Storytelling with Uniview #05:
Kepler's Laws of Planetary Motion

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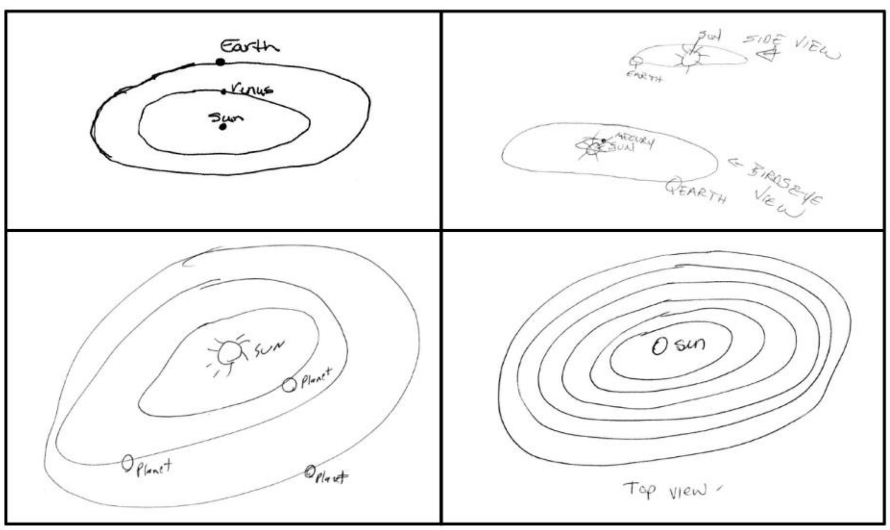
Johannes Kepler derived three Laws of Planetary Motion, which are usually stated as:

1. Planets orbit the Sun in elliptical orbits, with the Sun at one of the foci of the ellipse.
2. The planets sweep out an equal area in equal amounts of time as they travel in their elliptical orbits.
3. When comparing two planets in orbit around the Sun, the ratio of the squares of their periods in years is equal to the ratio of the cubes of their semi-major axes in astronomical units, or $P_1^2/P_2^2 = a_1^3/a_2^3$.

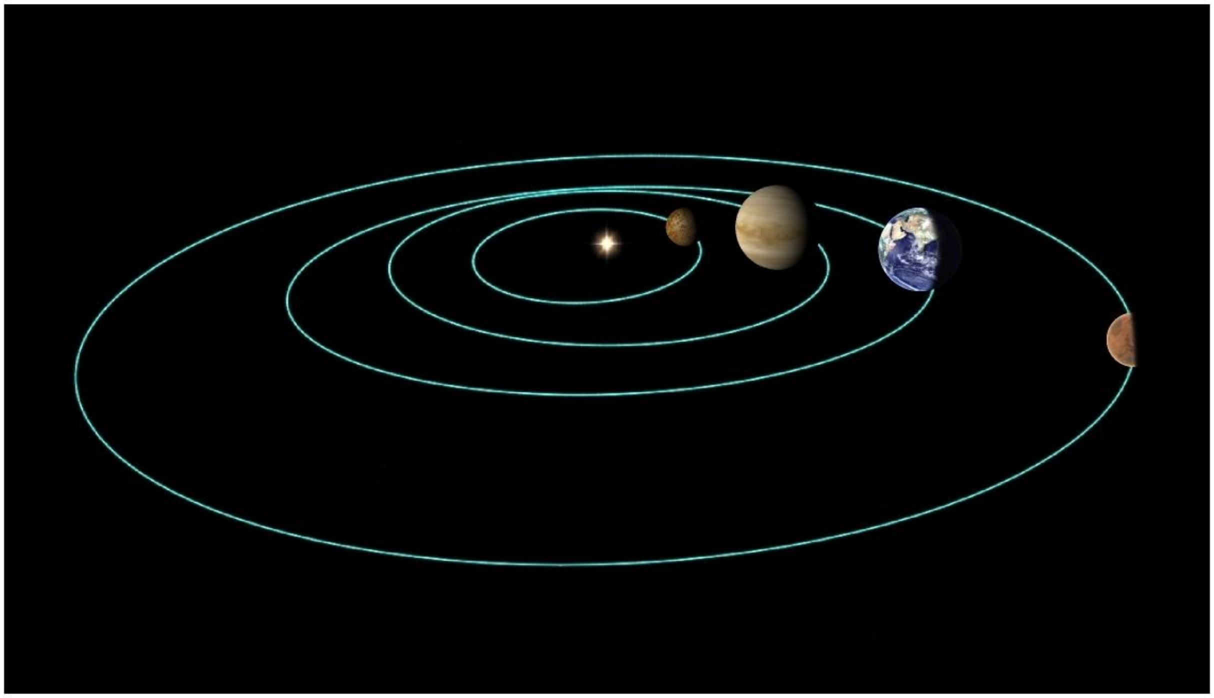
Unless someone was really interested in the details of these laws of planetary motion, I would never state them in the form given above. However it is useful to discuss simplified versions of these with visitors. To me, an important point about the Universe for the public to understand is that gravity is the dominant force for objects in our Solar System (as well as for objects at larger scales, from our Milky Way Galaxy to clusters and superclusters of galaxies). And when we show the dynamics of Solar System bodies, we are also demonstrating that the Universe can be predictable and understandable, and the simplest example of this is that of the planets orbiting our Sun.



For **Kepler's 1st Law**, tell the public that planetary orbits are circles—or very near circles. People get confused when you say ellipses, since many think of an ellipse as an extremely elongated cigar-shape, and don't consider circles to be a special case of an ellipse. For instance when undergraduates were asked about the shapes of planetary orbits, not only did most students state they were elliptical or "oval," but the drawings they gave were distinctly flattened. When making the above drawings, undergraduate students were asked if they were showing orbits from a "top-down" or "sideways" view. They all universally said these were views from above the plane. In the upper-right picture, you will note that one student has actually drawn *both* the face-on (or "birdseye") and side views and has labeled them as such, and both look like flattened bananas! So mention circles first, and bring up ellipses carefully, lest you reinforce the notion that orbits are sausage-shaped.

I suspect the origin of such extreme shapes is the prevalence of views of the Solar System in flat media.

Do a Google search of "planet orbits" or "solar system" and you will see lots of representations like this:

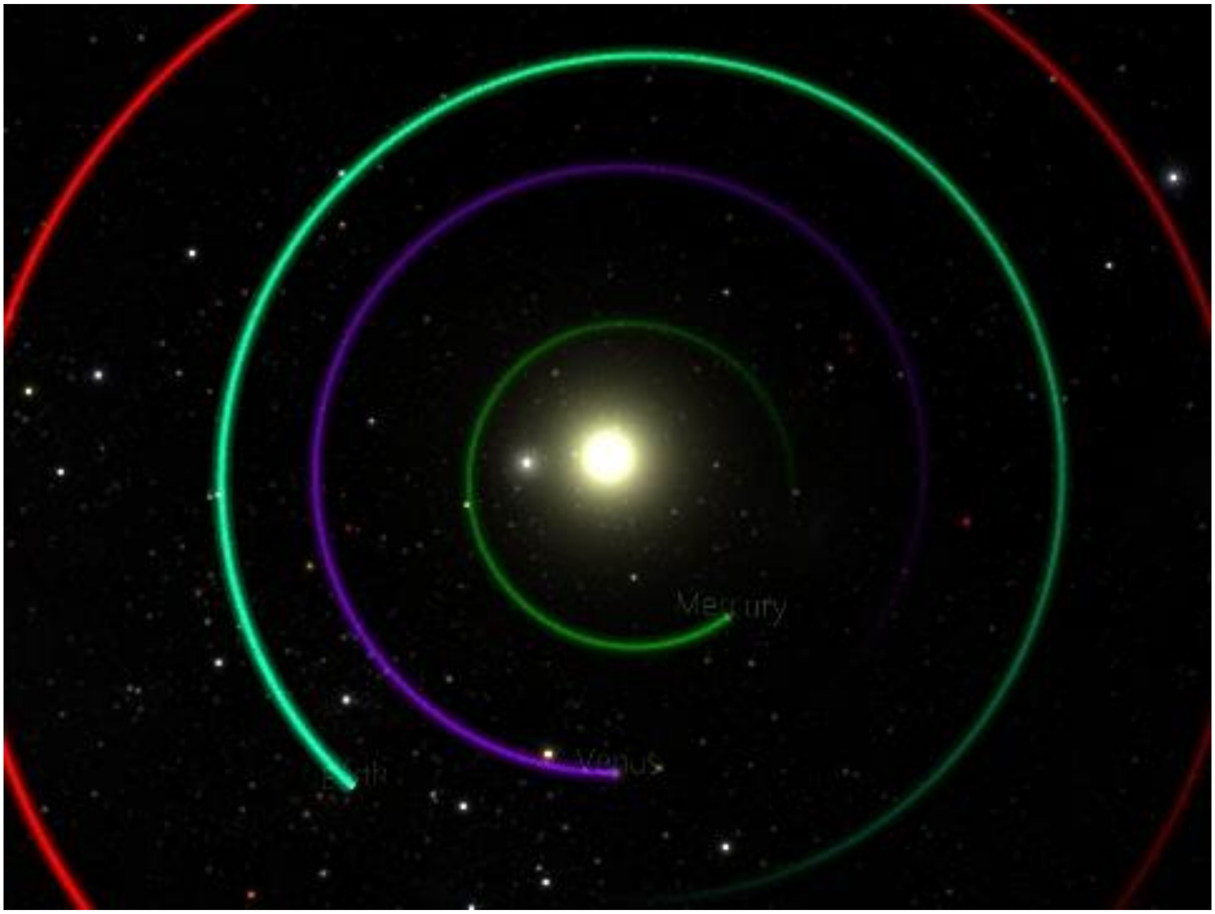


When we are limited to a two-dimensional view of a three-dimensional phenomenon like planetary orbits, these side-view orbital shapes may get lodged in people's mental models of the Solar System. But with a virtual simulation like Uniview, you can escape this locked-in perspective and give visitors a chance to see orbits from multiple frames of reference.

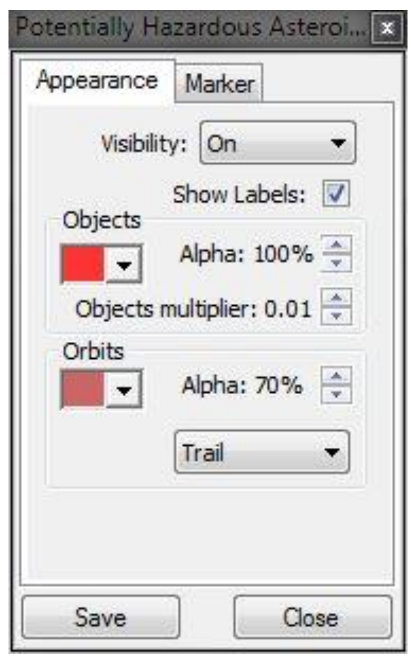
If you've played with Uniview, you know that none of the planets have the extreme shapes shown in the above student drawings. So one misconception you can dispel is the "eccentricity" of planetary orbits—that is how much the ellipse deviates from a circle. If the eccentricity is *e=0,* the orbit is a circle. As the eccentricity increases above zero, the shape stretches out into an increasingly elongated ellipse. In Uniview, you can challenge a visitor to see if he can detect any deviation from a perfect circle for planetary orbits. For most of the planets, it's very hard to do. Earth has *e=0.0167,* so its orbit is very close to circular. The most distinctly elliptical orbit is Mercury's with *e=0.2056*, which is large enough that you can tell it is distinctly squashed.

If you feel the visitor understands the shape of planetary orbits reasonably well, you can proceed to showing off comet or asteroid orbits. Many of these are clearly elongated. More below in the section on the **3rd Law** on what you can do.

One way to simplify **Kepler's 2nd Law** is to state simply that planets further from the Sun orbit slower. The reason why has to do with the inverse square fall-off with distance of the strength of gravity (which as you will recall in the last column, can be a tricky topic to discuss). To demonstrate this, position the camera above the plane of the Solar System so that the inner planets are clearly visible:



Then turn the simulation time to run 7 days per second or more. It should be clear that Mercury is moving faster than Venus, Venus is orbiting faster than Earth, Mars moving faster than Jupiter, and so on. This is the case even if each successive planet has farther to travel along its wider orbital track.



A simplified form of **Kepler's 3rd Law** for the public: along its orbit, a planet will have a greater velocity when it is closer to the Sun than when it is further away. This is not easy to see unless you have a highly elliptical orbit. It is difficult to see the difference between the speeds of Mercury at its closest and furthest points from the Sun. A better bet is to pick a comet or asteroid with a highly elliptical orbit. If you don't have a comet loaded in the Object Tree, but you do have **Potentially Hazardous Asteroids** loaded, select that class of objects in the Object Tree. Then go to the Properties window, reduce the "Objects multiplier" to 0.01, and make sure the Orbits pull-down menu is set to "Trail." Now if you run time forward at 30 days/second or more, you will see a lone asteroid ***(1566)Icarus*** orbiting the Sun. Its eccentricity is high enough (*e=0.8268*) that not only does it have a nicely elliptical shape, but its velocity changes noticeably between the furthest and closest points in its orbit. It's also inclined by 22 degrees relative to the ecliptic, so it's also a good example of how not everything in the Solar System has orbital planes that line up.

As a final thought, where else may we see gravitational dynamics played out? Unfortunately the simulation software does not show stars orbiting the Milky Way or whipping about inside a globular cluster. But if we stick with the Solar System, we find that the moons around each planet will follow behaviors similar to planets orbiting the Sun. Because of their familiarity, Earth and its natural and artificial satellites are a good choice for reinforcing these ideas. There are plenty of examples of satellites orbiting at different altitudes and with varying velocities. The International Space Station is at low Earth orbit (roughly 240 miles above the surface), and so completes a trip round the Earth in about 90 minutes. Satellites at geostationary orbit (22,236 miles up) take 24 hours. The Moon which is about 1000 times further than the ISS takes four weeks. Most satellites are in circular orbits. One example of highly eccentric (and inclined) orbits is that of Earth Satellites→Communication→Molniya, the Russian military communications satellites. Switch on the Orbit Trails and toggle on the labels to see them move over time. Turn the "Objects multiplier" down to 0.07 to reduce the flock of birds to a manageable one. The satellites' orbital trails lengthen when they near Earth, and shorten when they are far away, again reemphasizing the idea behind Kepler's 3rd Law.

Reference

Yu, K.C., Sahami, K., & Denn, G. 2010, "Student Ideas about Kepler's Laws and Planetary Orbital Motions," 2010, *Astronomy Education Review*, 010108-1.