SPECTROSCOPY OF EXOPLANETS

Maryam NASIROLISLAMI*, Amir EHTESHAMI**

Key words: exoplanets, Super-Earths, Hot Jupiters, Rogue planets, Thermal emission

Astronomers usually use indirect methods such as radial velocimetry to detect and study an exoplanet's macroscopic properties parameters such as its mass and distance from its host star, spin-orbit alignment, eccentricity etc. Studying an exoplanet's atmosphere is a different story!

Why spectroscopy of exoplanets is important?

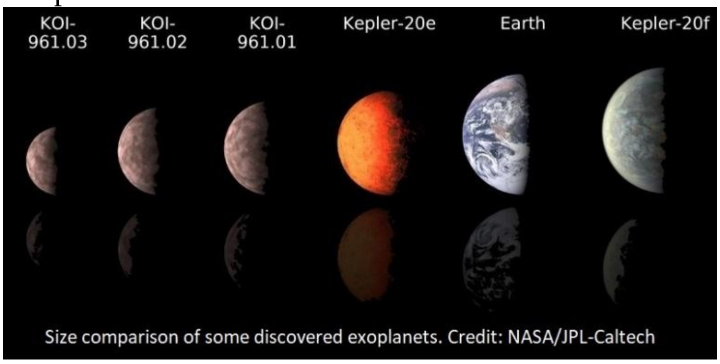
You might have asked yourself, are we alone in this universe? To answer that question, we have to search for life in our known universe. Life, as we know, it needs a safe comfortable place with water on it to exist, just like our own Earth. If life comes to existence, it will need an atmosphere to support it and existing life will have its own signatures on a planet's atmosphere, for example if we look at the earth, it has nitrogen, oxygen, water vapor, CO_2, methane, ozone, and many other gases. Some of them are critical for living creatures and some are produced by living creatures (life by product). So, by studying an exoplanet's atmosphere, we can understand its composition, density of clouds and the material they are made of, albedo, temperature gradient etc. which will help us determine the possibility of existing life there. Although even if we really find a second Earth, it might be in the wrong stage of evolution and no bio-signs might show up in the measurements.

Types of exoplanets

As we see different kinds of planets in our solar system, other planetary systems also have different types of planets.

Terrestrial exoplanets

Just like in our solar system Rocky planets are mainly composed of heavier elements such as silicate rocks or metals and their solid planetary surface makes them especially suited for harboring complex life if there is water there.



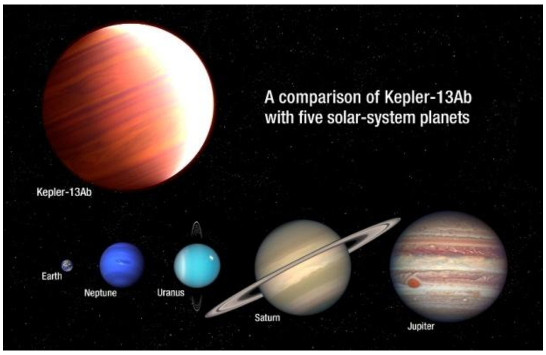


Figure nr. 1 and nr. 2 *Size comparasion of some discovered exoplanets*[1]

Super-Earths

The term "super" only means that exoplanet's size is between 1 and 10 Earth radii. Among them, many are ocean planets, meaning their surface is covered with deep oceans and many are just plain rocky deserts. Super-Earths with a low bulk density are mainly composed of hydrogen and helium. After evaluating many super-Earths it turned out that the density increases with the planet's radius up to a value of about 1.5 Earth radii, for larger planets the density rapidly drops.

---

* Director of Vanand Institute of Physics Iran, and Astronomy Research.
** Astrophysics researcher.

[1] Credit: NASA/JPL-Caltech; NASA, ESA, and A. Feild (STScI)

Gas giants All planets with masses exceeding 10 Earth masses are called gas giants. These planets might have a small rocky core, but they are mainly composed of hydrogen and helium just like our own Jupiter or Saturn. Because they are big and easier to detect, all the first discovered exoplanets were in this category.

Hot Jupiters

A hot Jupiter is basically a gas giant that has migrated much closer to its host star and has a distance between 0.015 to 0.5 AU of their host star. We say that they have migrated because basically a planet in their size cannot form this close to their host star, the star wind would have blown all the gas away in their protoplanetary phase, so it is believed that all hot jupiters are formed somewhere further than the stars snow line (a certain distance from the parent star where hydrogen compounds such as water or ammonia have frozen into solid ice, creating ice giants).

Rogue planets

Also called orphaned planets or nomad planets, these planets have no star to orbit, they just free float in galaxies. They are mostly failed stars that couldn't gather enough mass or they might be gas giants that migrated too far from their host star and got loose. They could have any size, but most of rouge exoplanet candidates have been gas giants up to now. They are detected by direct infrared imaging or through microlensing which is much more difficult.

Methods used in spectroscopy of exoplanet atmospheres

We need direct methods such as imaging the exoplanet itself and study its atmosphere (mostly in infrared, but promising UV/Visible/NIR studies are carried on), or study an exoplanet transiting in front of its host star (as seen from earth) carefully and extract as much data as possible out of it. Generally speaking, there are two methods to study an exoplanet's atmosphere: first, measurements of time varying signals, which include transits, secondary eclipses, and phase curves, and second, spatially resolved imaging (direct imaging) and spectroscopy which has been done on at least 10 exoplanets. The Earth/Sun brightness ratio is about 10^{-10} in the visible light and around 10^{-7} in the thermal infrared, so it's important to keep away the light of host star from exoplanetary emission, but we are not covering this in here.

According to latter, studying an exoplanet's atmosphere is currently possible in these manners:

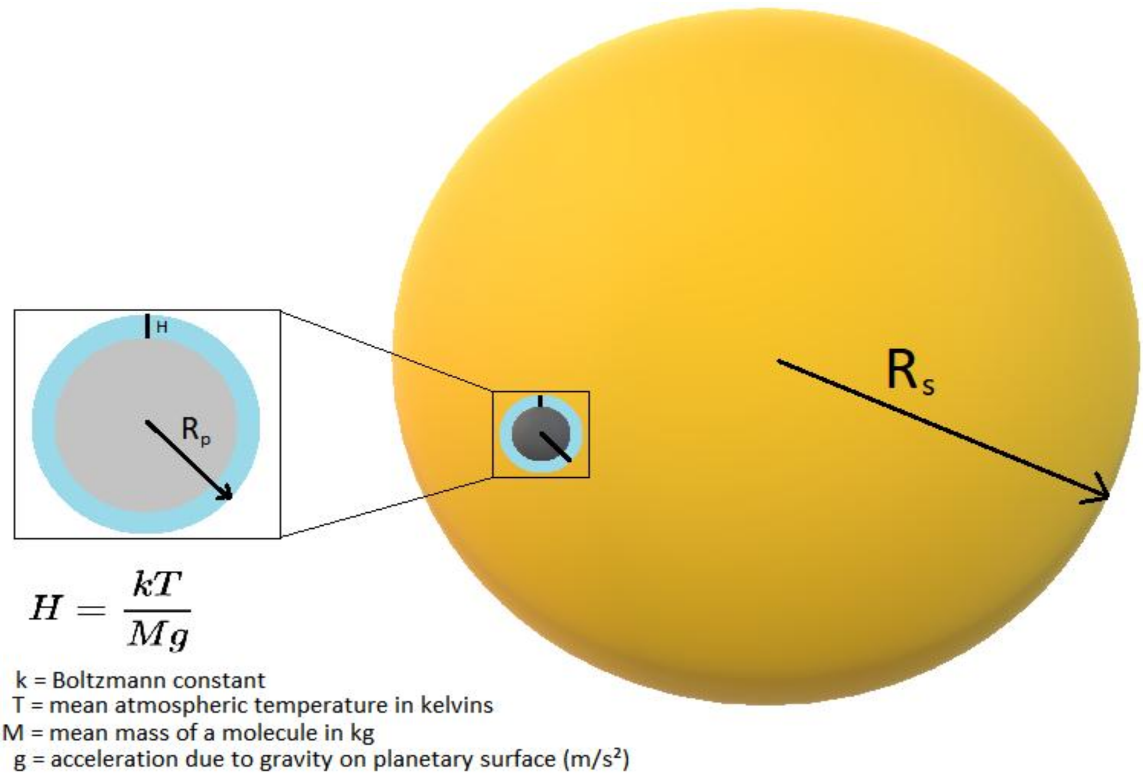


Figure nr. 3 *Exoplanet transit*

Transmission

During a transit, some light from the host star will pass through the atmosphere of the exoplanet on its way to our telescopes. The problem is only a very tiny fraction of host star's light is going to pass the detectable atmosphere in the first place, then this tiny fraction is combined with the much brighter star's light.

All the light we have for transit spectroscopy is the tiny amount that passes through planets atmospheric scale height. Scale height for Earth is roughly 8.5 km.

Although the transmitted light it is a tiny portion, but using transiting exoplanets to obtain transmission spectroscopy is now a proven method to probe exoplanetary atmospheres.

A very good example is the detection of sodium in XO-2b from differential long-slit spectroscopy.

As different wavelenghts get absorbed by different intensities, chemical composition can be measured from their fingerprint absorption bandsin the exoplanet's atmosphere. For example, look at this modeled earth-like exoplanetary atmospheric absorption bands.

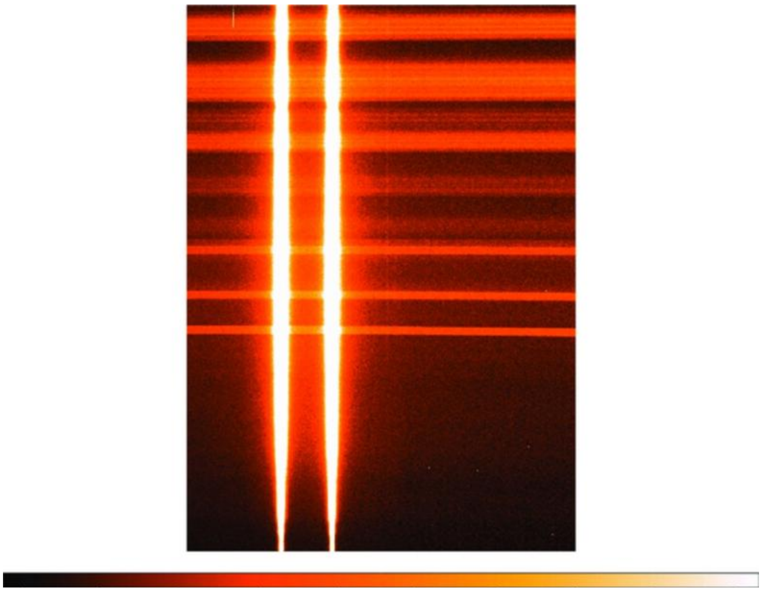


Figure nr. 4 *GTC OSIRIS CCD frame of XO-2A (right) and XO-2B (left) long-slit spectra from 2012 February 23 taken with the R500B grism and a 5-arcsec-wide slit. The spectra cover wavelength ranges from 3750 Å (bottom) to 8587 Å (top), with background sky emission lines seen in the cross-dispersion direction.*

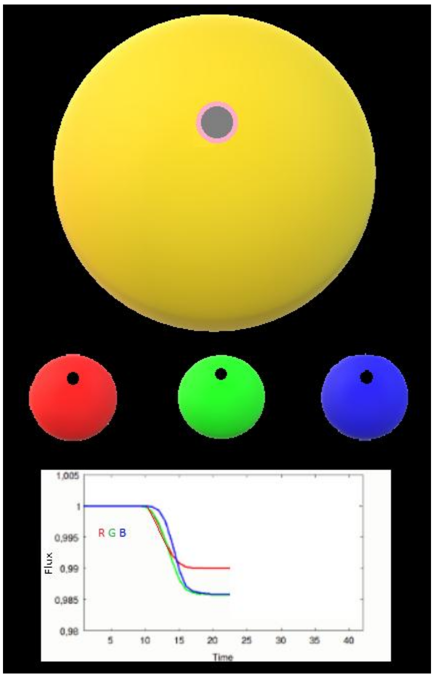
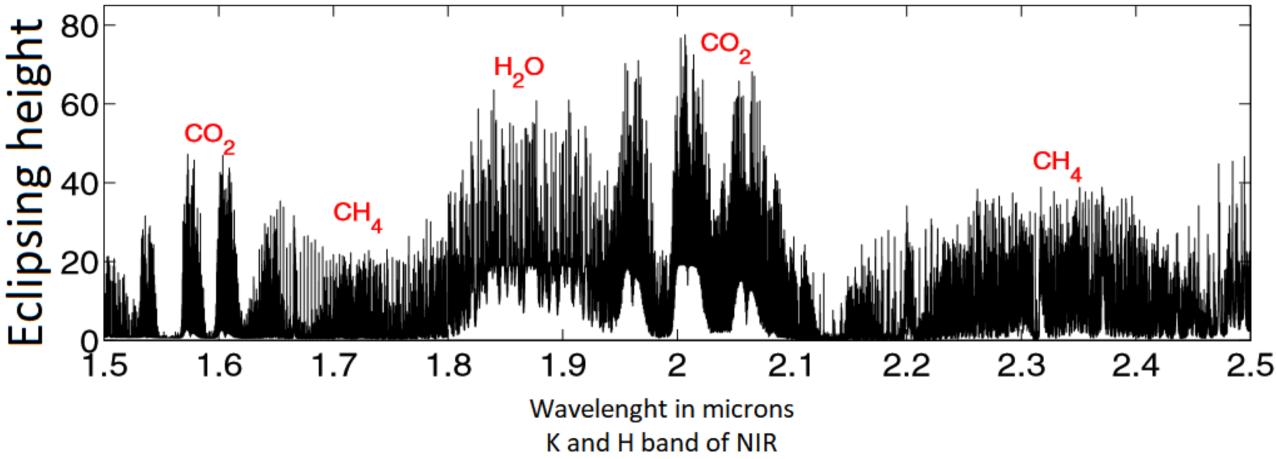


Figure nr. 5 *Very rough demonstration of different absorption intensities.*

[2] Mon Not R Astron Soc. 2012;426(2):1663-1670. doi:10.1111/j.1365-2966.2012.21938.x; Mon Not R Astron Soc © 2012 The Authors Monthly Notices of the Royal Astronomical Society © 2012 RAS



Reflectance

Have you ever noticed that the dark side of the moon's face is not that really dark? The dim light that shines on the dark side of the moon is called Earthshine, the light that bounced off of Earth's atmosphere (including reflections from oceans, clouds, deserts, polar regions etc.). Soat any point during an exoplanet orbit, light from the host star may reflect off of the exoplanet's atmosphere and head back towards the earth. For the best viewing angle, we have to study an exoplanets atmosphere just before and after secondary eclipse of the planet, a little before and after the planet's face is covered by its host star.

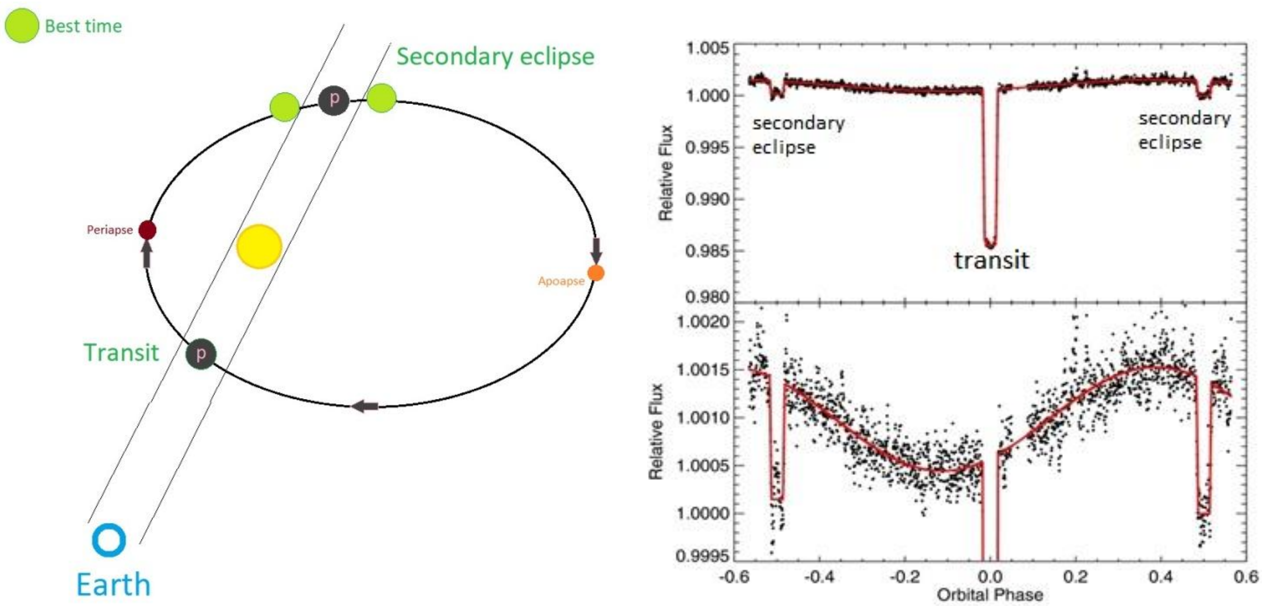


Figure nr. 6 and nr. 7 *Method of transit and graphical of transit*[3]

When we study the reflected light, we can detect absorption bands in the spectra. These absorption bands serve as "fingerprints" to identify composition of exoplanet's atmosphere, so we can find out if life can come to existence and the atmosphere is supportive for it.

There are a few things to consider here, some molecules, like methane, have both biological origin and non-biological origin, so they are bio indicators whereas some molecules like N_2O have

[3]The 4.5 μm Full-orbit Phase Curve of the Hot Jupiter HD 209458b
Robert T. Zellem et al. 2014 ApJ 790 53 doi:10.1088/0004-637X/790/1/53 With modifications

only biological causes like anaerobic denitrifying bacteria (Des Marais et al. (2001)), these are called bio-markers. N_2O bands are hard to detect and beyond that overlapped by CH4, CO2 and H2O (Kaltenegger & Selsis (2009)). The reflected light acts like a probe, different wavelengths are reflected in different depths of atmosphere.

Thermal emission

If the planet itself or its atmosphere is hot enough, it may emit blackbody radiation detectable by our today's technology. We all know that no exoplanets emit blackbody radiation comparable to its host star.

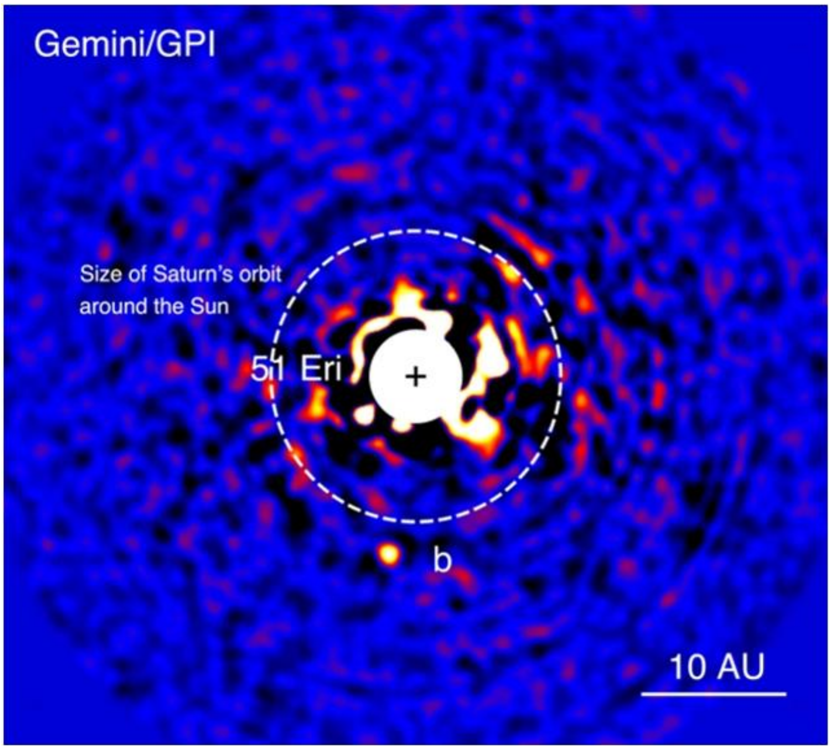


Figure nr. 8 *Jupiter-like exoplanet around 51 Eridani (labeled b)*[4]

A direct image using Adaptive Optics on the 8 m Gemini South telescope and its Gemini Planet Imager instrument permitted the discovery and characterization of a 1-million time fainter.

If our technology gets revolutionized in the future and give us more signal to noise ratios, higher resolution spectrometers and higher spatial resolution imaging we might be able to detect existence of artificial light sources, air pollution, auroras, lightning etc. someday.

SPECTROSCOPIA EXOPLANETELOR

Astronomii folosesc, de obicei, metode indirecte, pentru a detecta și a studia parametrii unei exoplanete, cum ar fi masa și distanța față de stea, excentricitatea etc.

S-ar putea să te întrebi, oare suntem singuri în acest univers? Pentru a răspunde la această întrebare, trebuie să căutăm viață în universul nostru cunoscut. Viața, așa cum o știm, are nevoie de un loc sigur și confortabil, cu apă, ca și pe propriul nostru Pământ. Chiar dacă viața va ajunge la existență, va avea nevoie de o atmosferă care să o susțină şi existența vieții va avea propriile semnături pe atmosfera unei planete. De exemplu, dacă analizăm atmosfera planetei noastre, aceasta are în compoziţie mai multe elemente chimice: azot, oxigen, vapori de apă, dioxid de carbon, metan, ozon și multe alte gaze. Unele dintre acestea sunt indispensabile pentru creaturile vii, iar

[4] Image credit: J. Rameau & C. Marois under CC-BY-SA

unele sunt produse de organismele vii (produs secundar al formelor de viaţă). Deci, studiind atmosfera exoplanetei, putem înțelege compoziția, densitatea norilor și materialul conținut, albedo, gradientul termic etc. care ne vor ajuta să determinăm posibilitatea existenței vieții acolo.

Deși, chiar dacă într-adevăr găsim un al doilea Pământ, s-ar putea să fie într-un stadiu neprielnic evoluției și să nu apară semne biologice în măsurători.

Tipuri de exoplanete

Pe măsură ce vedem diferite tipuri de planete în sistemul nostru solar, de asemenea, alte sisteme planetare dispun de diferite tipuri de planete.

Exoplanete terestre

La fel ca în sistemul nostru solar, planetele telurice sunt, în principal, compuse din elemente mai grele, cum ar fi rocile silicate sau metalele, iar suprafața lor planetară solidă le face deosebit de potrivite pentru a adăposti viața complexă dacă există apă acolo.

Super-Pământuri

Termenul "super" înseamnă doar că dimensiunea exoplanetei este cuprinsă între 1 și 10 raze ale pământului. Printre acestea, multe sunt planete oceanice, ceea ce înseamnă că suprafața lor este acoperită de oceane adânci și multe sunt doar deșerturi stâncoase. Super-Pământuri cu o densitate redusă sunt compuse în principal din hidrogen şi heliu. După evaluarea mai multor super-Pământuri, s-a constatat că densitatea crește cu raza planetei până la o valoare de aproximativ 1,5 raze de Pământ, iar pentru planetele mai mari densitatea scade rapid.

Giganți de gaz

Toate planetele cu masă ce depășeșc 10 mase ale pământului se numesc giganți de gaze. Aceste planete ar putea avea un miez stâncos mic, dar ele sunt în principal compuse din hidrogen și heliu la fel ca propriul nostru Jupiter sau Saturn. Deoarece sunt mari și mai uşor de detectat, toate primele exoplanete descoperite se găsesc în această categorie.

Jupiter fierbinte

Un Jupiter fierbinte este, practic, un gigant de gaze care a migrat mult mai aproape de steaua gazdă și are o distanță între 0,015 și 0.5 UA a stelei gazdă. Spunem că au migrat, deoarece, de fapt, o planetă de dimensiunea lor nu se poate forma aproape de steaua lor gazdă, vântul stelei ar fi aruncat tot gazul în faza protoplanetară, considerându-se astfel că toate planetele din această categorie se formează undeva în continuarea limitei de îngheţ a stelelor (o anumită distanță de steaua unde, compuși de hidrogen, cum ar fi apa sau amoniacul se transformă în gheață solidă, creând giganții gazoşi).

Planete singuratice

De asemenea, numitele planete orfane sau planete nomade nu se rotesc în jurul unei stele, ele doar călătoresc liber în galaxii. Acestea sunt în mare parte stele eșuate care nu au putut aduna suficientă masă sau ar putea fi giganți gazoşi care au migrat prea departe de steaua lor gazdă.

Metode de detectare a exoplanetelor.

Cea mai cunoscută metodă este cea a **tranzitului.**

Această metodă presupune că planeta trece prin dreptul stelei şi optureazǎ o mică parte din lumină. Cu ajutorul unor echipamente speciale şi a unui program se poate măsura variaţia în strălucire a stelei. De asemenea, în timpul unui tranzit, o parte din lumina stelei gazdă va trece prin atmosfera exoplanetei. Problema este că doar o mică parte a luminii stelei gazdă va trece în atmosferă şi poate fi detectată.

Prin această metodă se poate descoperi atmosfera exoplanetei şi chiar compoziţia chimică a acesteia. De asemenea, se poate determina dacă atmosfera planetei poate să întreţină forme de viaţă.