International Year of Astronomy 2009

Schools Projects for Autumn Moonwatch

Project 4: The Moons of Jupiter

Suitable for advanced primary and secondary ages, and for telescopic observing.

One of the most important of Galileo's discoveries was the four moons of the planet Jupiter. These are still known today as the Galilean satellites and they are: (in order of increasing distance from Jupiter) Io, Europa, Ganymede and Callisto.

In recent years we have come to know these four worlds in fantastic detail, thanks to the Voyager and Galileo spacecraft which visited them. In 1610 through Galileo's telescope, however, they appeared simply as points of light – like little stars accompanying Jupiter across the sky. Nonetheless, Galileo's discovery was remarkable: for the first time there was clear evidence that celestial bodies did *not* orbit the Earth. This was a crucial step towards establishing that the Earth was *not* at the centre of the Universe.

Fig 1: Extract from Galileo's diary, January 1610, showing the changing positions of the four moons of Jupiter

During the autumn and winter evenings of 2009-10 Jupiter and its moons are well placed for observing through binoculars or a small telescope. Over the course of a few nights, you will see the moons change their position as they orbit the giant planet – sometimes crossing the disk in front, sometimes disappearing behind it.

The orbit of Io, the closest Galilean moon, lies at roughly the same distance from Jupiter as our Moon does from the Earth. And yet, because Jupiter is more than 300 times more massive than the Earth, its gravity whips Io around in its orbit once every 42 hours.

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Callisto, the outermost Galilean moon, orbits Jupiter at nearly 5 times the Earth-Moon distance, yet still completes almost two circuits of the planet in the time it takes our Moon to orbit the Earth.

The orbital periods of the Galilean Moons are no accident. They follow a strict mathematical relationship – as do the orbits of the planets around the Sun.

Ultimately, the explanation for these relationships lies with **Isaac Newton**'s law of Universal Gravitation, but they were first described – if not explained – by a near contemporary of Galileo, **Johannes Kepler**.

Fig 2: Images of the Galilean moons, as observed by the Galileo spacecraft. Clockwise from top left: Io, Europa, Callisto, Ganymede
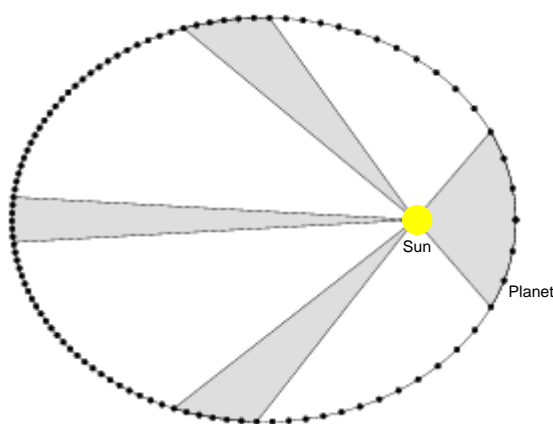
Fig 3. Illustration of Kepler's First and Second Laws of planetary motion.

In 1609 and 1619 Kepler published his **Three laws of Planetary Motion**.

Kepler's First Law abandoned the 2000 year-old idea, due to the Greeks, that the orbits of the planets were built from circles. Instead, the orbits are actually ellipses – flattened circles – With the Sun at one focus of the ellipse.

Kepler's Second Law states that planets sweeps out equal areas in equal times – which means that a planet will move faster when it is closer to the Sun.

Kepler's Third Law states that the average distance of a planet from the Sun is related to the period of its orbit: the **square** of the orbital period is proportional to the **cube** of its average distance from the Sun.

For example, Jupiter orbits the Sun at an average distance of about **5.2** times the average Earth-Sun distance. Now, 5.2 cubed equals 140.6.

According to Kepler's third law, that means that Jupiter's orbital period should equal (in years) the square root of 140.6, or **11.86 years**. This is extremely close to Jupiter's actual orbital period.

Kepler's laws also apply to the Galilean moons, and you can test this for yourself during the autumn and winter of 2009-10.

- By carefully observing when the Galilean moons appear furthest from the planet Jupiter, you can measure the relative **size** of their orbits.

- By carefully timing how long it takes each moon to return to the same position with respect to Jupiter, you can measure the **period** of their orbits.
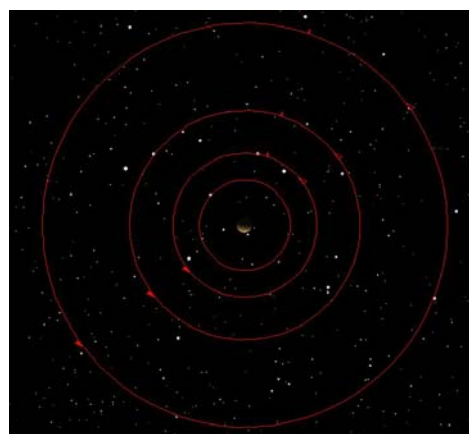
If Kepler's third law is correct, then you should find that (e.g. for Io and Europa):

Fig 4. Aerial view of the Jupiter system, showing the orbits of the Galilean moons.

$$\left(\frac{\text{size of Io's orbit}}{\text{size of Europa's orbit}} \right)^3 = \left(\frac{\text{period of Io's orbit}}{\text{period of Europa's orbit}} \right)^2$$

And you can test the equivalent relation for any other pair of Galilean moons.

Fig 5. Simulated view of the Jupiter system through a small telescope.

Figure 5 shows a simulation of Jupiter and its four Galilean moons, as they appeared through a small telescope at midnight on October 24th – i.e. the start of Autumn Moonwatch week.

By keeping a regular record of the relative positions of Jupiter's moons from night to night (and throughout the night), and by analysing your drawings or photographs, you can test Kepler's Third Law.

Of course this may be trickier in practice because there will be gaps in your records – due to cloudy weather and daylight, or when Jupiter has set below the horizon.

To help you fill in these gaps, you can download from the Scottish Solar System website an archive of simulated images, showing the positions of the Galilean moons and Jupiter at 3 hour intervals, from Autumn Moonwatch week to the end of November 2009. The archive images will be updated regularly later in the autumn and winter of 2009-10. (Note that all times refer to Greenwich Mean Time).