EXOPLANETS

XUVI: Lecture 3

EXOPLANET

Exoplanets are planets, much like the ones in our Solar system, that we have discovered orbiting stars other than our Sun.

They can be a rocky world, a gas giant, fluffy as a cotton candy or something even more bizarre!

FYI, just like stars, planets might theoretically orbit black holes as well. Such planets are called “blanets”

HOW DO WE DETECT EXOPLANETS?

01 DIRECT IMAGING

02 RADIAL VELOCITY

03 ASTROMETRY

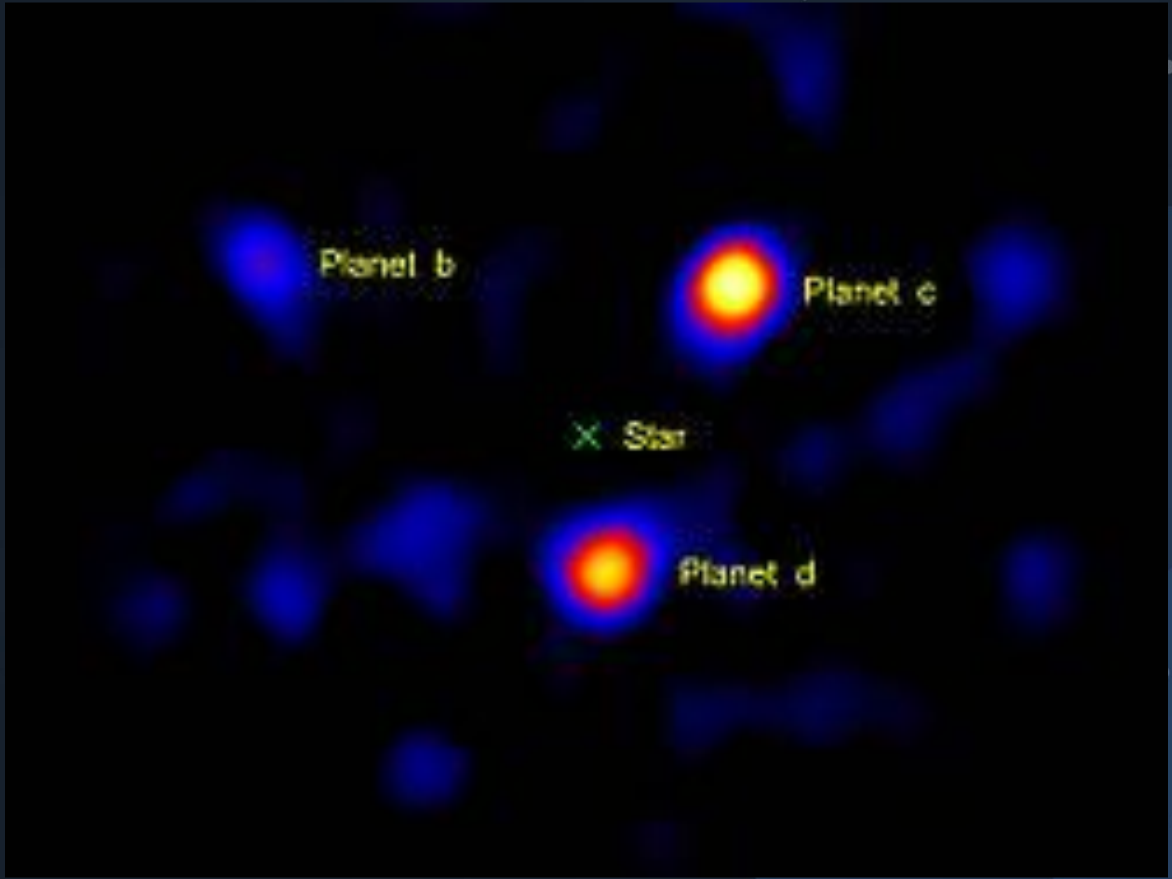
04 TRANSIT PHOTOMETRY

I. DIRECT IMAGING

Planets can be detected based on the light rays they emit. Naturally, these rays are not in league with that of it's star, so a few adjustments have to be made.

Thermal imaging (in the infrared wavelength) is done is the stellar backyard of the star, in order to detect the presence of **hot** exoplanets.

The parent star(s)'s light is blocked off using stellar coronagraphs.



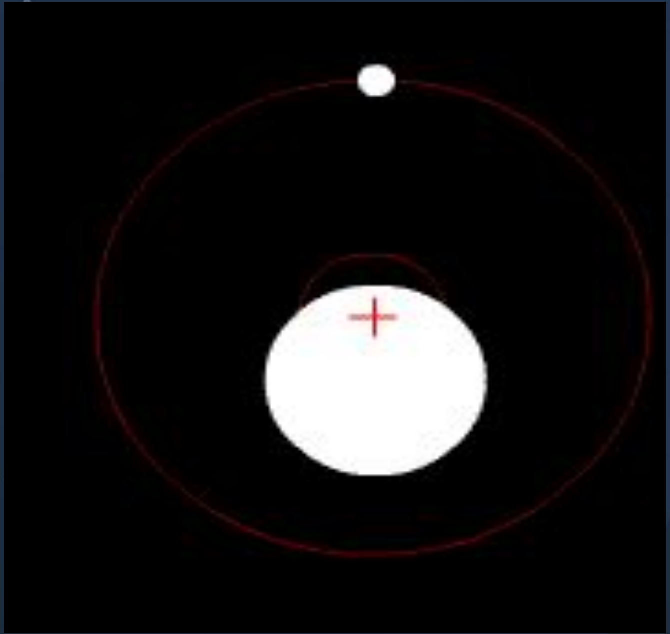
DIRECT IMAGE OF EXOPLANETS AROUND THE STAR HR8799

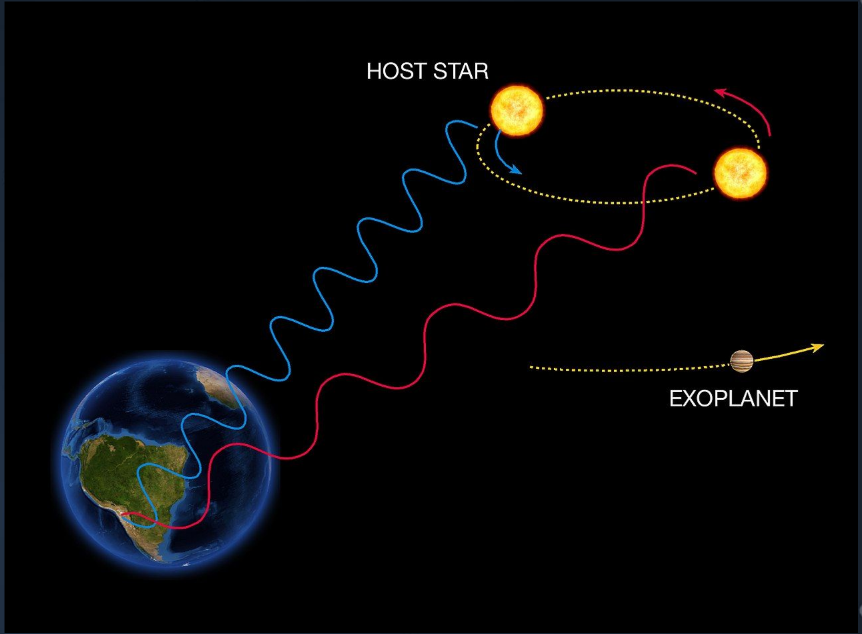
2. RADIAL VELOCITY

Planets don't revolve around their star, they revolve around the Center of Mass (CoM) of the star-planet system. Hence, the star also orbits the same point. If the orbital plane is not normal to the earth-star vector, we can perceive the star's back and forth movement via doppler shift.

The shift in the star's light can be measured via advanced spectroscopes, which can then be processed to calculate the effect of the planet's mass on the star. This method works quite well for stars located near to us (~160 lys)

Although it is historically the first method for exoplanet detection. multiple false positives can be detected via this method as well.

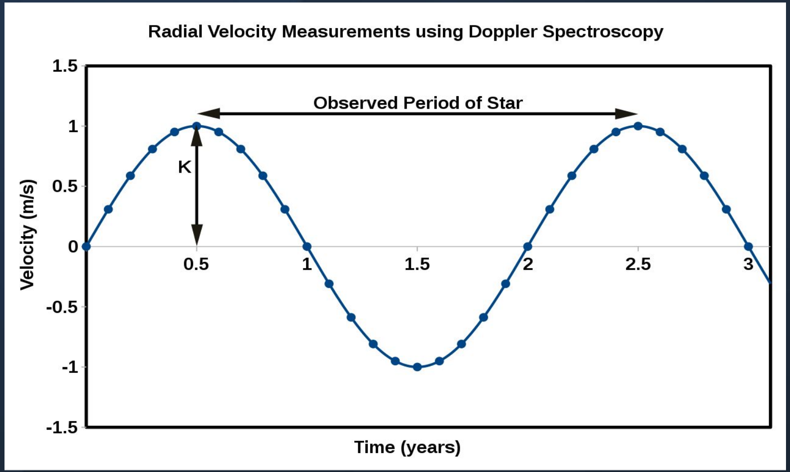




How a smaller object (such as an exoplanet) orbiting a larger object (such as a star) could produce changes in position and velocity of the latter as they orbit their common center of mass

Doppler spectroscopy detects periodic shifts in radial velocity by recording variations in the color of light from the host star.

If an exo planet is detected, a minimum mass for the planet can be determined from the changes in the star's radial velocity. To find a more precise measure of the mass requires knowledge of the inclination of the planet's orbit. A graph of measured radial velocity versus time will give a characteristic curve (sine curve in the case of a circular orbit), and the amplitude of the curve will allow the minimum mass of the planet to be calculated using the binary mass function.



This theoretical star's velocity shows a periodic variance of ±1 m/s, suggesting an orbiting mass that is creating a gravitational pull on this star. Using Kepler's third law of planetary motion, the observed period of the planet's orbit around the star (equal to the period of the observed variations in the star's spectrum) can be used to determine the planet's distance from the star r using the following equation:

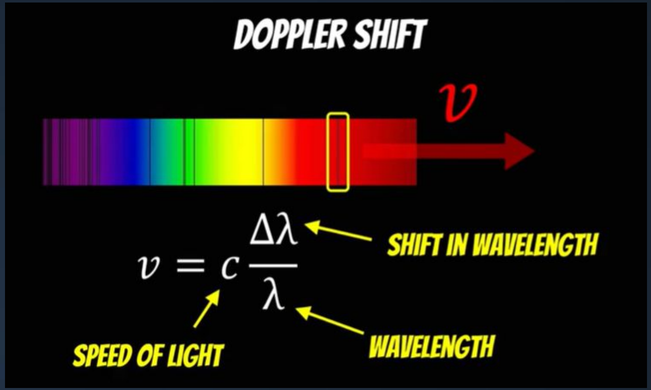
$$r^3 = \frac{GM_{star}}{4\pi^2} T^2_{Star}$$

Having determined r, the velocity of the planet around the star can be calculated using Newton's law of gravitation, and the orbit equation:

$$V_{planet} = \mathrm{sqrt}(GM/r)$$

The mass of the planet can then be found from the calculated velocity of the planet:

$$M_{planet} = \frac{M_{star} * V_{star}}{V_{planet}}$$



The observed Doppler velocity,

$$K = V_{star} * (\sin i)$$

… where i is the inclination of the planet's orbit to the line perpendicular to the line-of-sight.

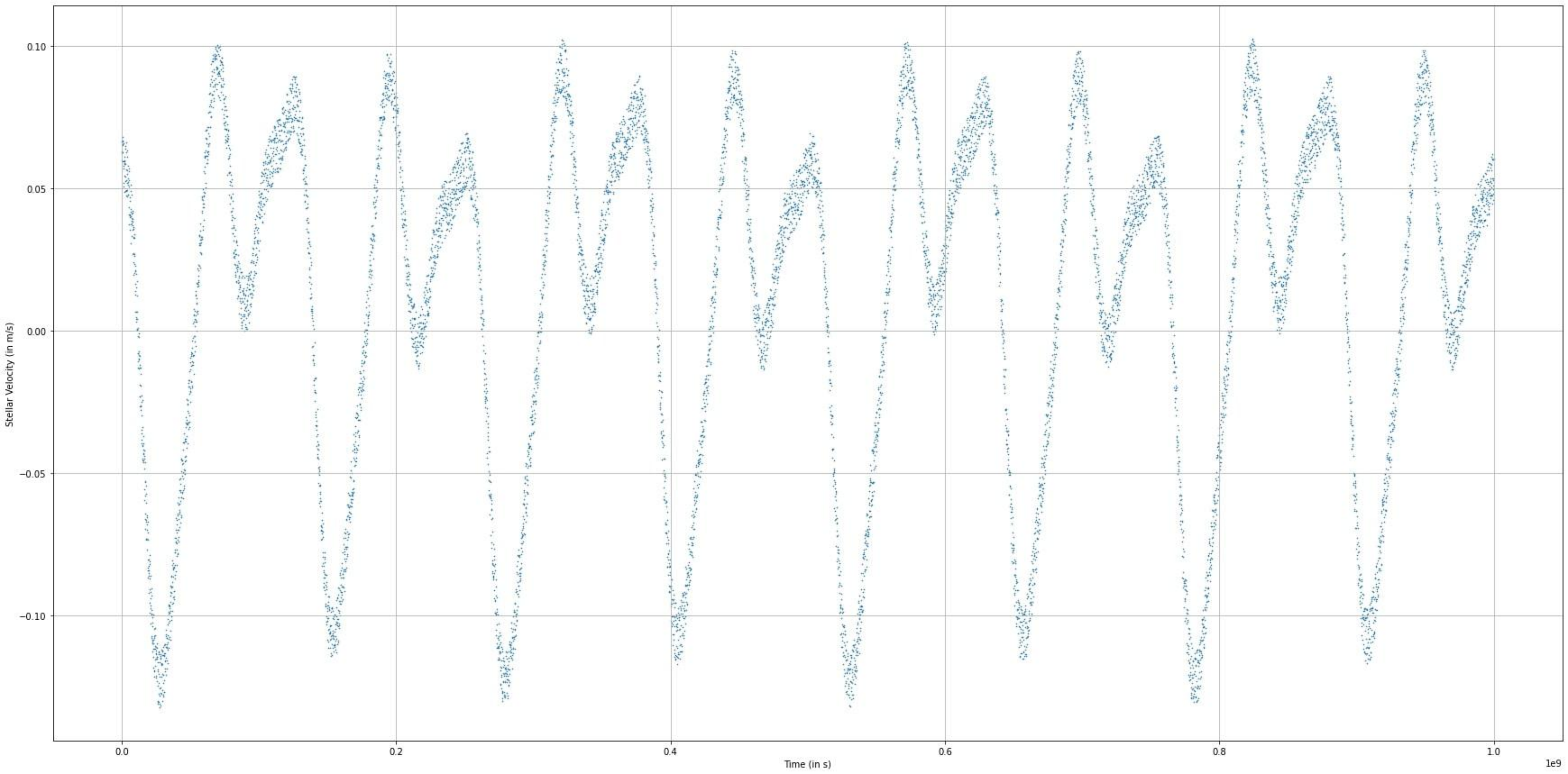
Thus, assuming a value for the inclination of the planet's orbit and for the mass of the star, the observed changes in the radial velocity of the star can be used to calculate the mass of the exo planet.

3. ASTROMETRY

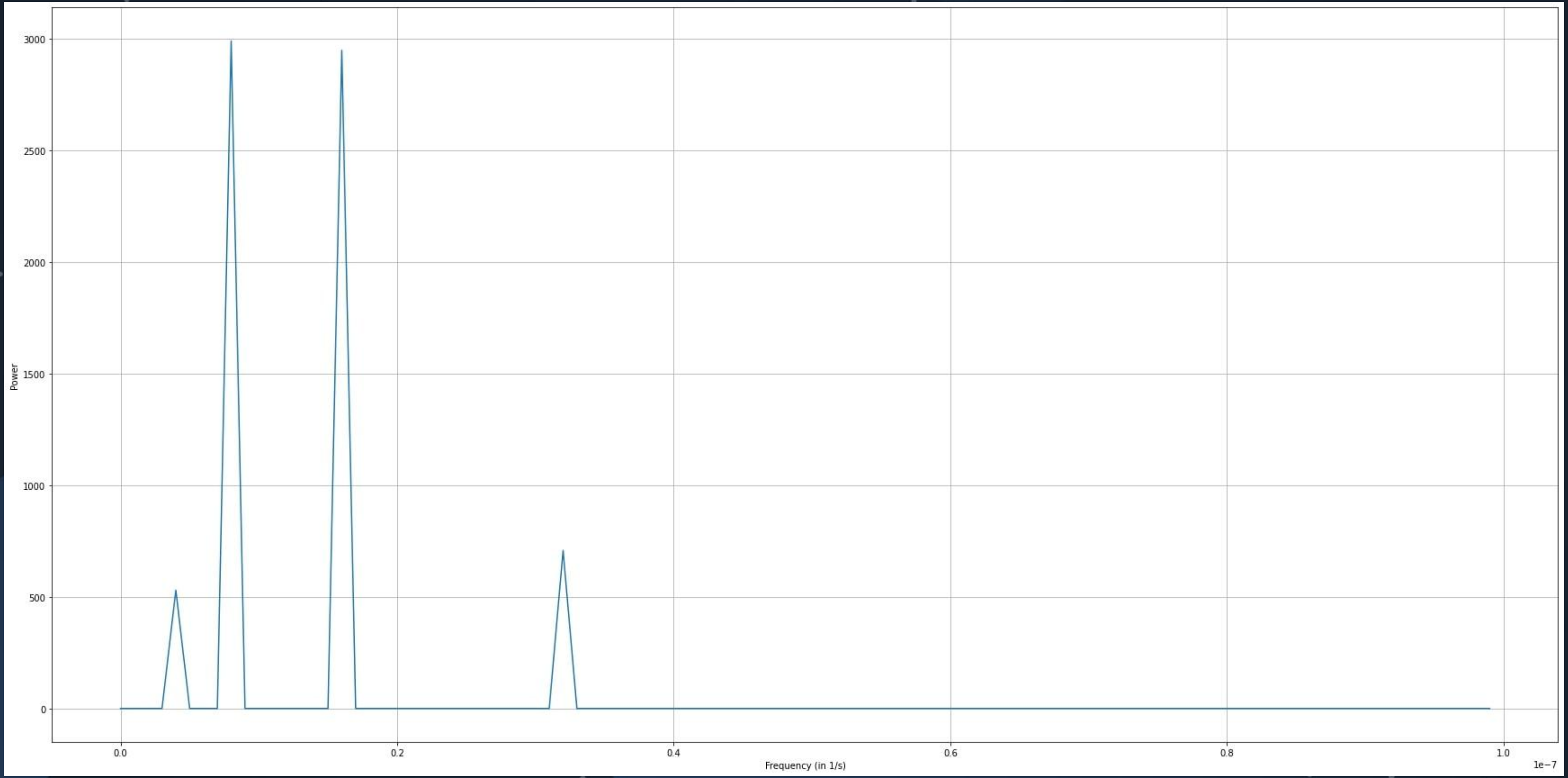
Planets also exert gravitational force on their parent star, which results in **wobbling** in the star's trajectory. Since planets orbit periodically, their effect can be seen while observing the motion of the star though the galaxy.

A planet with huge mass exert a much higher force than a planet with a lower mass and hence is much more easier to detect.

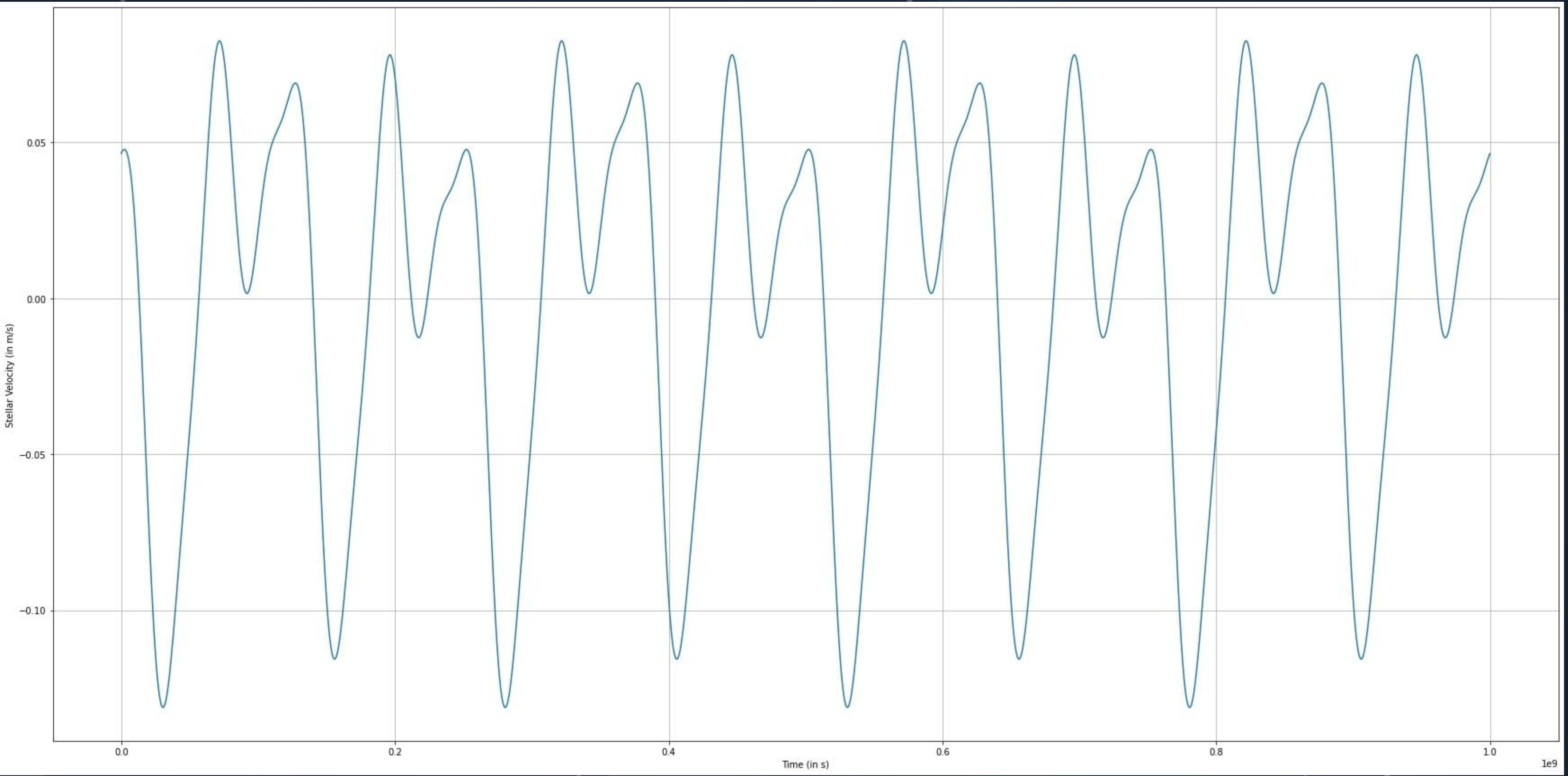
FYI, this method of tracking the path of a star over long periods of time can actually give us the **Dark Matter Density** in the universe. An interesting read: Link



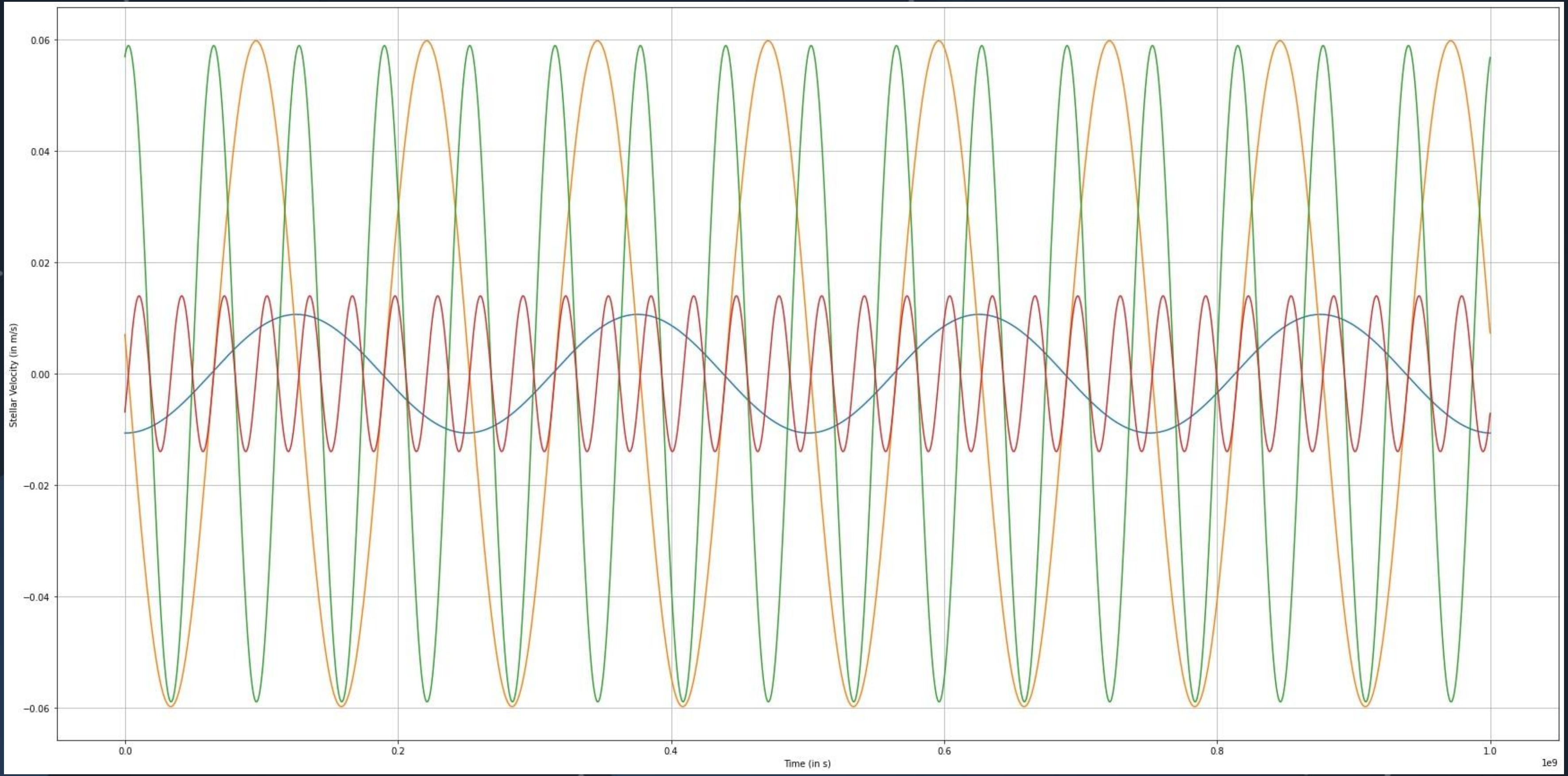
Sample Radial Velocity of a Star (in m/s) v/s Time (in s)



Cleaned Discrete Fourier Transform



Taking Inverse Fourier Transform to get smoothened graph

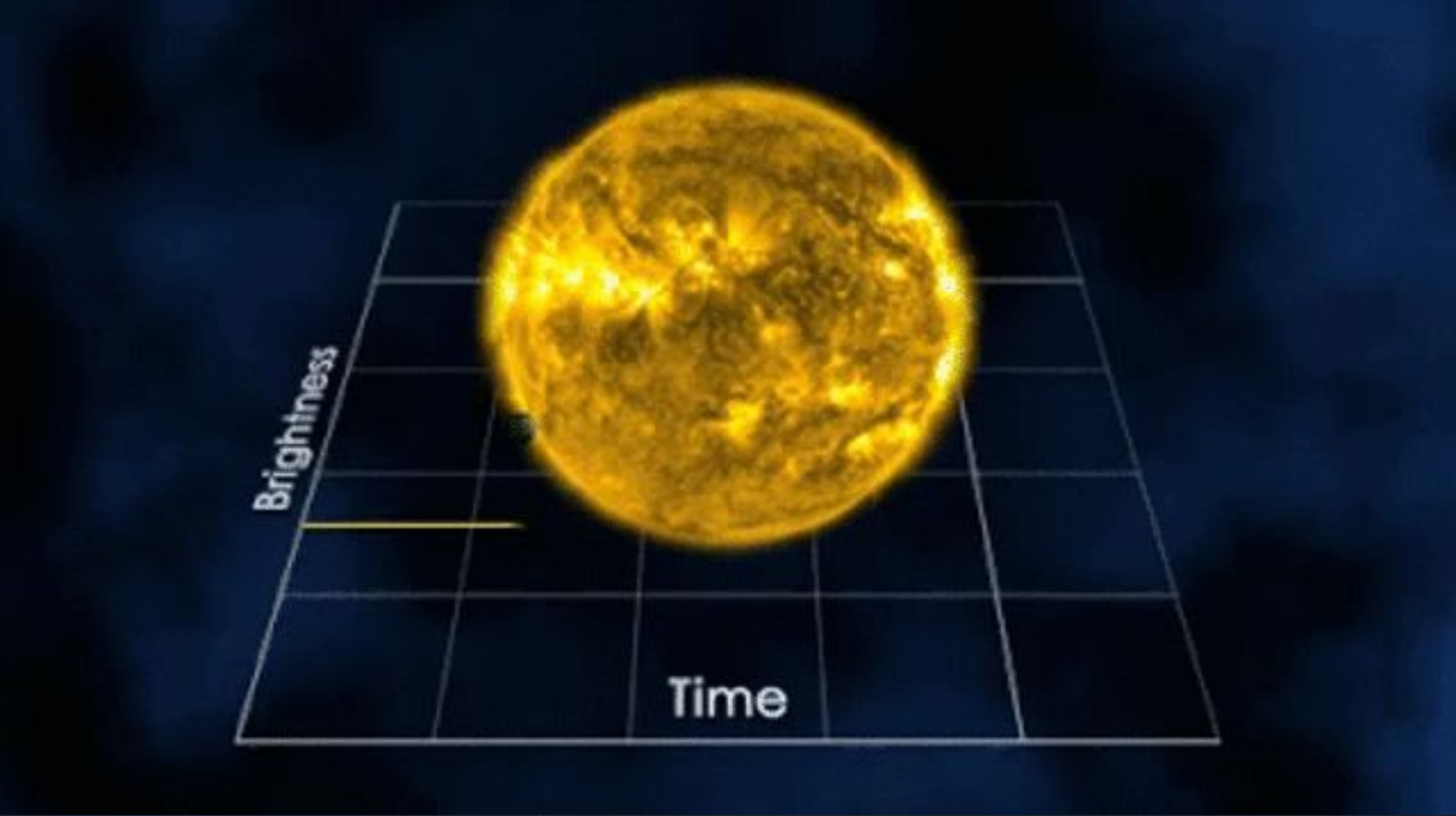


Effect of individual planets

4. TRANSIT PHOTOMETRY

Just like we are able to experience Mercury and Venus **transiting** in front of the sun, similar phenomenon happens in other stellar systems as well.

Exploiting this, we can detect exoplanets using the dip in the star's relative brightness as perceived to us, when the exoplanet passes in front of the star. For this to happen, the planet must be orbiting within the Field of View of the telescope.


Brightness
Time

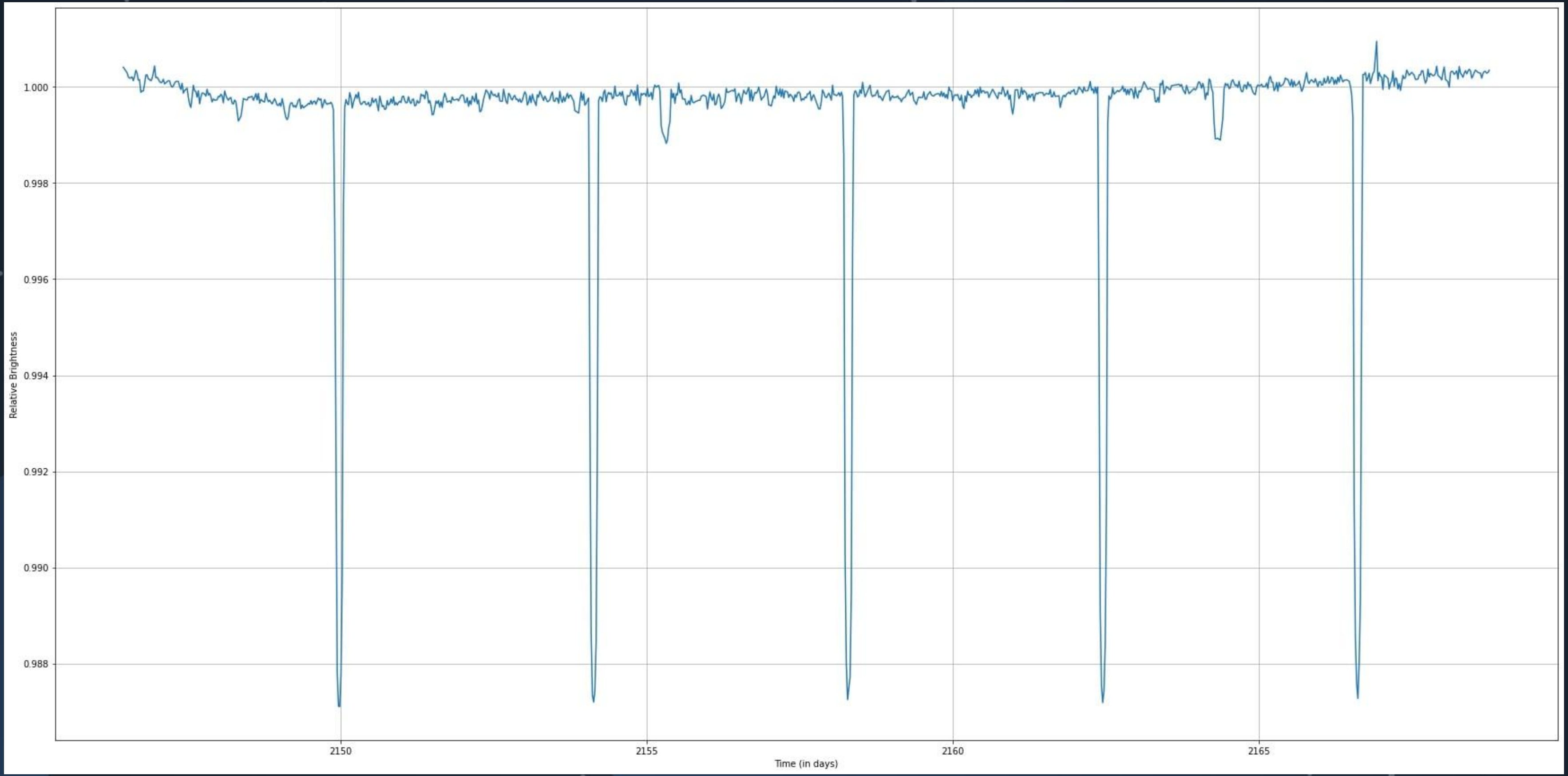
$$DEPTH = (\text{Area of Planet}) * c$$

$$= \frac{R_p^{\ 2}}{R_o^{\ 2}}$$

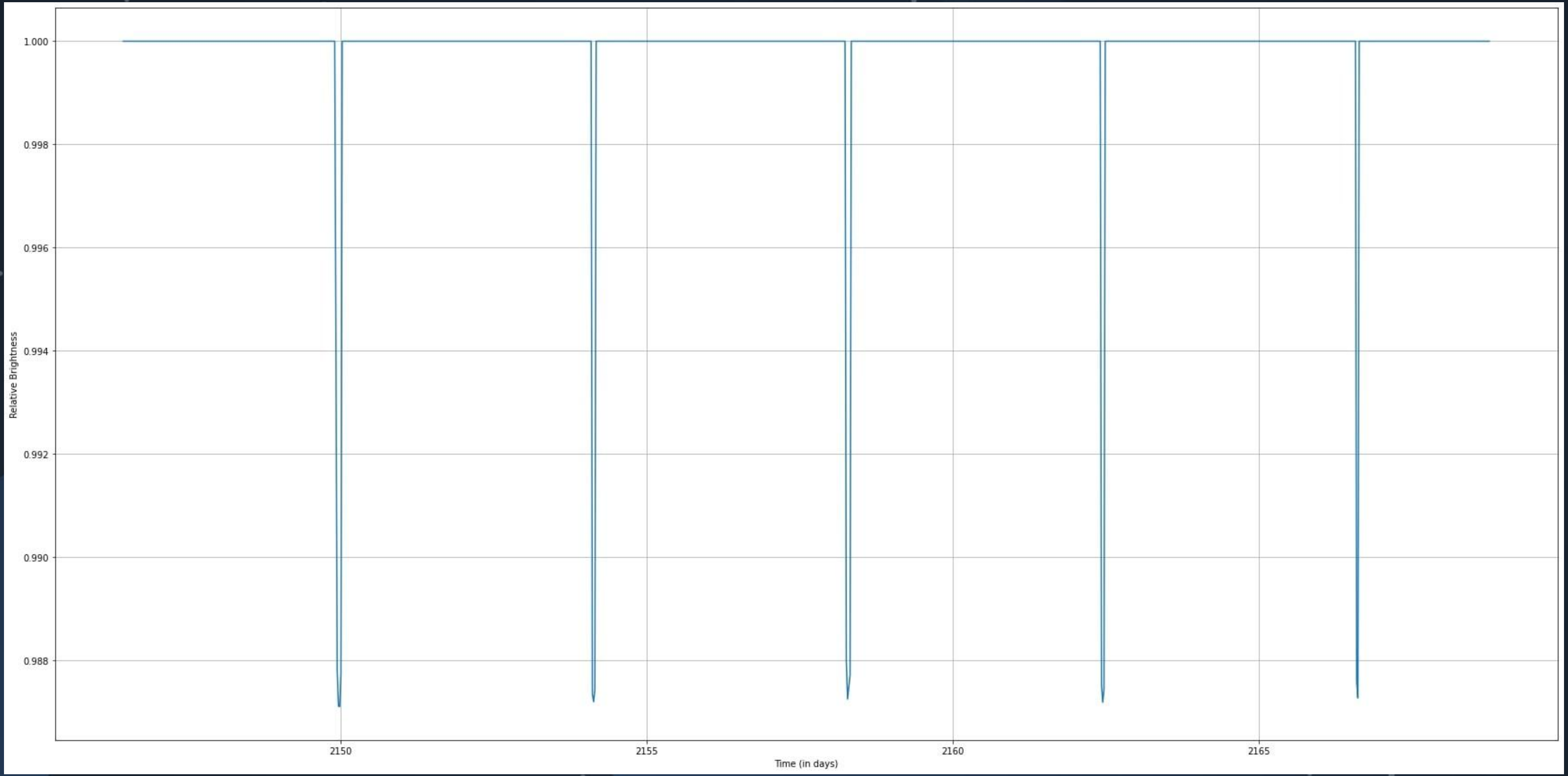
$$\Rightarrow R_p = R_o * \sqrt{Depth}$$

… R_o = Radius of star

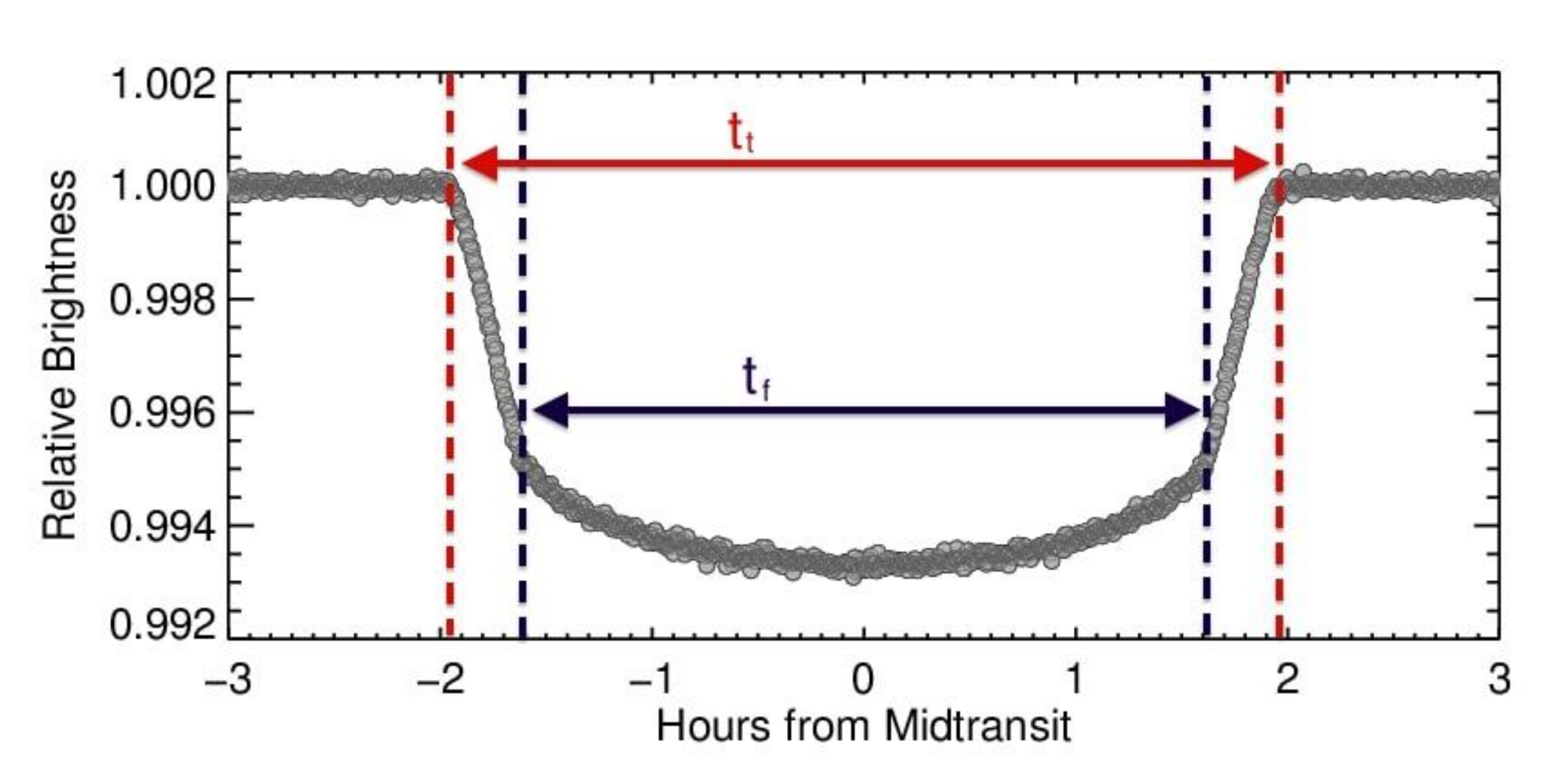
Reference: Link



Light curve of the parent start of the exoplanet wasp-47



Processed Light curve



Expanded transit of an exoplanet

NAMING CONVENTION

Exoplanets are usually named after their parent star. The first detected planet is suffixed with ‘b’, the next one with ‘c’ and so on and so forth.

If multiple exoplanets of the same star system are detected simultaneously, naming convention follows the orbital radii of the exoplanets.