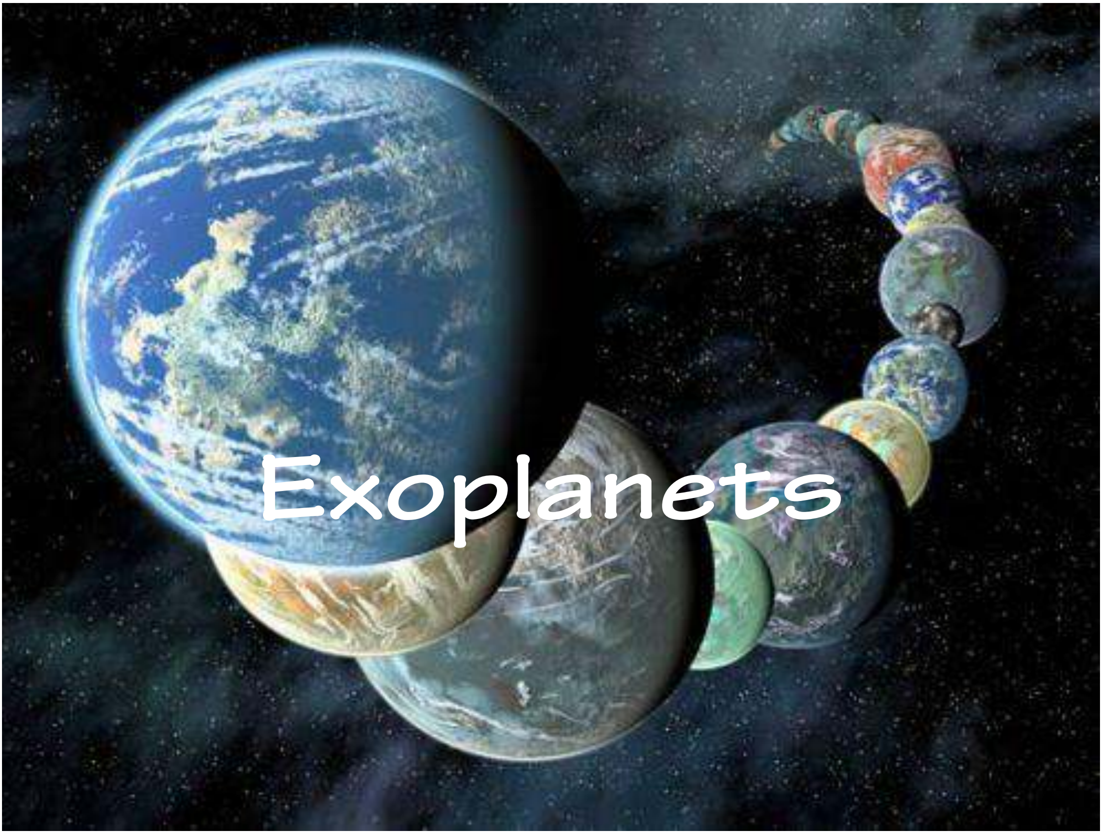
The Universe in my pocket



Exoplanets

No. 8

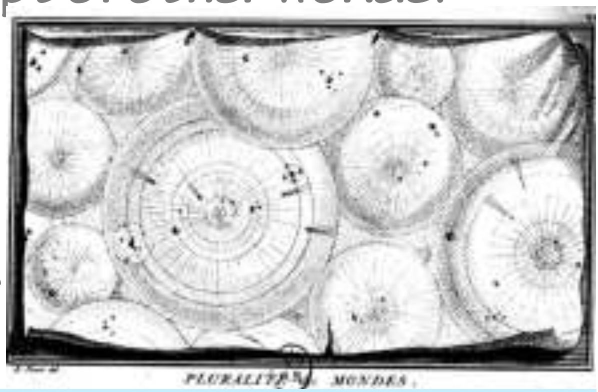
Jean Schneider
Grażyna Stasińska

Paris Observatory

The idea that ‘other worlds’ can exist beyond our Solar System was suggested by the Greek philosopher Epicure, 2,300 years ago.

In 1584 the philosopher Giordano Bruno argued that stars are suns, just like ours.

In the XVIIth and XVIIIth centuries, many scientists and philosophers, such as Charles Huygens and Immanuel Kant, further developed the concept of other worlds.



A drawing representing ‘the plurality of worlds’ as imagined by the French writer Fontenelle in 1686.

A color version of an engraving from a book published in 1888 by Camille Flammarion. It depicts a pilgrim discovering another world.

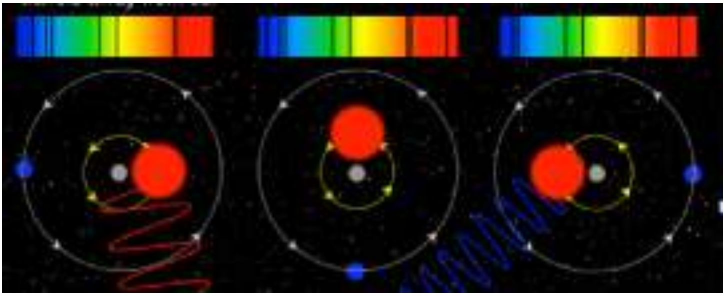
The first attempts by astronomers to detect planets around other stars were in the late1930s, but until 1989 there were only false alarms.

Why search for exoplanets ?

There are about 100,000,000,000 stars in our Galaxy, the Milky Way. How many exoplanets – planets outside of the Solar System – do we expect to exist? Why are some stars surrounded by planets? How diverse are planetary systems? Does this diversity tell us something about the process of planet formation? These are some of the many questions that motivate the study of exoplanets.

Some exoplanets may have the necessary physical conditions (amount and quality of light from the star, temperature, atmospheric composition) for the existence of complex organic chemistry and perhaps for the development of Life (which may be quite different from Life on Earth).

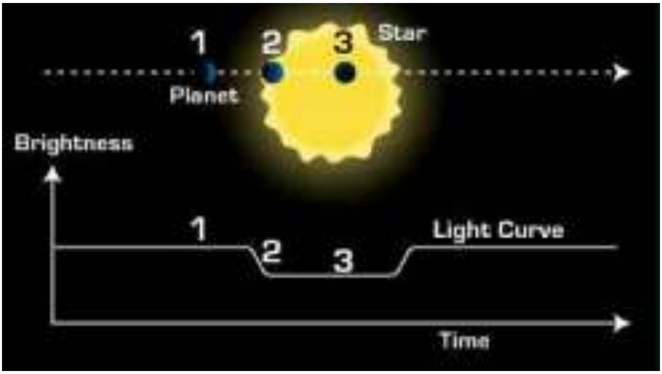
Dynamical methods :



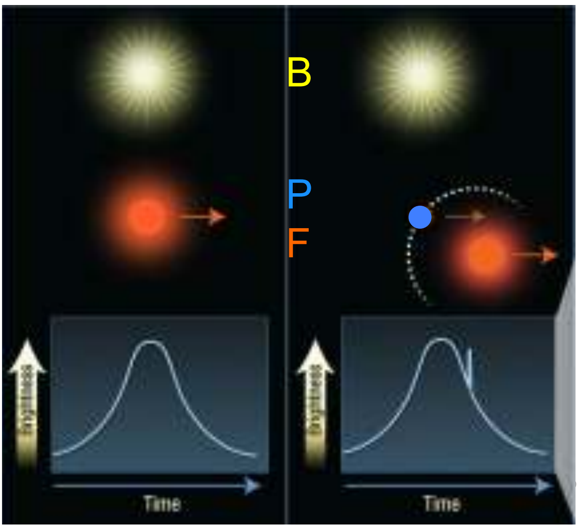
The planet and the star orbit their common center of mass. The motion of the star around the center of mass is detected by the displacement of the lines in its spectrum (see TUIMPs 2 and 10).

Transits:

If a planet passes in front of a star it produces a small eclipse.



Microlensing:

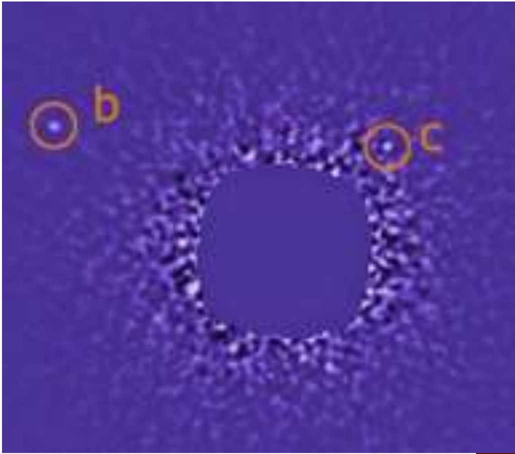


When a star F passes in front of a star B, it creates a 'gravitational lens' which magnifies the light. If a planet P orbits the star F, it too will lens the star B, but for a shorter time.

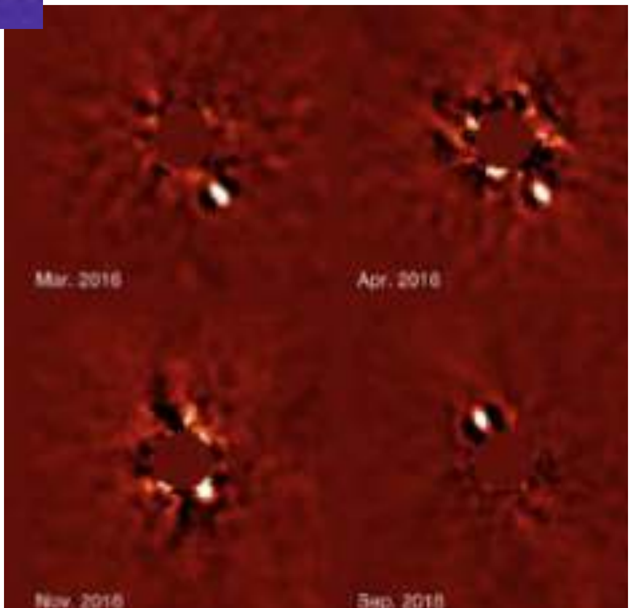
Indirect methods of discovery

The first detections of exoplanets used the effects of the planet on its star (see opposite page), allowing the derivation of many planetary properties.

- With dynamical methods, by studying the variations of the radial velocity of the star, we obtain the size and eccentricity of the orbit, the period of revolution and a lower limit on the mass of a planet. The true value of the mass and the orbit orientation are derived from the change in position of the star with respect to nearby stars (astrometry).
- With the transit method, we obtain the size of the planet from the depth of the light curve during the eclipse and the period of revolution from the time between eclipses.
- With microlensing we obtain the mass of the planet and its distance to the star.

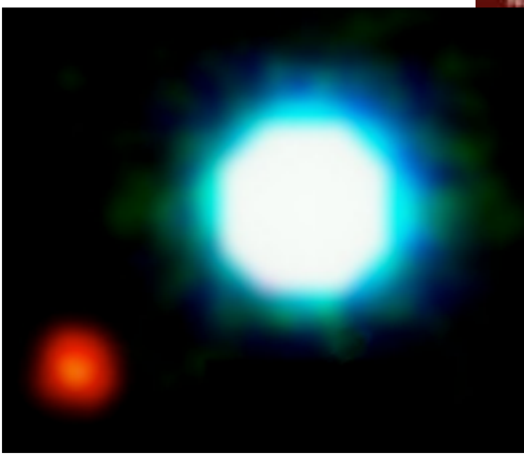


Two planets around the star HR 8799, discovered in 2008 using coronography in infrared light with the Gemini North telescope in Hawaii.



Sequence of images taken at the ESO Very Large Telescope in Chile. It shows the motion of the planet Beta Pictoris b as it orbits its star.

Credit: Lagrange et al.



The first image of an exoplanet, taken at the ESO VLT in 2004. It orbits the 'brown dwarf' star 2M1207, a faint, low-mass star shown here in white.

Credit: Chauvin et al.

Direct methods of discovery

Direct detection of an exoplanet is difficult because planets are small and dim and lie very close to their stars, which are at least 10 million times brighter. Thus, we need to carefully mask the star by a technique called coronography.

Direct detection, when possible, is very fruitful, because with several images we can determine the full orbit.

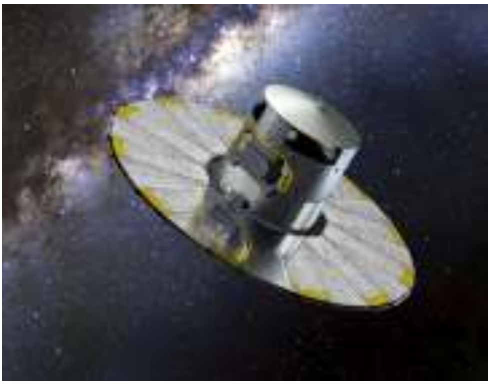
Spectroscopy of the planet reveals the molecular composition of its atmosphere as well as its climate and weather.

Photometric monitoring of the planet gives its rotation period, that is, the length of its day.

The size and mass of the planet, however, can only be obtained by indirect methods.

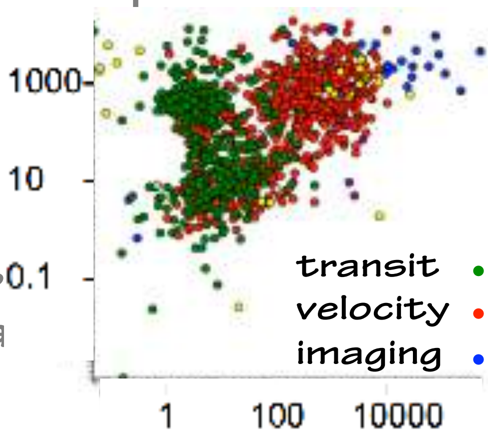
The satellite CoRoT discovered 36 exoplanets. 600 candidates are still being examined.

The Kepler mission observed 530,000 stars, finding 2500 exoplanets so far. Another 2500 candidates await analysis.



The European satellite Gaia, launched in 2013, will operate until 2022. It will study the position and motion of over one billion stars with exquisite precision.

The masses (with respect to the Earth) versus the year length (in terrestrial days) for all known exoplanets as of February 2019. (data from exoplanets.eu).



A brief history of discoveries

The first discoveries of exoplanets were made from the ground with the radial velocity method using high-precision spectrographs. HD114762b was the first planet discovered, in 1989. In 1992, 3 planets were found around a pulsar. Then the number of detections skyrocketed. As of 2019, over 800 planets and 600 multi-planet systems have been found using this method.

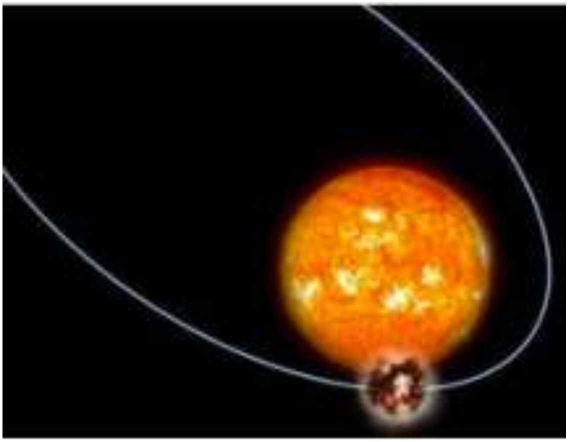
In 2006 the French-ESA satellite CoRoT was launched, followed in 2009 by the NASA Space Telescope Kepler. Both used the transit method. CoRoT was the first to detect a rocky planet. Kepler discovered thousands of planets.

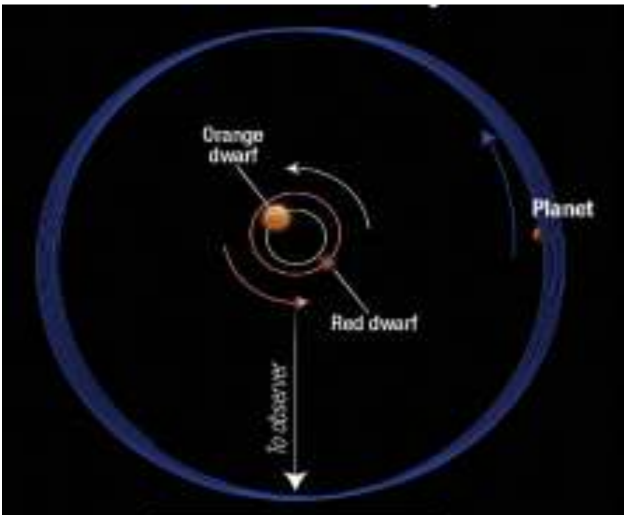
90 planets were found by microlensing, and 100 planets were found by direct imaging from Earth.

Gaia will provide astrometry and proper motions for over 1 billion stars. It should detect thousands of new planets.

An imaginary view (not to scale) of the very hot Super-Earth CoRoT-7 b

An artistic representation by G. Thimm of the planet Kepler-432b, with its highly eccentric orbit which produces extreme seasons.





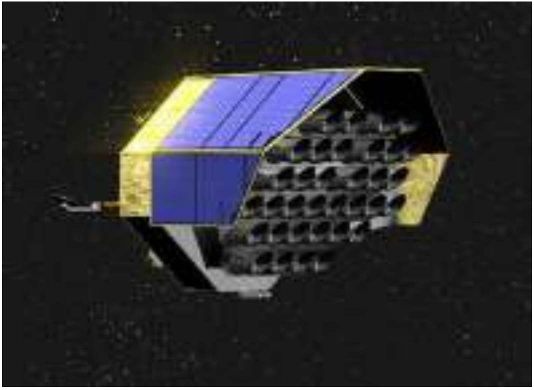
The planet Kepler-413b, which revolves around two stars: an orange one and a red one.

The diversity of worlds

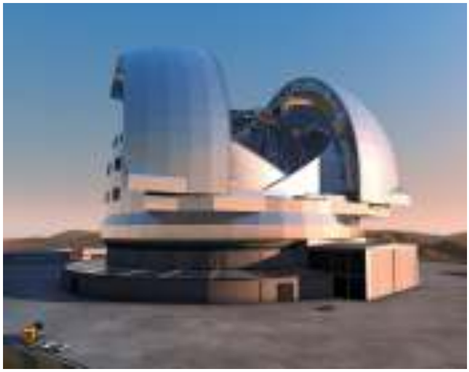
As of 2019, more than 4000 planets have been confirmed while more than 3000 await confirmation.

Many strange planets have been discovered that do not exist in the Solar System:

- Planets with temperatures of more than 1000°C that orbit their star in only a few days (as compared to one year for the Earth)
- Evaporating planets
- Planets twice as big as the Earth, called Super-Earths, with extreme seasons (-100°C in winter, +100°C in summer).
- Planets with two suns
- Systems of planets very tightly packed around their sun.



Plato, the future European exoplanet hunter, to be launched in 2026. It will observe hundreds of thousands of stars, looking for planets using the transit technique.



An artist's impression of the future European Extremely Large Telescope, which will begin operation in Chile in 2025. It will gather 13 times more light than the largest existing telescopes and produce images 16 times sharper than those from the Hubble Space Telescope.

The hypertelescope project by A. Labeyrie. A future, very large interferometer in Space, for the cartography of exoplanets with a resolution of 100 m.

The future

Within the next 10 years, 30 to 40m diameter telescopes will operate from the Earth to detect exoplanets by imaging and velocity variations of the stars. Satellite telecopes including Cheops, JWST, Plato and Ariel, will be launched to detect planets by the transit method. The JWST will also do direct imaging.

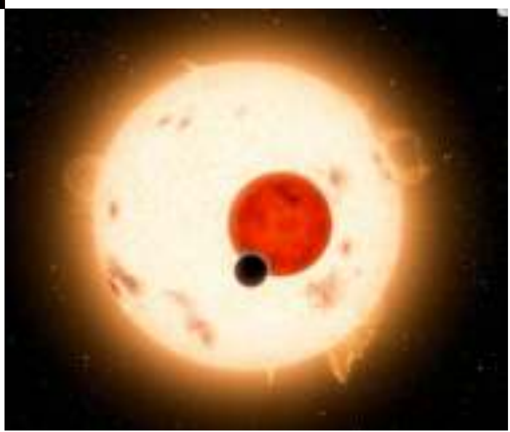
Large Space telescopes 8 to18m in diameter (LUVOIR, Habex) are being designed at NASA to detect signs of life on exoplanets by 2050.

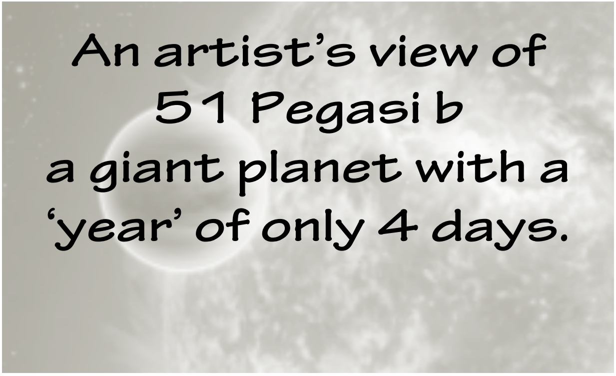
In the more distant future, huge space interferometers will make detailed maps of planets. And possibly, interstellar probes will be launched towards the nearest exoplanets to take close-up images. Engineers are already working on propulsion techniques to reach such distant targets.

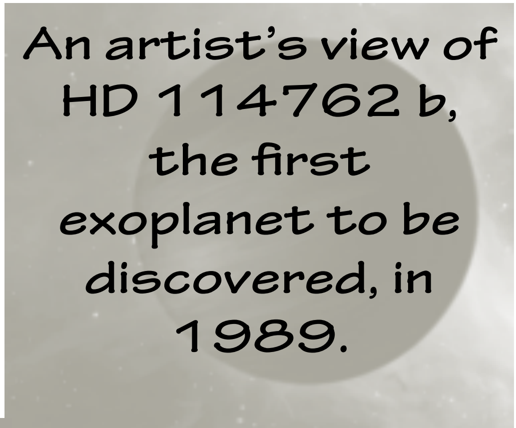
Quiz

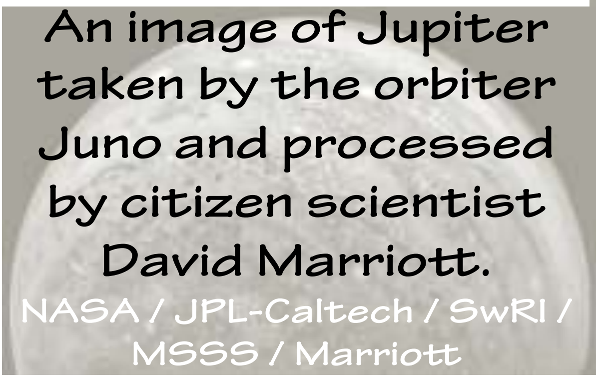
Which of these images represents a planet of the Solar System?

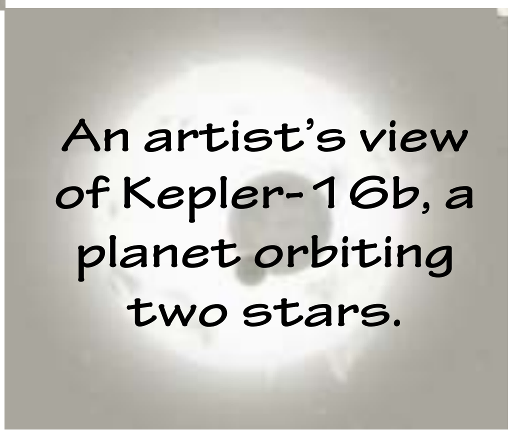
Answers on overleaf




An artist's view of 51 Pegasi b a giant planet with a 'year' of only 4 days.


An artist's view of HD 114762 b, the first exoplanet to be discovered, in 1989.


An image of Jupiter taken by the orbiter Juno and processed by citizen scientist David Marriott.
NASA / JPL-Caltech / SwRI / MSSS / Marriott


An artist's view of Kepler-16b, a planet orbiting two stars.

The Universe in my pocket No. 8

This booklet was written in 2019 by Jean Schneider and Grażyna Stasińska from Paris Observatory (France).

Nr 1

Cover image: This picture illustrates the idea that rocky worlds may be both plentiful and highly diverse in the Universe (credit JPL). All the images of exoplanets and of satellites in this booklet are artist's depictions . Credits: NASA, ESA and ESO.

To learn more about this series and about the topics presented in this booklet, please visit http://www.tuimp.org