A celestial game of catch

Over the centuries earth and Venus toss the asteroid Toro between them like a giant tennis ball

by Dietrick E. Thomsen

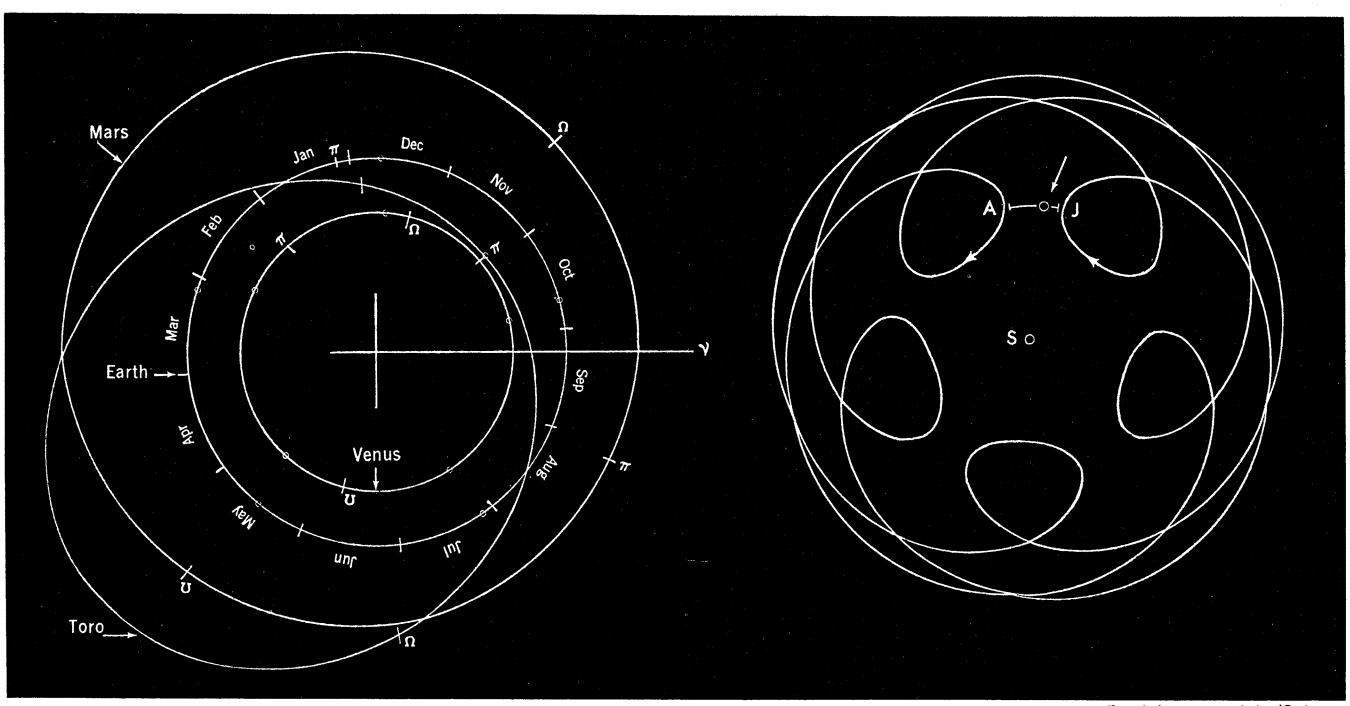
All the bodies of the solar system influence each other's motion more or less. Most of these perturbations are fairly minor effects, but when the perturbing body is a planet and the perturbed body is as small as an asteroid, a close passage will have a large effect on the motion of the asteroid. In fact, according to the work of a group of scientists from California and Sweden, it appears that the inner planets control the motion of several asteroids by means of complicated motional resonances.

The story begins with calculations of the orbit of the asteroid Toro by L. Danielsson of the Swedish Royal Institute of Technology and W.-H. Ip of the University of California at San Diego. Toro is an irregularly shaped asteroid about a mile and a half long and a mile wide.

The two found that the motion of Toro seems to be locked in resonance with the earth. A resonance tends to build up and maintain the motion it controls. The difference between resonance and nonresonance is the difference between pushing a swing at its natural oscillating frequency and pushing at some other frequency. Perturbation of an asteroid by passage near a large planet could result in a radical change in the asteroid's orbit, one that could be serious enough to send it colliding with something or even make it escape the solar system completely. In Toro's case, however, things are set up so that each passage near the earth gives it just the right kick to send it around and back for another close passage. The whole works out to a complicated cycle involving a repeating series of passages at various distances behind and before the earth.

Danielsson and Ip published their first results in the May 26 SCIENCE. They said then that the resonance with earth appeared to be unstable—after a long time it might gradually come out of phase. They also hinted at a possible resonance with Venus. But at that point they had calculated only about 200 years of Toro's motion, and that was not enough to be certain. Since then, working with Ramesh Mehra of the Swedish Royal Institute of Technology, they have calculated more than a thousand years of Toro's motion.

The new calculations show that there is indeed a stable resonance, but it is a complicated one with both earth and Venus. The result is that for several centuries earth controls Toro's motion; then control passes to Venus; then after a while back to earth again. Earth has controlled Toro since 1580; in 2200 Venus will take over. Control comes back to earth in 2350 and then goes back to Venus in 2800. Gustaf Arrhenius of the Scripps Institution of



Danielsson and Ip/Science

Orbit of the captured asteroid Toro plotted normally (left) and in a coordinate system rotating with the earth.

Oceanography, who spoke for a larger group working on planetary resonances generally, says that this is a permanent situation that could have been in effect since the beginning of the solar system.

Arrhenius hastens to point out that this kind of resonance is not merely a curiosity of the motion of Toro alone. Danielsson, Ip and Mehra have investigated the orbits of four other asteroids that come within the orbit of Mars and found that three of them, Ivar, Eros and Amor, are involved in similar resonances with the inner planets. (Geographos is not.)

The existence of a group of objects that behave that way has a direct bearing on theories of the origin of the moon. The moon's composition leads many astrophysicists to think it must have been formed in another part of the solar system. The usual scenario has the moon being formed somewhere in the asteroid region and then coming loose—if it was originally in a bound orbit—and drifting to the neighborhood of the earth. The difficulty with this scheme has always been that the chances a drifting moon would hit exactly the spot to be captured by the earth are astronomically small. But if the moon was formed in one of these complicated resonance orbits, then it would have made repeated passages close to the earth. "It would have come by many times and knocked on the door, so to say," Arrhenius remarks. The chances of its hitting the point for transfer into a simple circumterrestrial orbit are greatly enhanced by such a supposition.

On Aug. 8 Toro made one of its close passages, at 12.6 million miles, and a number of scientists interested in what asteroids are made of took advantage of the event. The Jet Propulsion Laboratory's large spacetracking antenna at Goldstone, Calif., was used to bounce a radar beam off the asteroid. From the data the scientists hope to determine Toro's dielectric constant, which will give information on the metal-rock mix in its composition. Observers at the University of Arizona and elsewhere are looking at Toro's visible light to check the rotation period (known to be 10 hours 11 minutes) and determine the distribution of light and dark spots on its surface. Its infrared emanations are being studied to determine what minerals are there.

The convenient thing about Toro's behavior for people interested in the physics and chemistry of asteroids is that its close passage is not a one-time event. If the results of these observations need rechecking or open new questions, as they probably will, new observations will be possible. Toro will be back again and again thanks to its resonant behavior. □