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Using the exoplanetary database to visualise and analyse the properties of exoplanets

(approximate duration 1h30)

Explore the exoplanet.eu website:

1. Go to the "plots" tab on the exoplanet.eu site and use the appropriate tool to produce a histogram of the number of exoplanet discoveries over time.

2. Explain the variations observed. If necessary, you can use the Internet to find the dates of certain missions or instruments.

1995: The discovery of 51 Pegasi b, the first confirmed exoplanet orbiting a Sun-like star, 2009-2018 : NASA's Kepler mission revolutionised the search for exoplanets. Kepler has discovered more than 2,600 exoplanets, with a notable peak in discoveries between 2014 and 2016 Since 2018: The launch of the Transiting Exoplanet Survey Satellite (TESS) has continued to increase the number of discoveries, focusing on the stars closest to Earth

3. Use the histogram tool to analyse the spatial distribution of stars hosting exoplanets. What do you conclude?

By displaying the "declination" and then "RA" coordinates, we can see that the distribution is isotropic. Exoplanets are everywhere!

4. Explore the mass histogram. Comment on the minimum and maximum limits. The mass distribution shows an increasing number of planets as the mass decreases. Is this real? Activate the log scale to "zoom in on small values", and change the mass unit to Earth masses. What happens around 30 Earth masses?

- The upper limit of the histogram is linked to the definition of the catalogue, which is based on mass. Objects less massive than 60 Jupiter masses (MJ) are entered in the catalogue, or at least those whose lower limit of the mass error bar is less than 60 MJ (e.g. 70 plus or minus 20MJ).
- the more massive objects are brown dwarfs and stars. The population of objects between 13 and 73 MJ most probably contains a mixture of brown dwarfs and planets -.
  >art37].
- The lower limit of the histogram, the least massive planet, is defined by the sensitivity of the instruments. This limit will decrease as increasingly powerful instruments detect lighter planets.
- The mass distribution shows an increasing number of planets as mass decreases. This is a real trend, since all detection methods tend to detect massive planets more easily. There are actually many more low-mass planets than massive planets.
- By activating the log scale and units in terrestrial masses, the histogram shows a dip at around 0.1 Jupiter masses (30 terrestrial masses). This dip is not a bias, since it persists when we limit ourselves to a single detection method, transits or

radial velocities. This could be the boundary between telluric ?and gaseous planets.

5. Explore the histogram of the semi-major axes. Where are the most distant exoplanets detected? Put it into perspective in relation to the distances in the Solar System. Where are most of the planets discovered? Justify this value with a quick calculation.

The histogram extends to over 100,000 AU. For comparison, the farthest planet from the Sun is 30 AU, and the most distant space probes have only recently exceeded 165 AU. Exoplanets beyond 100 AU from their star have all been detected by direct imaging. It should be noted that it is then difficult to be sure that the planet detected is gravitationally linked to the star.
Most of the planets are less than 10ua from their star. If we play around with the detection methods, we can see that this bias only concerns planets detected by transits or radial velocities. These indirect methods require us to follow the movement of the star for at least one period of the planet. Since the search for exoplanets began 30 years ago, indirect methods have only been able to detect planets with periods of less than 30 years. Kepler's 3rd law can be used to calculate that this period corresponds to a semi-major axis of $30^{2/3}$= 10 AU.

6. Explore the histogram of eccentricities. Any comments?

- Several exoplanets have exactly zero eccentricity. These are planets for which we have no information about the shape of the orbit, which is therefore assumed to be circular (e=0).

- We also note that the distribution of eccentricities is decreasing, but that there are still many planets with very eccentric orbits. With an eccentricity of 0.2, the planet will be one and a half times further from its star at its greatest distance (apocentre) than at its greatest proximity (periapsis).

- If we compare them with the planets of the Solar System, we can see that many exoplanets have much more eccentric orbits than the planets of the Sun:

Mercury: 0.2 - Venus: 0.007 - Earth: 0.02 - Mars: 0.09 - Jupiter: 0.05 - Saturn: 0.05 - Uranus: 0.05 - Neptune: 0.004

7. Use another tool on the exoplanet.eu website to produce a figure showing all the exoplanets known to date, classified by distance from the star (x), mass (y) and eccentricity (variable size).

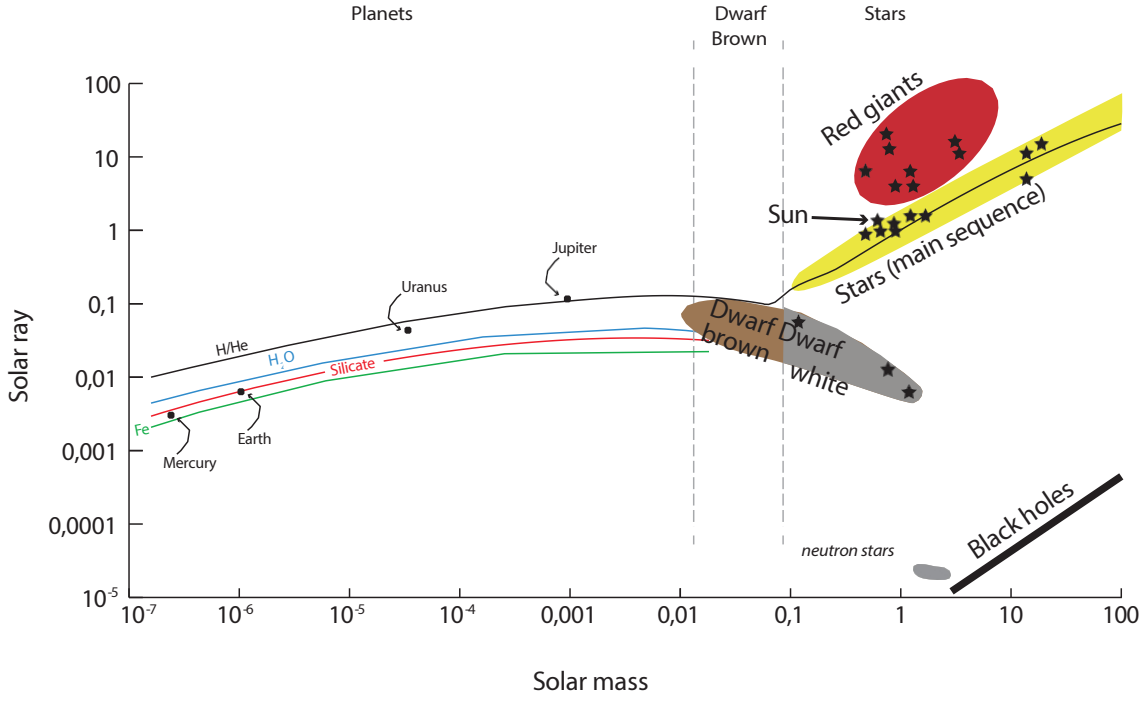
- Locate the planets in the Solar System on this figure, as well as 51 Peg b (a=0.05UA; m=0.47 $_{MJ}$) and Kepler 10 b (a=0.017UA; m=4.6 $_{MT}$).
- Find the different families of exoplanets presented in the course.

Zoom in to see the 2 planets more clearly and use the mouse to display the grid of coordinates to see the targets more clearly!
The different families: hot Jupiter; super-Earth; warm Jupiter,...

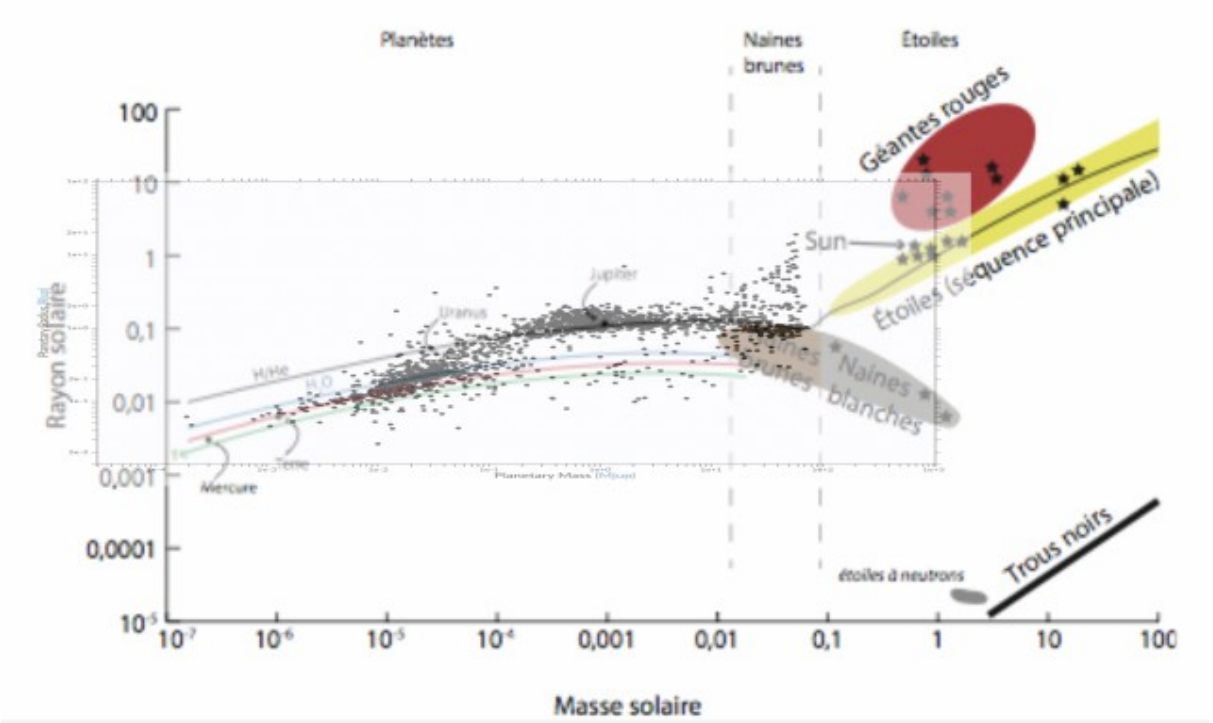
8. Explore the Mass - Radius diagram, in log-log coordinates and in Earth units. How are planets of Earth radius dispersed? The following diagram shows all the celestial objects and compares them with material densities. We can see that the Earth and Mercury are compatible with rocky objects. Any comments?

Remember that the radial velocity method gives information about the mass but not the radius, and the transit method gives the value of the radius but not the mass. You need to use both methods to access both parameters.

Although, overall, we can see that the mass of the planets increases as their radius increases, there is enormous dispersion. Planets with a radius of 1 Earth are scattered between 0.7 and 30 Earth masses. If we add the error bars, we can see that some of this dispersion is due to measurement errors, but some of it is real and reflects objects of extremely different densities. For example, the planets in the solar system (black dots below) are much less dispersed.



The diagram above is superimposed on the data. To do this, assume that one solar ray is worth 10 Jupiter radii and that one solar mass is worth 1000 Jupiter masses. Brown dwarfs are between 13 and 60 M_J. The densest objects are at the bottom right of the diagram (e.g. black holes).



9. Display the diagram Periods - Semi-major axes, in log-log coordinates. What does it show? Explain the dispersion of the points

   It shows a relationship of proportionality between the logarithm of the semi-major axis of the orbit, **a** , and the logarithm of the orbital period, P. This is Kepler's third law:

   P^2/a^3= cste expressed as:2*log(P)=3*log(a)+C

   This law is used to deduce the value of the semi-major axis of an exoplanet's orbit, from the measurement of the period of revolution and knowledge of the star's mass. The dispersion of the points is due to the dependence of the constant on the mass of the host star.

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