Orbital Shape Distributions of Exoplanets

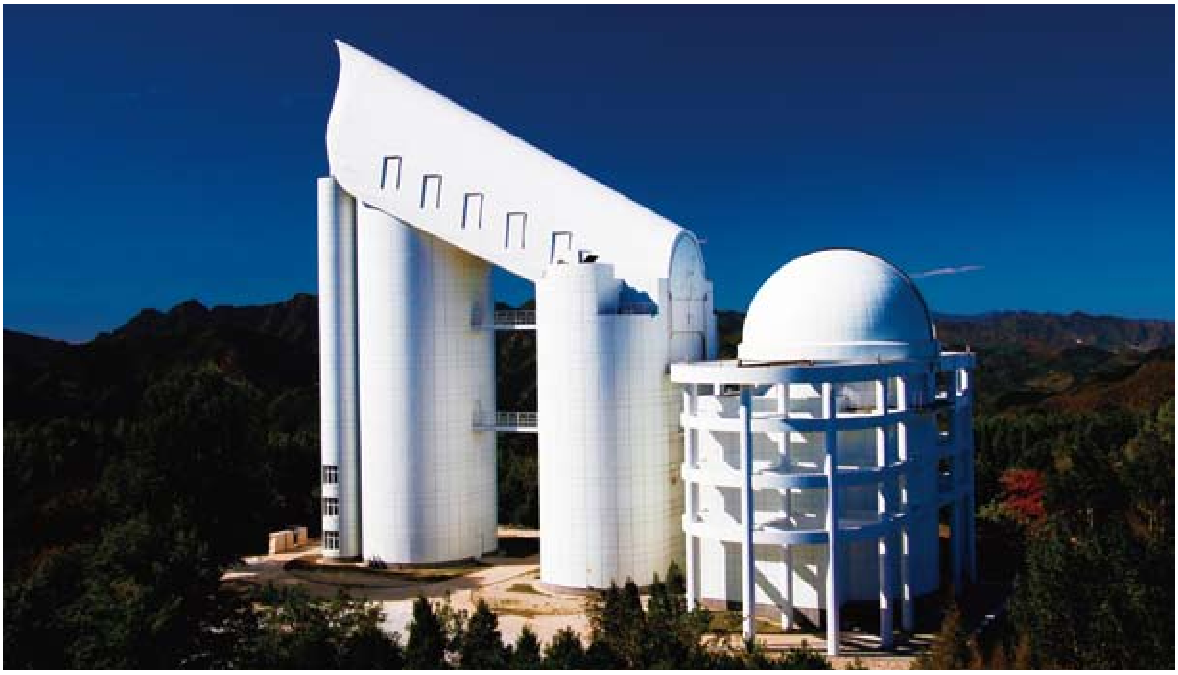
Using data from China's Large Sky Area Multi-Object Fiber Spectroscopy Telescope (LAMOST) telescope, a consortium of astronomers from Nanjing University, Peking University, the National Astronomical Observatories of CAS and Beijing Normal University have revealed new evidence about the distribution of orbital shapes of extrasolar planets.

Until two decades ago, the only planetary system known to mankind was our own solar system. Most planets in the solar system revolve around the Sun in nearly circular orbits, which happen to be on the same plane, more or less, with an average inclination angle of only three degrees.

Astronomers use a parameter called "eccentricity" to describe the shape of a planetary orbit. Eccentricity takes the value between 0 and 1: the closer its value is to 1, the more an orbit deviates from the standard circular shape. For instance, the averaged eccentricity of all planets in the solar system is 0.06. Motivated by circular and coplanar planetary orbits of our own solar system, Kant and Laplace hypothesized hundreds of years ago that planets should have been formed in disks, and this idea later developed into a "standard" theory on planet formation.

In 1995, scientists used the radial velocity technique to discover the first exoplanet around a Sun-like star, 51 Pegasi. This milestone discovery started an exciting era of exoplanet exploration. By the beginning of the 21st century, people had discovered hundreds of exoplanets, and most of them are giant planets comparable to the mass of Jupiter. These Jovian planets are actually relatively

The Large Sky Area Multi-Object Fiber Spectroscopy Telescope (LAMOST) telescope in Hebei, China. It is currently the most efficient "spectroscopy factory" in the world, capable of collecting up to 4,000 stellar spectra at once.

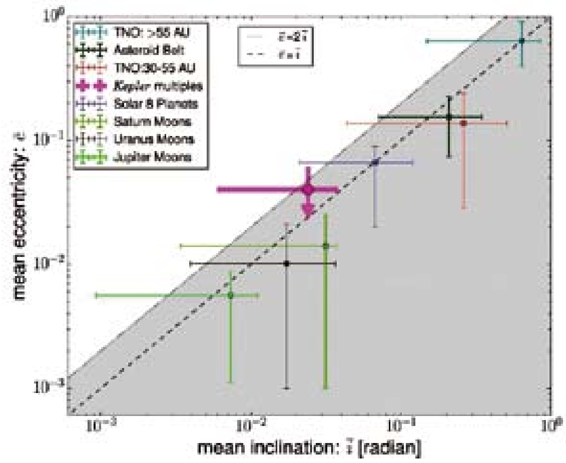


rare, found around approximately one tenth of stars studied by the radial velocity technique, and the shapes of their orbits turned out to be a big surprise. A large fraction of them are on highly eccentric orbits, with a mean eccentricity of as high as 0.3. This finding, therefore, challenged the "standard theory" of planet formation and raised a new puzzle for astronomers: are the nearly circular and coplanar planetary orbits in the solar system common or exceptional?

By far, the Kepler satellite launched by NASA in 2009 has discovered thousands of exoplanets by monitoring tiny dimming in the brightness of stars when their planets happen to cross in their front (which is called "transit"). Many of the planets detected by Kepler have sizes comparable to that of the Earth. Kepler's revolutionary discoveries have shown that Earth-size planets are prevalent in our galaxy. However, Kepler's data alone cannot be used to measure the shape of a transiting exoplanet's orbit. One way is to use the size of the host star as a "ruler" to infer the length of the planet transit. To implementing this method, scientists need precise information on the host star's key parameters such as size and mass.

With its innovative design, LAMOST can observe the spectra of thousands of celestial objects at once, boasting the most efficient "spectroscopy factory" in the world. So far, LAMOST has obtained tens of thousands of stellar spectra in the sky regions where Kepler has been monitoring planet transits, including many hundreds of stars hosting transiting exoplanets. The researchers found that high-accuracy characterization of stellar parameters can be reliably obtained from LAMOST spectra, and they can subsequently be used to measure the orbital shape distribution of Kepler exoplanets.

Therefore, they analyzed a sample of about 700 exoplanets, the spectra of whose host stars have been obtained by LAMOST. Then by combining LAMOST stellar parameters with Kepler transit data, they measured the eccentricity and inclination angle distributions. They



The mean eccentricity (e) and inclination (i) of Kepler multiples fit into the pattern of the solar system objects satisfying a relation e ≈ (1-2) x i. The dots represent the Kepler multiple planets (magenta), the eight planets of the solar system (blue), regular moons of Jupiter, Saturn, and Uranus (light green, yellow, and black); main belt asteroids (green); and trans-Neptune objects (TNOs; both the classical Kuiper Belt objects with orbital semi-major axes 30-55 AU shown in red and the scattered disk objects with semi-major axes >55 AU shown in cyan).

revealed that about 80% of the planet orbits analyzed are nearly circular (with averaged eccentricity below 0.1) like those in the solar system. Only about 20% of the planets have relatively eccentric orbits that significantly deviate from circular (their average eccentricity above 0.3). They also found that the mean eccentricity and inclination angle for the Kepler systems with multiple planets actually fit into the pattern of the solar system.

They concluded that circular orbits are not exceptional for planetary systems, and the orbital shapes of most planets inside and outside our solar system appear to distribute in a similar fashion. This implies that the formation and evolution processes leading to today's distributions of the orbital shapes of the solar system may be common in the Galaxy.

Their work has been published by the *Proceedings of the National Academy of Sciences.*