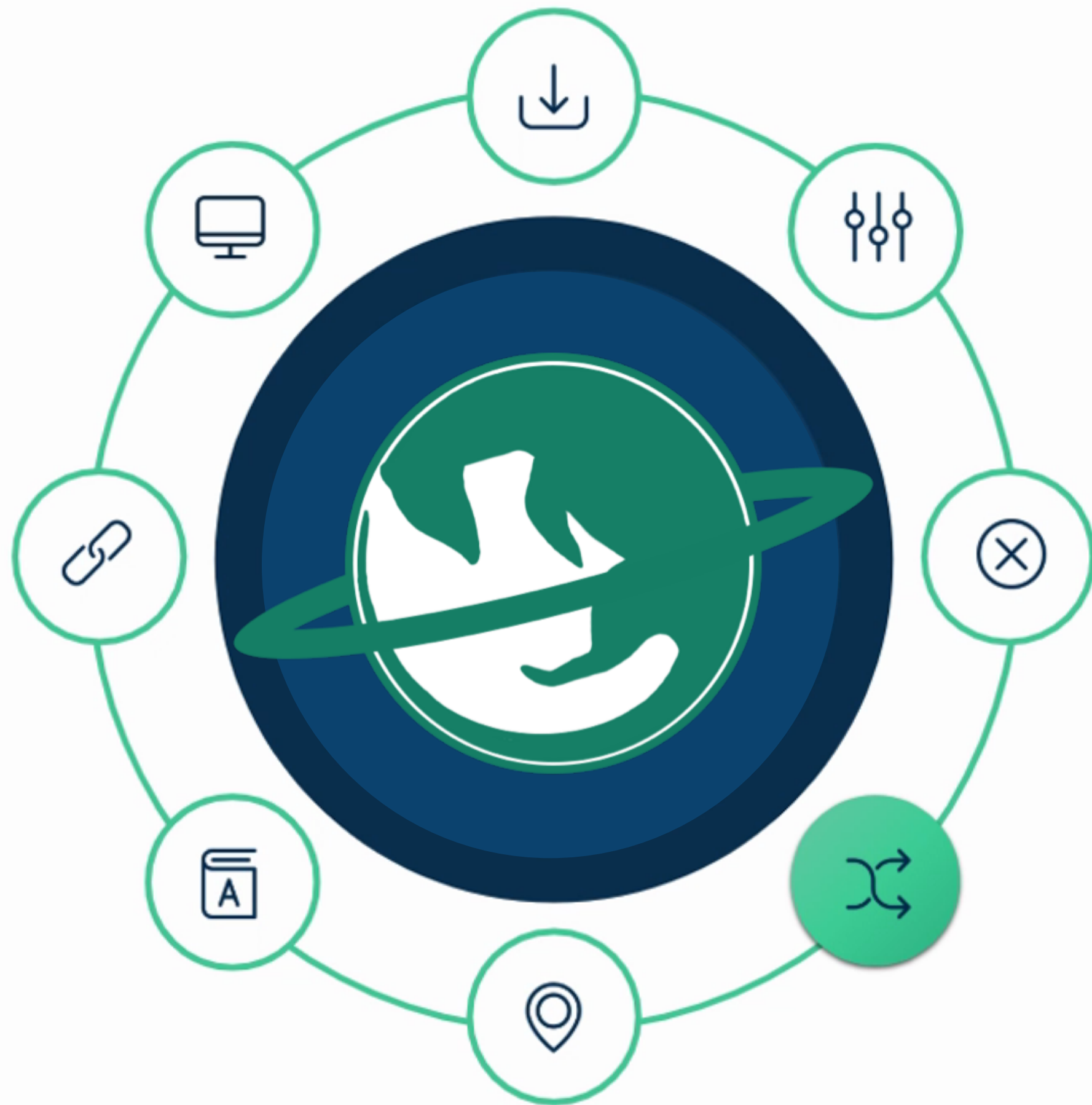
WORK IN PROGRESS

WORKING ON TESS CANDIDATES

# Alias check

Globally, we expect up to **four occurrences** for the same planet (one per catalog). But a planet could be labeled with an **alternative name**! Therefore:

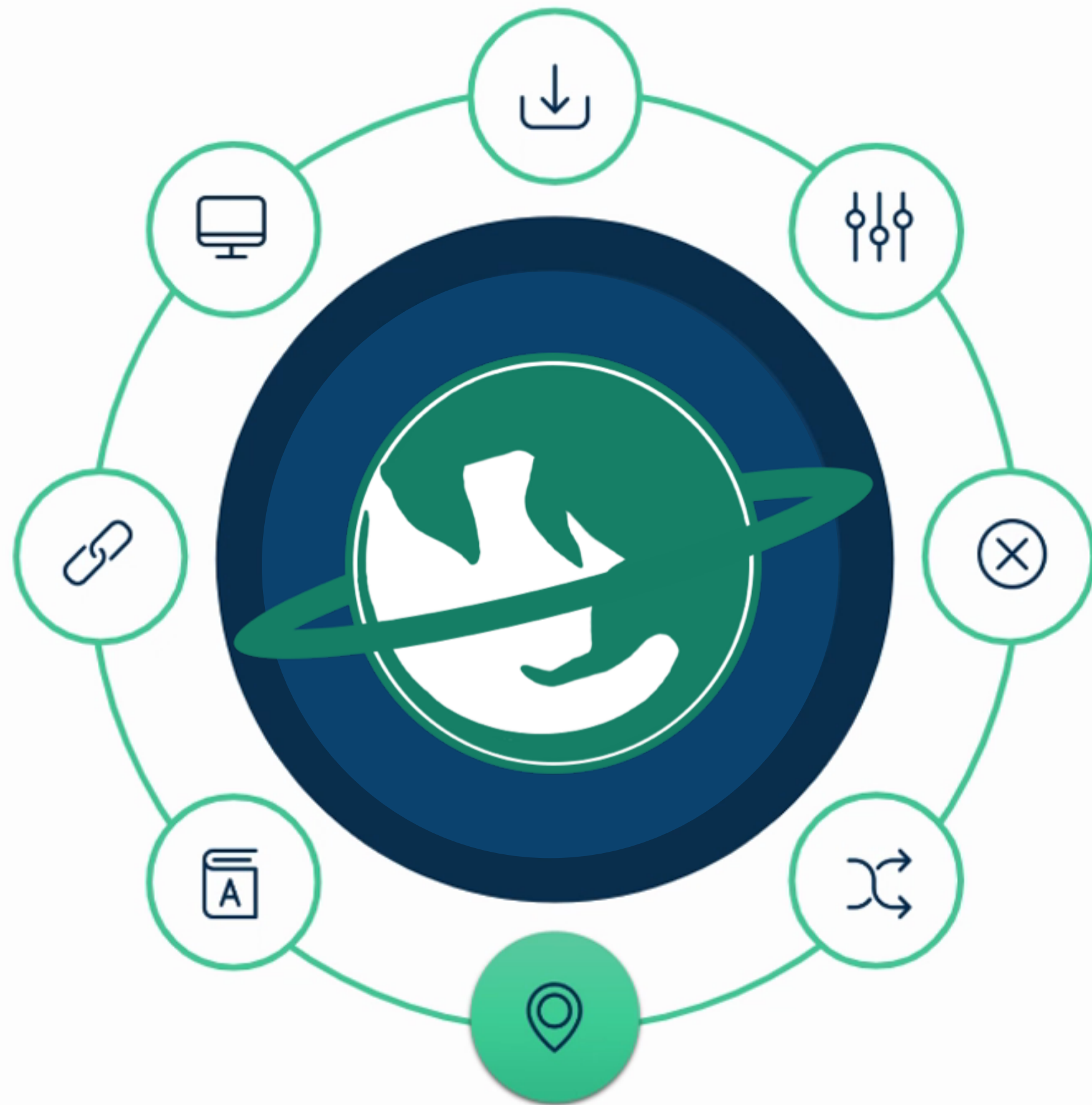
- SIMBAD TAP query for all known aliases for the host star.
- If one of the aliases for each star is found as a main identifier elsewhere in the databases, **uniform all occurrences**.



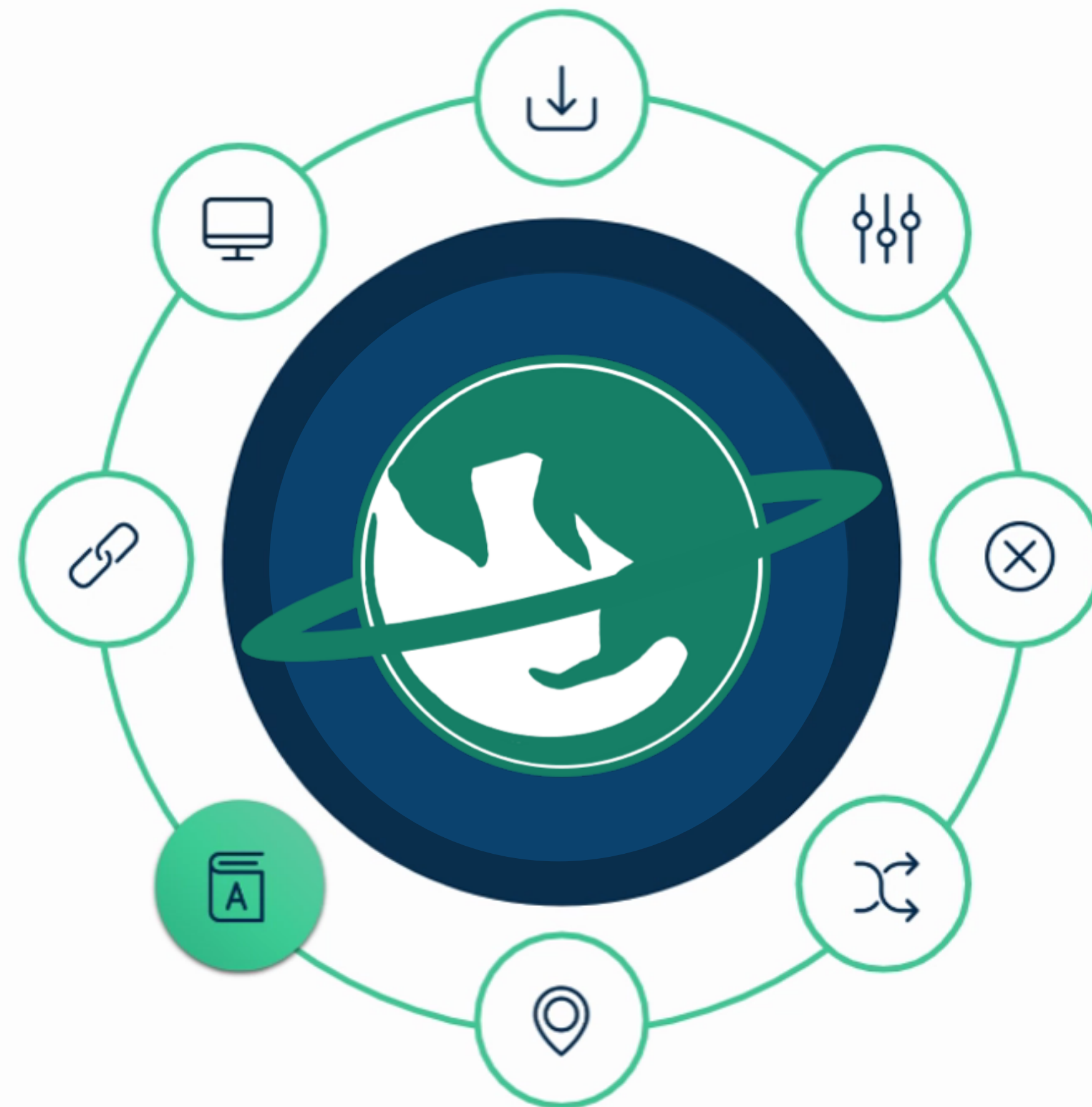


# Coordinate check

- For each host star, retrieve the **mode** of right ascension and declination in degrees. If one or more values are different from the mode, these are replaced by the mode itself.
- If no mode is found (i.e. there is no most common value), no replacement is made.
- **Warnings** are printed to be sent to the catalog maintainers in order to encourage a check on particular values.



# MAIN\_ID retrieval



#IDs

95%

96%

99%

100%

1. SIMBAD TAP query **host exact match**;
2. SIMBAD TAP query for **alias exact match**;
3. SIMBAD TAP query for **coordinate match** (tolerance 0.0005 degrees);
4. VizieR TAP query for **coordinate match** in Kepler-K2 input catalogs;
5. VizieR TAP query for **coordinate match** in GAIA DR2 catalog.



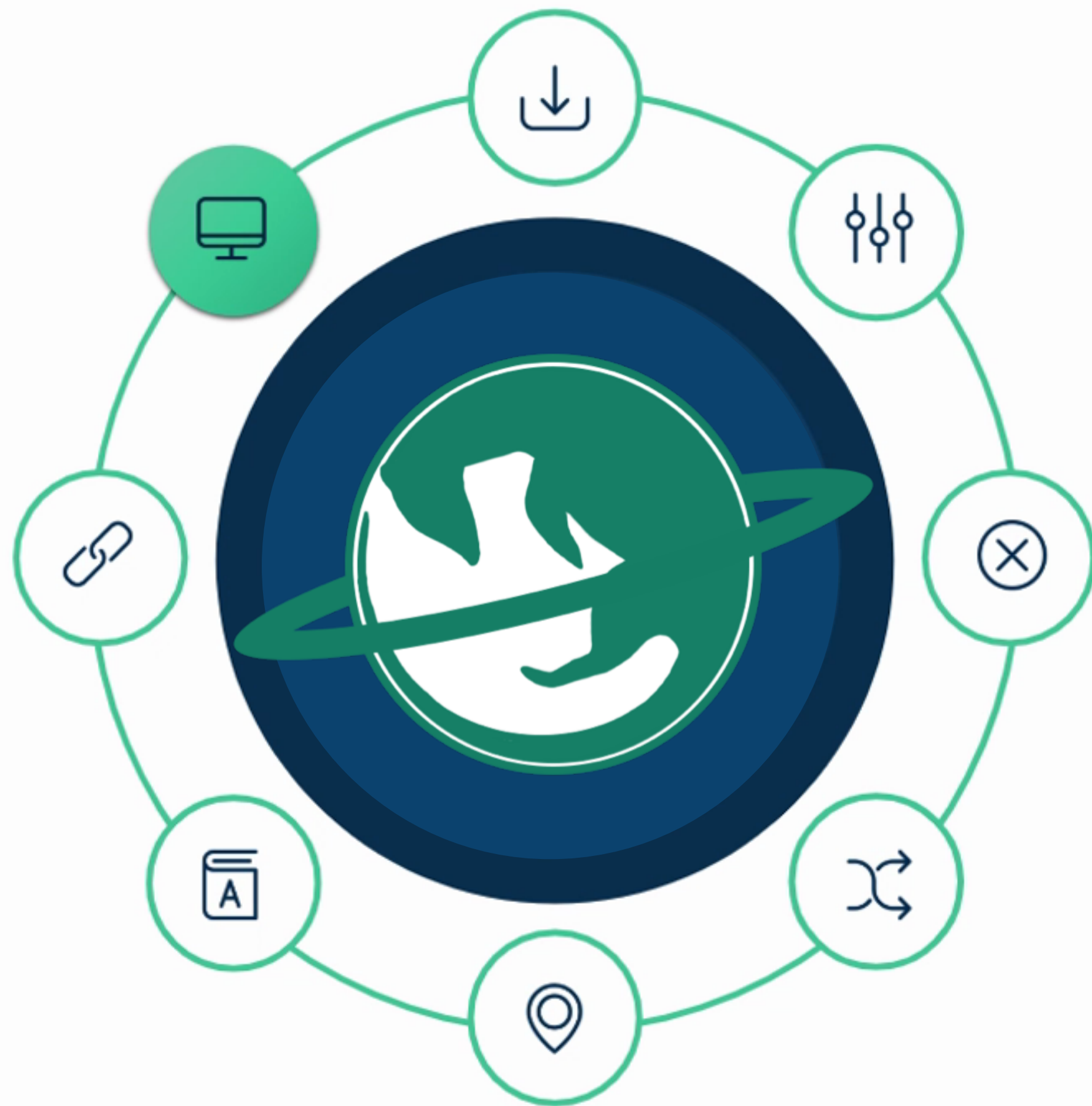
# Catalog retrieval

- Group by `MAIN_ID` and `Letter` (i.e. the name of the planet).
- For every parameter, choose the most precise dataset for each parameter (**smallest error**) with reference.
- Choose a **default name** for the planet, but **all aliases are stored**.
- Finally, each group is collapsed in a single line, which **may have measurements belonging to different papers and/or different catalogues**.



# Update workflow

- Periodic updates (once a week).
- Workflow described via the **Common Workflow Language**, useful for the versioning of the input files.
- Registered as a **VO resource** (IVOID: <ivo://ia2.inaf.it/catalogues/exomercat>)
- The catalog is **accessible by all VO-aware TAP-enabled applications** (using the service <http://archives.ia2.inaf.it/vo/tap/projects>)





# GUI

<https://gitlab.com/eleonoraalei/exo-mercat-gui>

An open-source Graphic User Interface is available to **directly download** the EMC catalog and to **filter** data, as well as to make some **plots**.

Parameter

MINIMUM

MAXIMUM

Unit

☐ only confirmed

Mass

Any

Any

M\_J

☒ Msini

☒ Mass

Radius

Any

Any

R\_J

Discovery Method

☒ All

Period

Any

Any

days

Radial Velocity

Transit

Astrometry

Imaging

Microlensing

TTV

Pulsar Timing

Other

Semi-major axis

Any

Any

AU

Eccentricity

Any

Any

Inclination

Any

Any

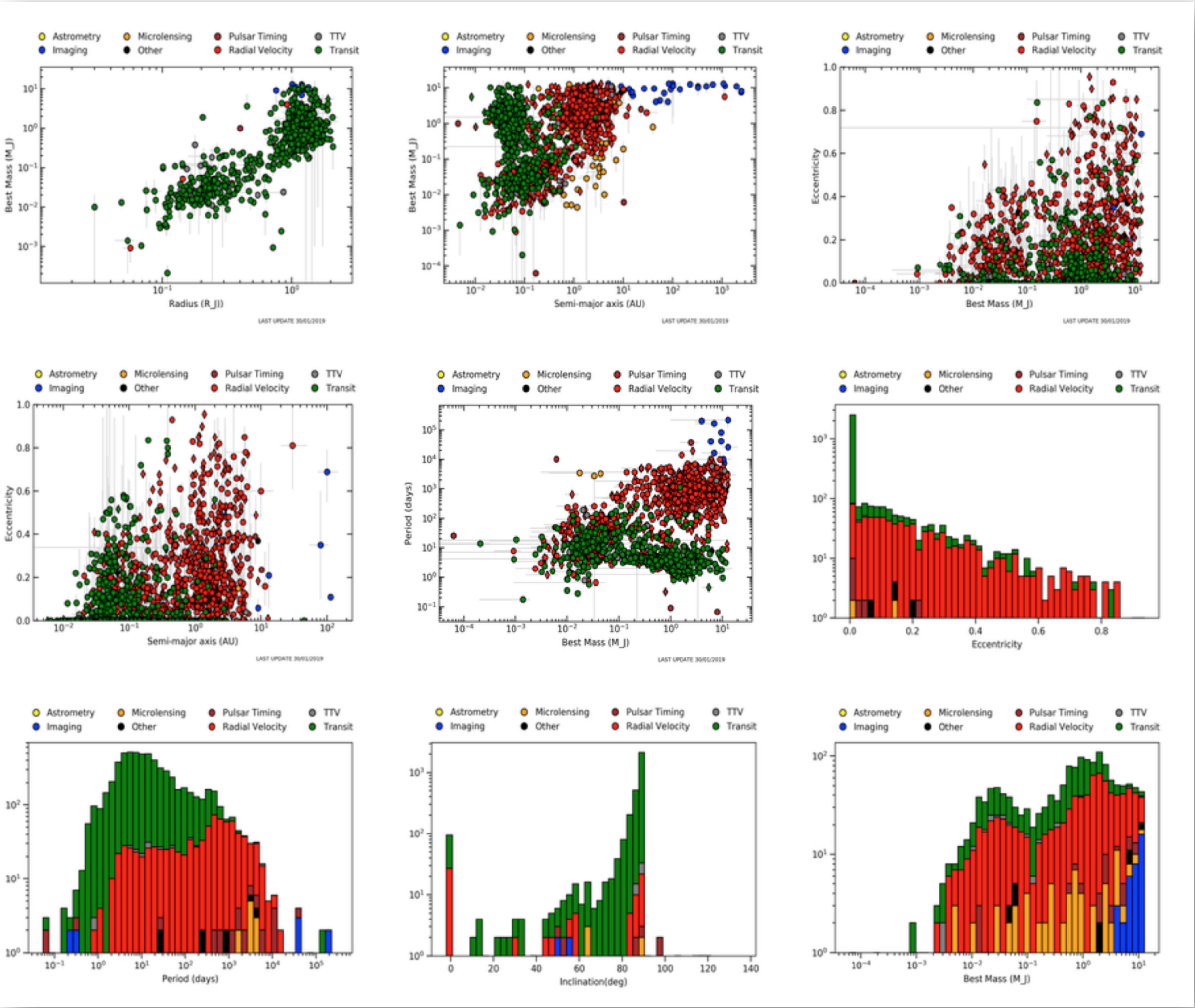
degrees

Folder Name

20190509/

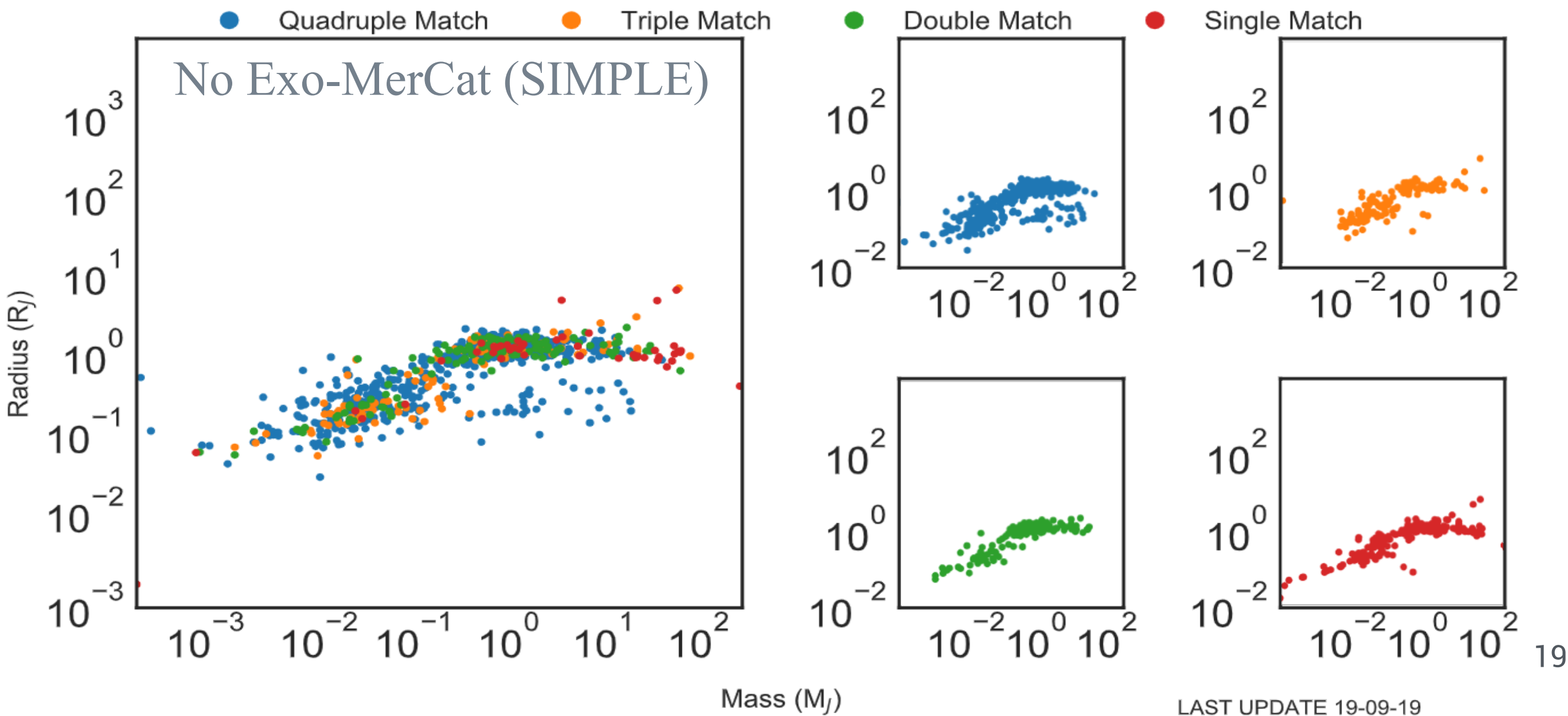
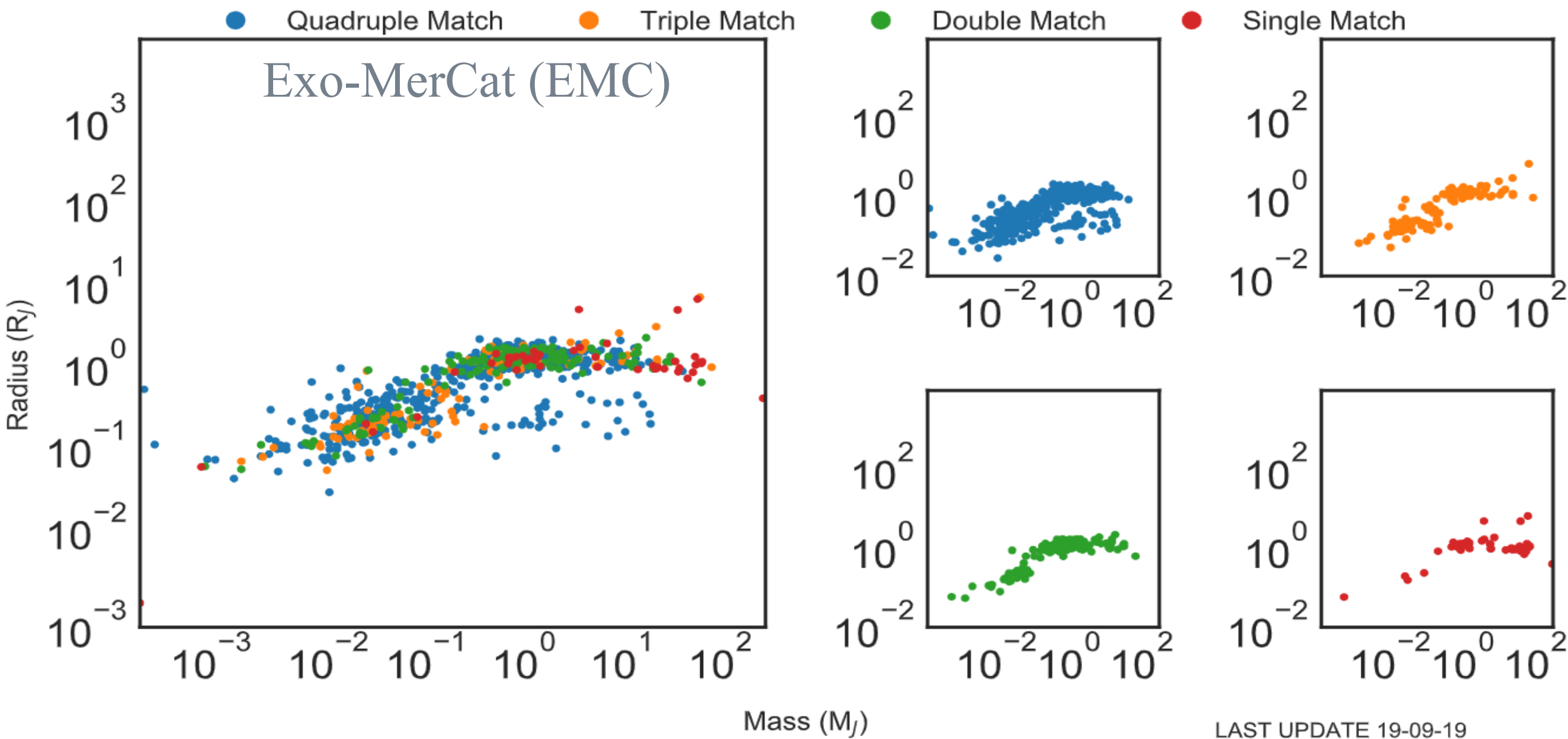
Advanced Plot

Plot



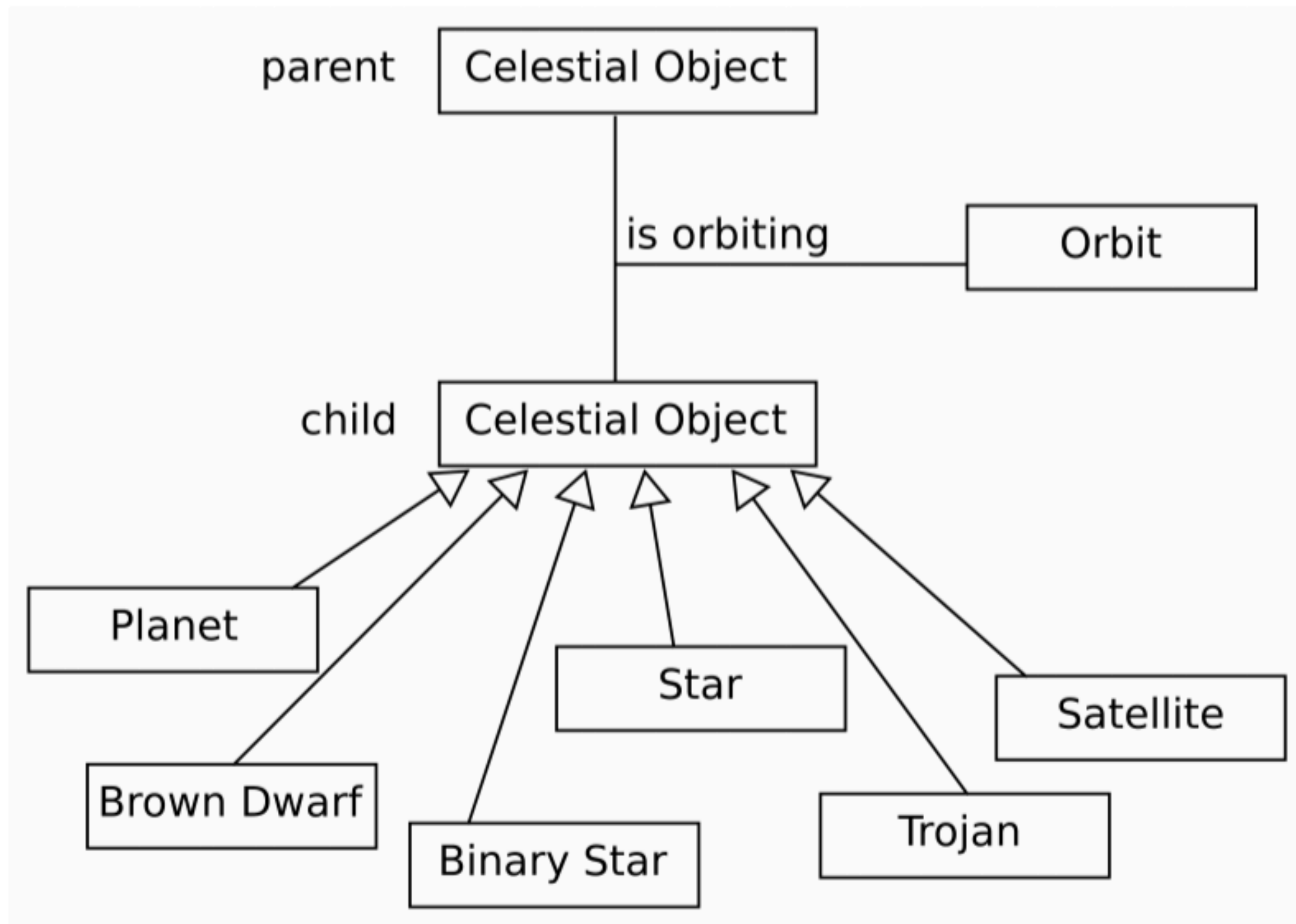
# Performances

Sample	EMC RUN	SIMPLE RUN
All Planets	7481	10185
All Confirmed/Candidate Planets	7002	10166
Quadruple Matches	3194	2929
CONFIRMED	3131	2901
CANDIDATE	62	28
FALSE POSITIVE	1	0
Triple Matches	362	437
CONFIRMED	299	412
CANDIDATE	55	24
FALSE POSITIVE	4	1
Double Matches	2414	581
CONFIRMED	446	525
CANDIDATE	1962	53
FALSE POSITIVE	6	3
Single Match	1500	6238
CONFIRMED	341	1041
CANDIDATE	691	5182
FALSE POSITIVE	468	15

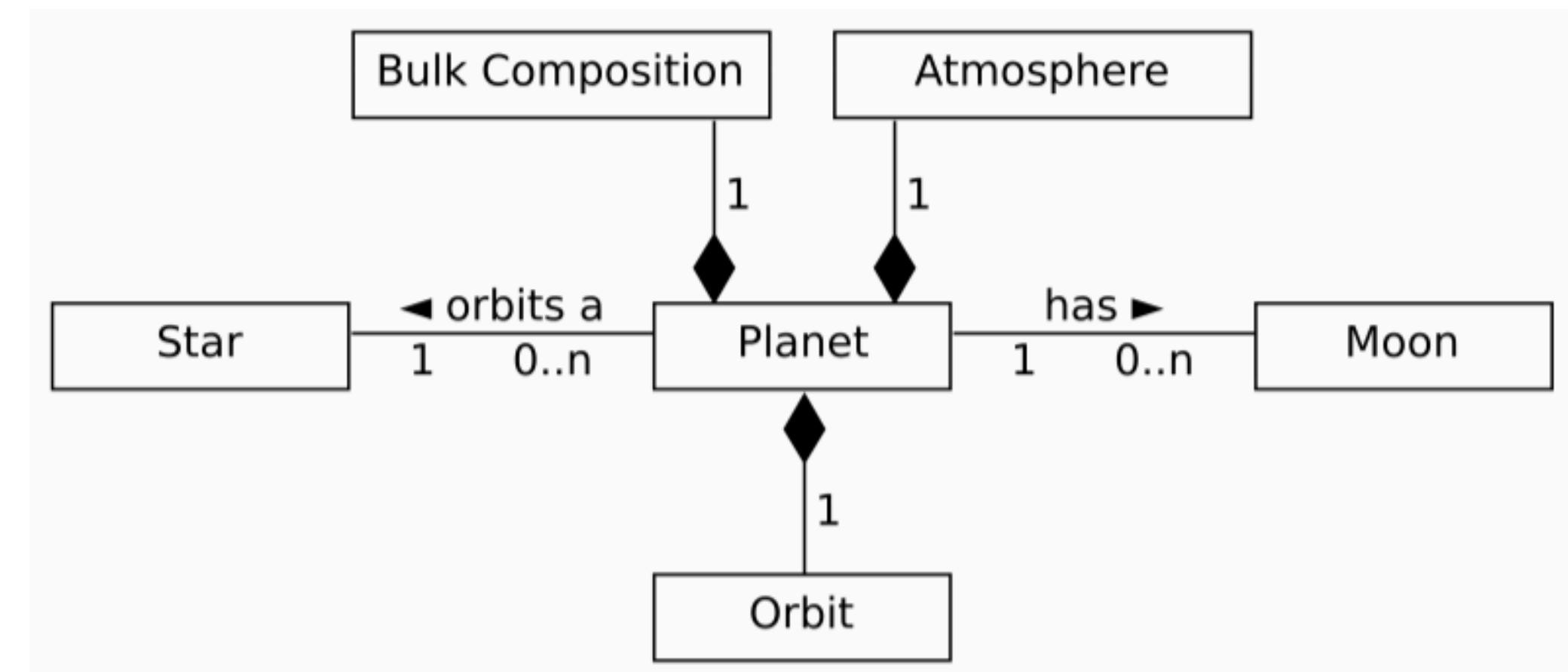




# Data Model for Exoplanets



Molinaro et al., ADASS XVIII



- First attempt to build a Data Model for Exoplanets;
- To be linked to the available IVOA DMs;
- Easily extensible for exo-moons, trojans, brown dwarfs;
- Link to data, archives, observations.



# Conclusions

- **Exo-MerCat** aims to standardize, correct and collect the most precise data from all available archives.
- It allows an easy **statistical analysis** of the current sample of exoplanets by reporting the updated status, the source catalogs, and the reference papers for each parameter. A **GUI** is provided to filter data, make easy plots and histograms.
- It is a **VO resource** accessible through VO-aware applications and a direct link to most famous stellar catalogs is provided.
- **To-do list**: possibility to query for one or more versions of the catalog; stellar datasets retrieval.
- But a standardization for exoplanet-related data is due! A new **Data Model** for such data needs to be developed.



Thank you!