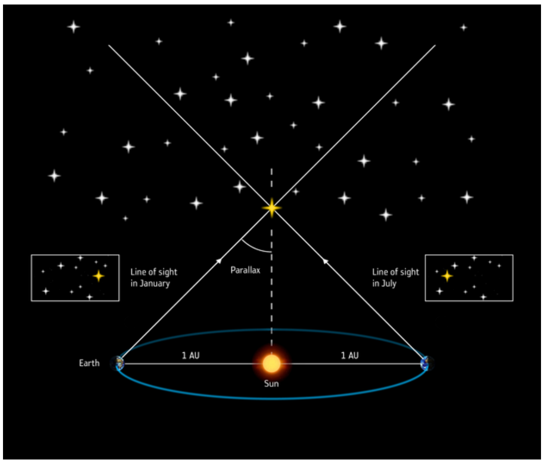
Today, I am William Herschel!



Recreate the discovery of planet Uranus.

Metadata

General Info

Title: Today, I am William Herschel!

Short description: Students simulate the historical observations of William Herschel and calculate the orbital period of Uranus.

Keywords
Uranus, Kepler's Law, planets, solar system, distance, space

Educational Context

Context: Students explore the concepts of triangulation, parallax and angular displacement and how one can use them to derive distances to astronomical objects. Then, they simulate the historical observations of William Herschel that led to the discovery of Uranus, and use the results to derive its orbital distance and period.

Age: 13-18

Prerequisites: trigonometry, basic information about the Solar System

Lv. Of difficulty 3

Aggregation Level

Duration :3-4hrs

Educational Objective

Cognitive Objectives

- To become familiar with the scale of distances that astronomers deal with.

Affective

- To understand the importance of technology's evolution in science.

Psychomotor

- Using measure devices (ruler, protractor)

Subject Domain

Big Ideas of Science

The Solar System is a very small part of one of millions of galaxies in the Universe.

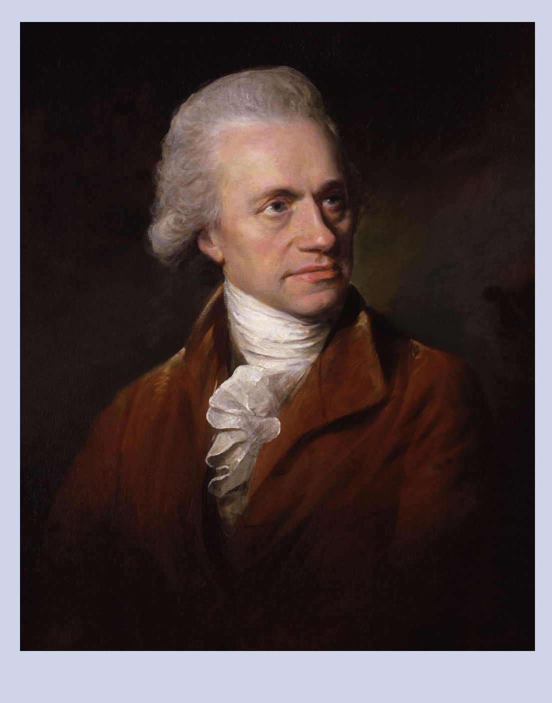
Subject Domain

Physics

Orienting & Asking Questions

Background

The year was 1781. William Herschel, a professional musician who decided to become an astronomer at age 35, was scouting the heavens in the Taurus constellation region with his home-built 15-cm telescope.



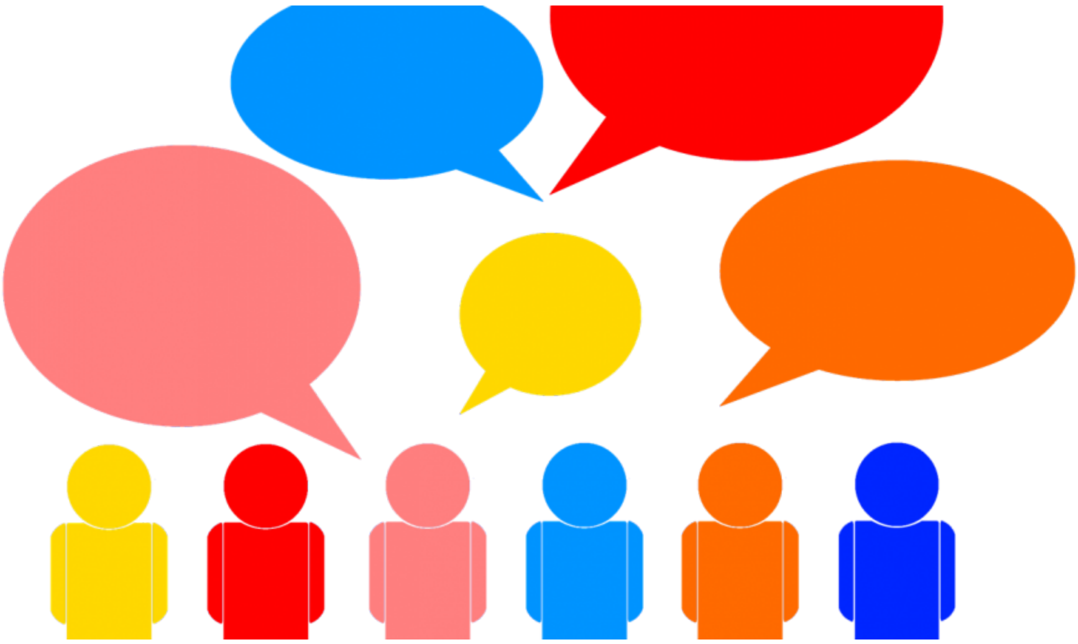
WILLIAM HERSCHEL (1738-1822) AND THE TELESCOPE USED TO DISCOVER URANUS.

On March 13, he accidentally found an uncommonly bright object that had a well-defined disk, unlike stars, and moved slowly from one night to another against the background stars.

At first, he thought it could be a comet, far away from the Sun, without a developed tail. But after several observations, he concluded that the object was not a comet after all, but a planet beyond the orbit of Saturn. Herschel had discovered Uranus, the seventh planet and the first planet discovered in the modern age.

In this demonstrator, you will retrace Herschel's steps, first by reflecting on how we can obtain the distance and orbital period of an object just by its apparent movement in the heavens. Then, you will recreate Herschel's historic observations using planetarium software. Finally, you will calculate Uranus' orbital period and distance using these simulations. **Today, you are William Herschel!**

Measuring the distance of distant objects



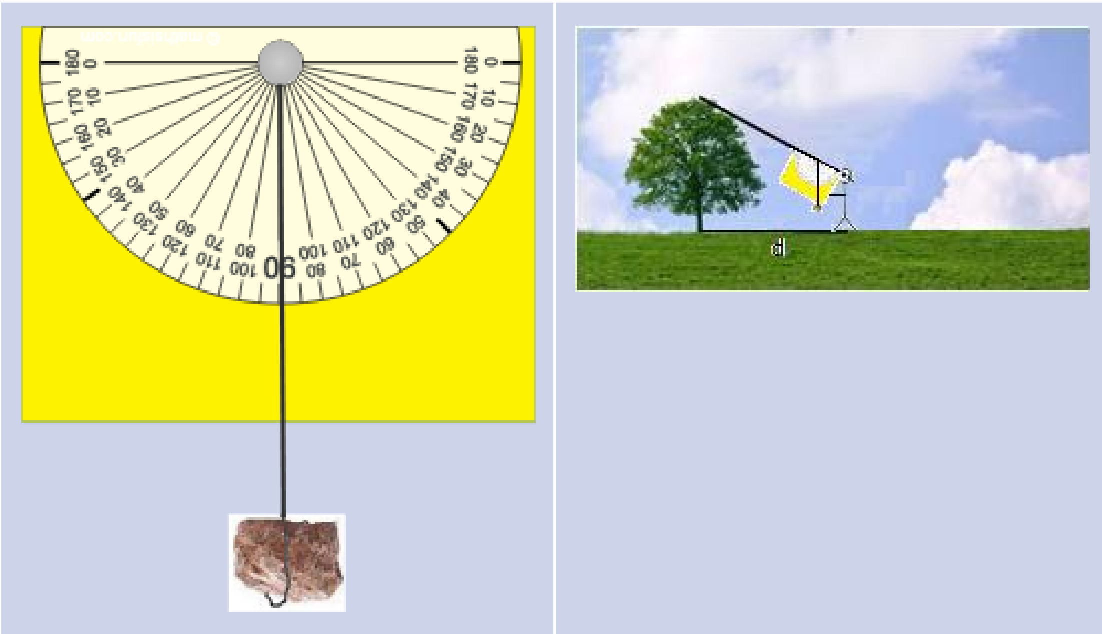
Before we pretend we are Herschel, let us ask you a question: how is it even possible to know the distance to a planet? There are no million kilometer measuring tapes available in the market. Can you imagine how people can calculate the distance to distant objects without actually using a measuring tape? Discuss the possibilities with your friends.

You probably have seen this scene: a few people with hard hats looking through a strange instrument positioned over a tripod. Most likely these are engineers or engineering students using a theodolite. This secular instrument allows for precise angular measurements of foreground objects relative to a more distant background.

Theodolites are very useful for measuring sizes and distances of objects. For instance, how can you measure the size of a tall tree or building? If you measure the angle the top of the object makes with the ground with a theodolite, and somehow know the distance from the object to you, then it's a straightforward calculation.

You don’t need to buy a theodolite to understand how it works. Instead, you can build a simple version using ordinary stationary materials. Following the instructions in this link, you will be able to build a simple theodolite and measure the height of a tree.

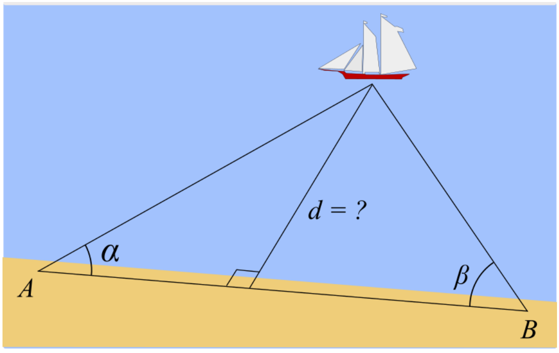
https://www.mathsisfun.com/activity/how-high.html



USING A SIMPLE THEODOLITE TO MEASURE THE HEIGHT OF A TREE.

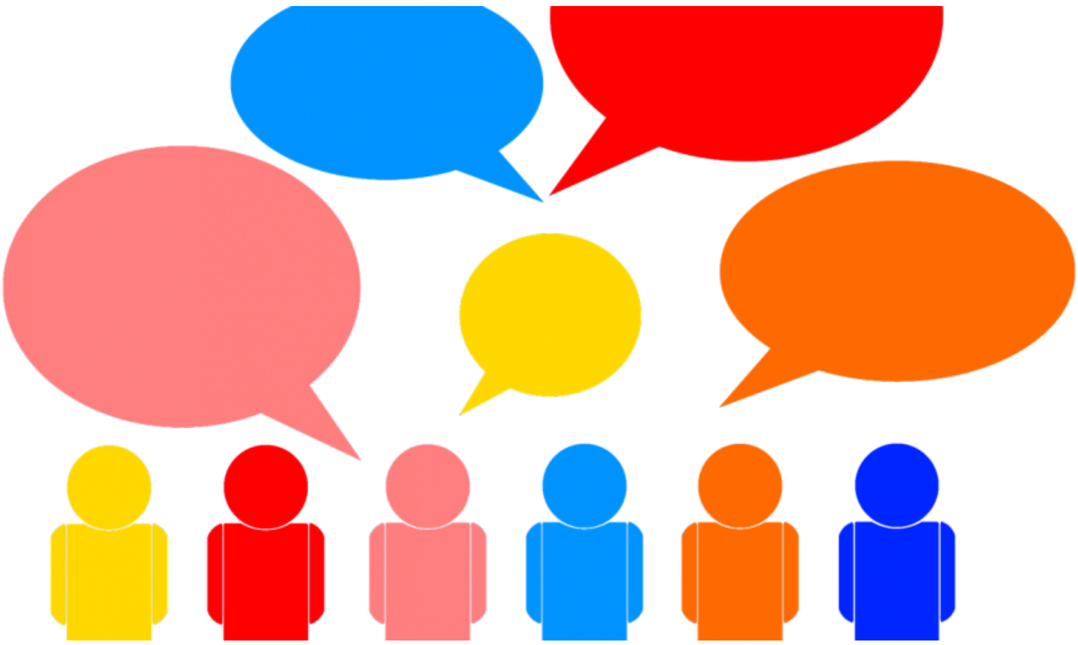
The same principle can be used to calculate a distance to a very distant object, such as mountains. This is done by comparing the apparent position of the object from two different viewpoints. This apparent displacement is called parallax.

Parallax can be demonstrated by closing one eye and holding up your index finger at arm’s length. Place your other index finger at a position that is closer to your face. Now, look at your fingers with the other eye. As you alternate between your left and right eye, your fingers appear to move back and forth. This observation is due to the fact that the position from which you are viewing your finger is changing.



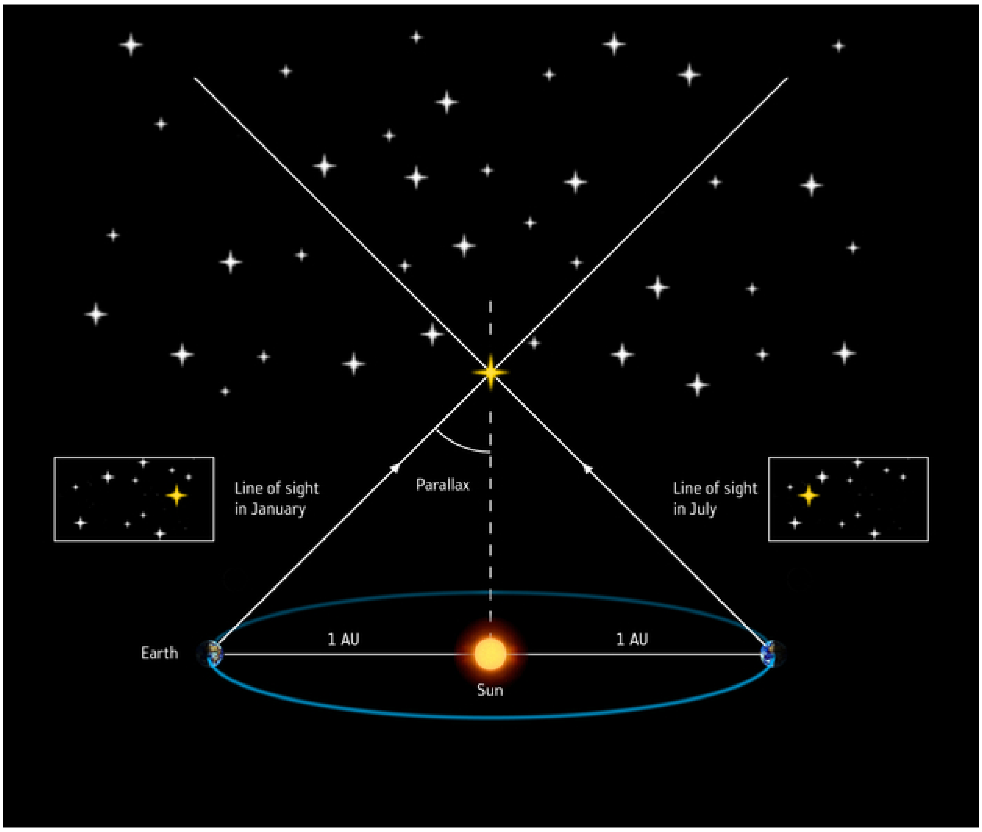
We can use parallax to measure the distance to a distant ship. Two observers at points A and B separated by a distance measure the angles α and β. Therefore, the distance d to the ship can be obtained using right triangle properties.

$$d = \ell \, \frac{\sin\alpha \sin\beta}{\sin(\alpha+\beta)}$$



What happens with the parallax angles as the distance to the object increases? Can you imagine how we can use parallax to measure the distance to planets? Discuss this with your friends.
Parallax occurs when observing planets and nearby stars from the Earth as it orbits around the Sun. The planets and some stars appear to move a lot,

whilst others do not seem to move as much. Therefore, by measuring the parallax angle, it is possible to determine approximately how far away a celestial object is. Astronomers achieve this by viewing the star or planet from two different locations in the Earth's orbit around the Sun. For very distant stars, there does not appear to be any shift in position and consequently, it can be difficult to estimate their distances from the Earth.

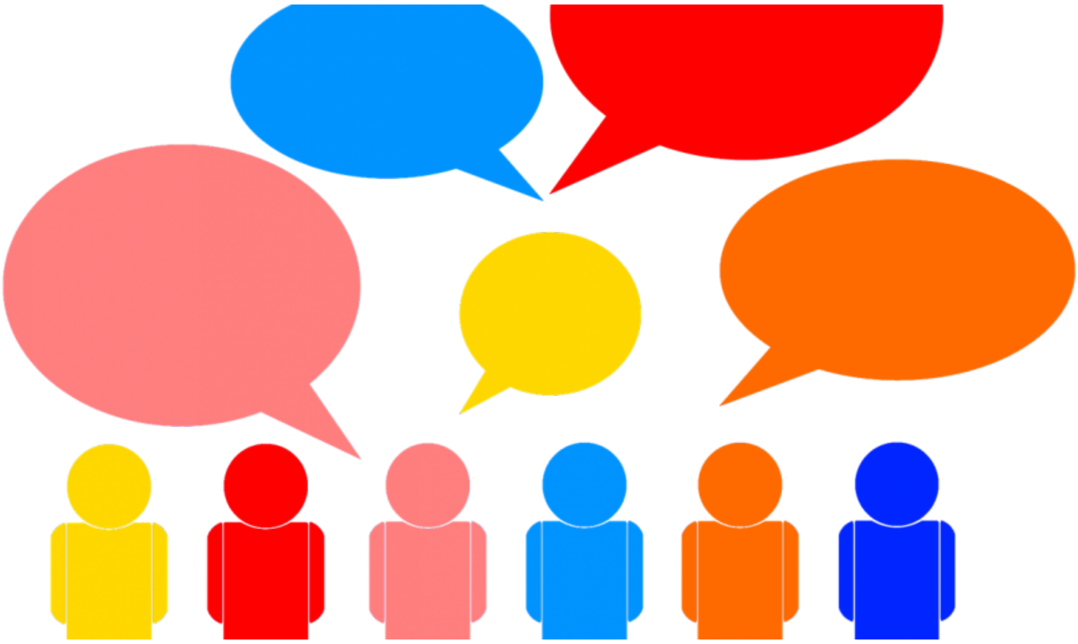


When Herschel accidentally discovered Uranus, he was actually trying to measure parallax angles of stars. It turns out that stars are so far away that these angles are incredibly small - ten thousand times smaller than one degree. It would take 57 years after Herschel's discovery for astronomers to successfully measure the distance of a star using parallax. This was done by Friedrich Bessel in 1838. He measured the distance to the star 61 Cygni using a special instrument called the heliometer. Its parallax angle is 0.287 arcseconds, which translates to a distance of 11,4 light years, or 100 trillion kilometers!

Hypothesis Generation and Design

Generation of Hypotheses or Preliminary Explanations

Apparent motion of solar system objects



Planets are much closer than the stars. In fact, Herschel immediately concluded that the object he discovered was a solar system object because it moved against the starry background night after night. It was a question of determining whether it was a comet or a planet. Can you imagine how he was able to tell the difference? What could be the main differences in apparent motion between the two kinds of objects? Discuss that with your friends.

When we look at the sky, we see celestial objects with very different distances from us. We have the Moon, our closest neighbour in space at 384 000 km, planets like Jupiter and Saturn who are several hundred million km away, and the stars much farther apart.

If we observe the sky during several nights, we will notice that some objects do not appear in the exact same position relative to the background stars. Which object presents the most noticeable apparent motion? What factor is the most relevant to the magnitude of this motion? Discuss that with your friends.

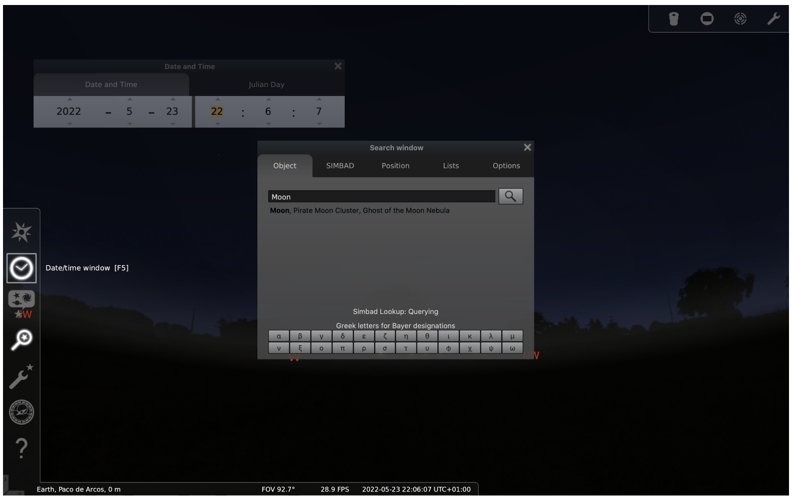
You have concluded that the closest the object is to the observer, the faster will be its apparent motion against the background. Astronomers name the interval period between two identical positions of an object orbital period. In the 17th century, astronomer Johannes Kepler discovered a remarkable relationship between the orbital period and the distance of solar objects.

The so-called Harmonic Law, or Kepler's Third Law of Planetary Motion, states that the square of the orbital period is proportional to the third power of the mean orbital distance. In other words, if one can measure the orbital period of a solar system object, one can derive its distance from the Sun by using Kepler's third law. This nice video summarises Kepler's historical discoveries regarding planetary orbits.

Design/Model

To recreate Herschel's discovery of Uranus, we will use a powerful tool: Stellarium, a planetarium software that was presented to you on our toolkit. Stellarium allows us to simulate the position of celestial objects with high accuracy thousands of years in the past or in the future.

Use Stellarium to simulate the sky at your location for tonight. Use the search tool (magnifying glass) to find the Moon. Now, advance the simulation one night. Did the Moon change its position relative to the background stars? By how much was this change?



LOCATING THE MOON IN THE NIGHT SKY USING STELLARIUM

Now, locate the planet Jupiter in the sky. Do the same experiment. Did you notice any change in Jupiter's position?

As you may imagine now, the farther away a planet is from the Sun, the slower is its movement in respect to the background stars. It takes several years for an outer planet to complete a full revolution around the Sun. So how can astronomers determine the orbital period of distant planets after a few months of observations? Discuss this with your colleagues and how you can test your hypothesis using Stellarium.

Planning and Investigation

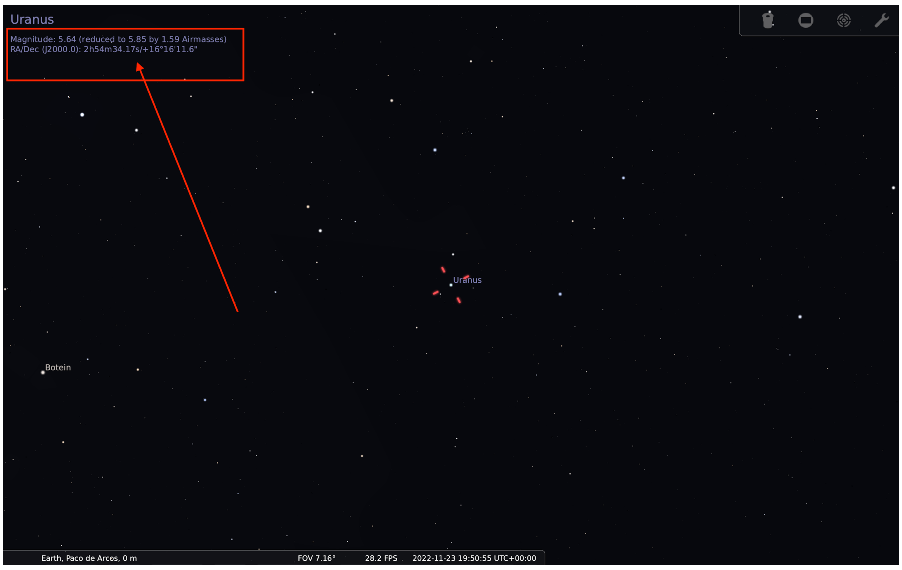
Plan Investigation

In the previous section, you should have concluded that astronomers do not need to observe a full revolution of a celestial object around the Sun to calculate its orbital period. It is only necessary to follow the body's motion against the background stars during a short time, usually a few months, and measure its apparent overall motion. This is called an observation arc, and it is measured in units of angle/time.

For example, if a hypothetical object displays an apparent motion of one degree per year, then a simple proportion rule results that it will take roughly 365 years for it to complete a full revolution around the sun.

Use this reasoning to plan simulations that will prove to you this method is useful. How can you use Stellarium to simulate observation arcs of Jupiter and Saturn? Then, how can you use the simulation results to derive these planets' orbital properties (orbital period and orbital distance)? Discuss with your colleagues.

It might be useful to use celestial coordinates Right Ascension (RA) and Declination (Dec) to measure the angular displacement. These are displayed at the top right corner. For historical reasons, Right Ascension is usually measured in hours, minutes and seconds instead of degrees. One hour of right ascension equals 15 degrees.



Use celestial coordinates To accurately measure positions in the sky.

Perform Investigation

Let's start by testing our method with Jupiter and Saturn. Measure the position of these planets until you have a large enough arc of observations (a few degrees will suffice). Then, estimate the orbital period and distance of these planets. Did you get an acceptable result? Compare it with the values below.

Planet	Orbital Period (years)	Orbital Distance (AU)
Jupiter	12	5.2
Saturn	29	9.5

It is now time to use our time machine to get back to 1781 and recreate Herschel's discovery of Uranus. Using Stellarium, set your location to Bath, England, and the date to March 13, 1781. That evening, Uranus was in the region of the star Zeta Tauri. Try to locate Uranus in the simulation.

Uranus position in the sky on the date of its discovery by William Herschel.

Analysis & Interpretation

Discuss with your colleagues how many nights Herschel would need to observe that sky region to perceive Uranus' apparent motion. Test these hypotheses by simulating them in Stellarium. Then, discuss how long it would take for Uranus to complete a full revolution in the sky and return to its starting point in Taurus. What is a good estimate for Uranus' orbital period? Using Keplers' law, what is Uranus' distance from the Sun?

Conclusion & Evaluation

Conclude and communicate result/explanation

Congratulations, you have successfully recreated the historical observations of William Herschel that led to the discovery of planet Uranus. Furthermore, you were able to estimate Uranus orbital period and distance. It's time to communicate the results to your colleagues. Work on a short presentation explaining the work you have done.