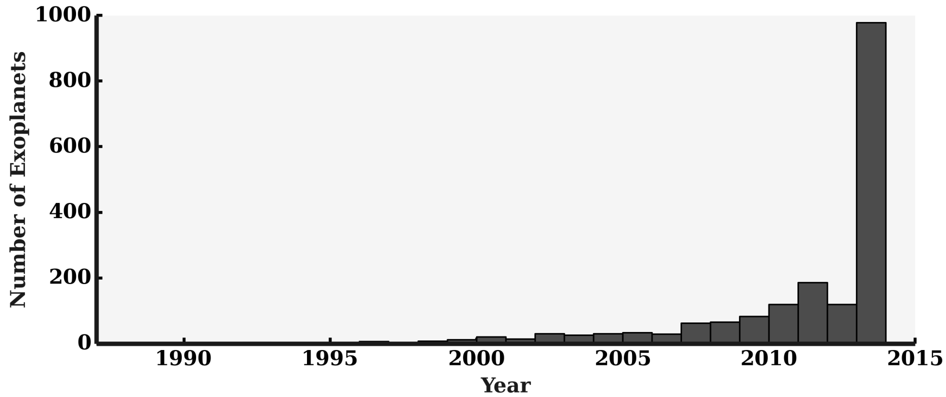
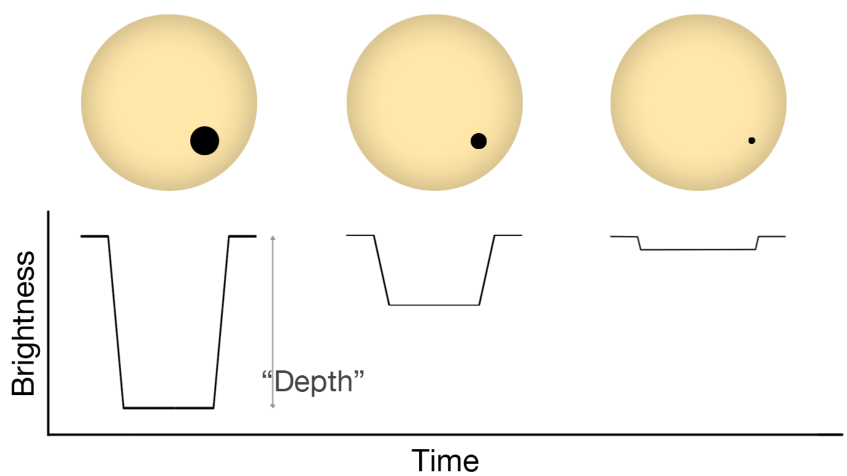
Exoplanets - Transits

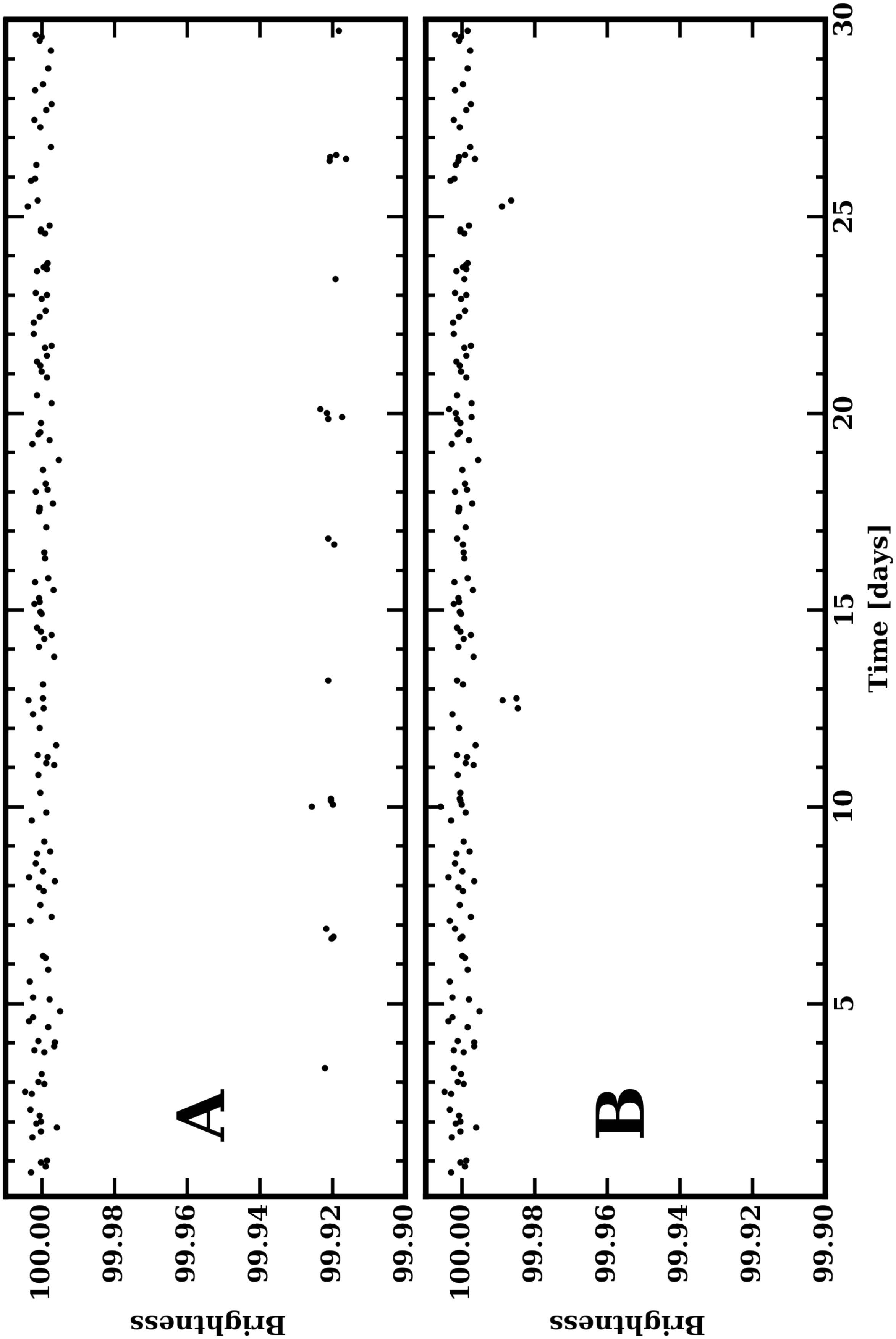
Planets that orbit stars other than the Sun are called **exoplanets**. The first published discovery of an exoplanet orbiting a main sequence star was in 1995. By the end of the 20th century, 50 exoplanets had been discovered. The early 21st century has seen the discovery rate increase tremendously, to the point that the number of discovered exoplanets has grown to nearly 2,000. The figure below shows the total number of exoplanet discoveries since 1995.



The huge jump in the discovery rate in 2014 corresponds to the release of data from the Kepler space telescope mission. The Kepler mission continually monitored the brightness of over 145,000 stars in a single field of view over a long period of time. The brightness of some of these monitored stars dimmed periodically as planets passed in front of the star, blocking out some of the starlight. We call these eclipses **transit** events, and this is how the majority of planets have been discovered to date.

The amount of light that a planet blocks out, known as the **transit depth** is related to how big the planet is. If the planet were the same size (had the same radius) as the star it would block out the star light completely when it passed in front, and if the planet were the size of a piece of dust it wouldn't block out much light at all (see figure below).




A
B
Brightness
Brightness
100.00
99.98
99.96
99.94
99.92
99.90
Time [days]
5
10
15
20
25
30

Change of Brightness

The data on the previous page shows the brightness of two solar-type stars measured over a time of 30 days. You can see that at certain times the brightness of both stars drops and then returns to the normal level (100%). This drop is due to a planet crossing in front of the star (transiting), blocking out a small portion of the light that reached the Earth.

The change of brightness (ΔB) can be calculated from the data by:

$$\Delta \mathrm{B} = \frac{100\% - \mathrm{Lowest}\%}{100} \tag{1}$$

Where Lowest% is the brightness of the star during the transit.

> **1** (2 pts) Calculate ΔB for each of the two stars and record your result in the data table.

Exoplanet Size

The amount of light that is blocked (ΔB) depends on how large the planet is. The larger the planet, the more light that is blocked. Using ΔB, we can calculate the ratio of the radius of the planet to the radius of the star:

$$\Delta \mathrm{B} = \left(\frac{\text{Radius of the planet}}{\text{Radius of the star}}\right)^2 \tag{2}$$

If we assume that the stars have the same mass and radius as the Sun, we can calculate the radius of the transiting exoplanets. The Sun has a radius 109 times larger than the radius of the Earth, so we can rearrange Equation 2 like so:

$$\text{Radius of the planet } [\mathrm{R}_\oplus] = 109 \times \sqrt{\Delta \mathrm{B}} \tag{3}$$

where the radius of the exoplanet in units of Earth radii, and ΔB is the change of brightness.

> **2** (2 pts) Calculate the radii for each of the two exoplanets and record your result in the data table.

Exoplanet Type

There's good reason to believe that exoplanets with radii 2 × larger than the Earth's are likely to be gaseous, and smaller exoplanets are likely to be rocky.

3 (2 pts) Determine what type of planet each of the exoplanets is and record your result in the data table.

Exoplanet Mass

The mass of an exoplanet can be estimated using the following equation:

$$\text{Mass of the planet } [\mathrm{M}_\oplus] = \frac{\rho \times \mathrm{R}_\oplus^3}{5.5} \tag{4}$$

where the mass of the exoplanet in units of Earth masses, $R_\oplus$ is the radius of the exoplanet in units of Earth radii, and ρ is the density of the exoplanet in g/cm^3.

The density of the exoplanet can be estimated from your answer to the previous question. For rocky exoplanets we can assume a density of $\rho = 3.5$ g/cm^3, and for gaseous exoplanets assume a density of $\rho = 1.5$ g/cm^3.

4 (2 pts) Calculate the mass for each of the two exoplanets and record your result in the data table.

Exoplanet Period and Distance

Looking back at the data, you can see that there are multiple times, during the 30 days of observation, when the planet passes in front of the star. The time between transit events is a direct measure of how long it takes the exoplanet to orbit the star (orbital period).

5 (4 pts) Calculate the orbital period of each of the exoplanets and record your result in the data table. Express you answer in both days and years (1 year = 364.25 days).

Once we have the orbital period of the exoplanets, we can calculate the distance of the exoplanet from the star that it orbits

$$\text{Orbital Period [years]}^2 = \text{Distance [AU]}^3 \tag{5}$$

6 (2 pts) Calculate the distance of each of the exoplanets and record your result in the data table.

Transit Probability

Transits can only be detected if the orientation of the exoplanet's orbit is near the line-of-sight (LOS) between the observer and the star. The orientation of exoplanet orbits are random, so we can only observe a very small fraction of the total exoplanet system. The probability for seeing a transit for any random planetary orbit is:

$$\text{Transit Probability [\%]} = \frac{0.465}{\text{Distance [AU]}} \tag{6}$$

7 (2 pts) Calculate the transit probability of each of the exoplanets and record your result in the data table.

	Exoplanet A	**Exoplanet B**
ΔB		
Radius [$R_\oplus$]		
Rocky or Gaseous?		
Mass [$M_\oplus$]		
Period [days]		
Period [years]		
Distance [AU]		
Transit Probability		

8 (2 pts) Is is likely that the rocky planet would have liquid water on its surface? Explain why or why not.

9 (4 pts) Assume when you were observing exoplanet B you could not collect any data on days 10 - 15 (it was cloudy). How would your knowledge of the exoplanet change without this data?

10 (2 pts) If you were to observe for 1 random day during the 30, How likely would you be to observe a transit of exoplanet A? Express your answer as a percentage (*i.e.* you would have a 90% chance of observing the transit).

11 (2 pts) Same question as above, but for exoplanet B.

12 (4 pts) Same question as above, but for an exoplanet at a distance of 1 AU.

You can increase the probability of observing a transit by collecting data over a long period of time or by look at lots of stars at once. If you have a 5% chance of observing a transit in a day for a single star, if you observe 20 stars in a day you will have a 100% chance of observing a transit.

13 (2 pts) How many solar-type stars would have to observer over 30 days to guarantee that you would observe the transit of an exoplanet at a distance of 1 AU?

14 (2 pts) How many solar-type stars would have to observer over 30 days to guarantee that you would observe the transit of an exoplanet at a distance of 1 AU, if your probability was only 0.47% of your original probability?