Activity 10  
Case Study: Orbiting Nothing

Over 450 years ago, German astronomer Johannes Kepler used observational data to determine that the planets orbit the Sun in elliptical orbits (Figure 1). As the planets get closer to the Sun, they speed up; as they get farther from the Sun, they slow down. The length of the year is defined as the amount of time taken for the planet to complete one orbit around the Sun.

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Figure 1 One of Kepler’s three main ideas is that the planets move in elliptical orbits around the Sun, with the Sun at one focus.

When Isaac Newton developed his law of universal gravitation, he was building on Kepler’s ideas. In Newton’s model, the mass of the Sun exerts a gravitational force on the planets, making them orbit in ellipses. The size of the ellipse and the speed of the planets can be used to determine the mass of the Sun. Newton’s model represents a pivotal moment in the development of astronomy: ideas that describe motion on Earth could be extended to describe the motion of the planets.

Scientists and engineers have since used Newton’s model for gravity to put satellites into orbit, to send people to the Moon, and to launch space probes, some of which have even left the solar system. The idea that less massive objects orbit more massive objects has been very well supported at many scales.

Observations of our own galaxy have confirmed that our Sun, which is 27 000 light years from the centre of the Milky Way, orbits once every 240 million years. But what is at the centre of the orbit? One of the challenges for astronomers trying to answer that question is that there is a huge amount of dust between us and the galactic centre, which prevents visible light from reaching us. Looking at other galaxies we can take measurements and build models that we can apply to our galaxy, but observational data is always preferable.

Unlike visible light, radio signals can go through dust clouds. So in the 1950s, astronomers began to use radio telescopes to study the universe. They discovered that many galaxies, including our own, are bright radio sources. The radio source at the centre of the Milky Way Galaxy is called Sagittarius A. Early radio telescopes lacked the ability to resolve the signals into clear images—astronomers knew something was there, but they could not tell what it was. As technology and techniques improved, astronomers were able to determine that the source of the signals was a disk of gas spinning around a very compact object dubbed Sgr A\* (pronounced “Sagittarius A star”).

The most compelling piece of evidence for the nature of Sgr A\* was released by the European Space Observatory (ESO) in 2002 after a series of observations spanning over 10 years produced the path of a star called S2 as it orbits Sgr A\* (Figure 2). Calculations based on the elliptical orbit of S2 point to something with a mass of over 4 million solar masses in a space that is less than the area of our solar system. Analysis of 28 other stars orbiting Sgr A\* gives the same value.

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Figure 2 The star S2 takes about 15.8 years to orbit Sgr A\*.

Further observations of Sgr A\* have also revealed that it is not moving. Stars such as S2 are orbiting at speeds above   
10 000 km/s, but Sgr A\* is essentially motionless. Another clue to the nature of Sgr A\* is the lack of infrared emission—Sgr A\* releases less infrared light than an average star, but it does have the occasional flare-up of infrared and X-ray emissions.

All the evidence points to Sgr A\* being a supermassive black hole (SMBH). Every star in our galaxy is orbiting a black hole that has a mass of 4.3 million Suns. Efforts are currently underway to image Sgr A\* with new techniques that will give a clearer picture of its size. Another exciting prospect is that a large ball of gas is approaching Sgr A\*. Starting in 2014, astronomers will be able to make detailed observations of the black hole as it pulls the gas into it.

Our galaxy is only one of hundreds of billions of galaxies. Observations made by the Hubble Space Telescope confirm that every galaxy close enough to see clearly has a SMBH at its centre. The same laws of physics that were identified to explain how the planets orbit the Sun are being used to prove that our Sun is orbiting a SMBH, and that all the stars in all the galaxies are orbiting SMBHs.

Understanding Content

Planets orbit the Sun

(a) in elliptical orbits.

(b) at a constant speed.

(c) once every day.

(d) in circular orbits.

2. SMBH stands for

(a) stellar mass black hole

(b) solar mass black hole

(c) supermassive black hole

(d) standard mass black hole

3. Which of the following is not observed near Sgr A\*?

(a) stars orbiting in definite elliptical orbits

(b) stars being pulled into the black hole

(c) occasional X-ray flare-ups

(d) faint infrared emission

4. How long does it take our solar system to complete one orbit around Sgr A\*?

(a) 1 year

(b) 10 years

(c) 27 000 years

(d) 240 million years

Write a summary statement that gives the key pieces of observational evidence that Sgr A\* is a supermassive black hole.

Exploring Context

1. Isaac Newton used the laws of motion developed on Earth to explain the motion of the planets. How far can these laws be extended?
2. One common idea about black holes is that they pull everything into them. How does the observational data refute that idea?

1. Some people reject the conclusion that there is a black hole at the centre of our galaxy. How can you convince someone about black holes when you can never see one directly?

1. Scientists are often portrayed in the media as not being very creative. How does the story of Sgr A\* show that scientists are creative?