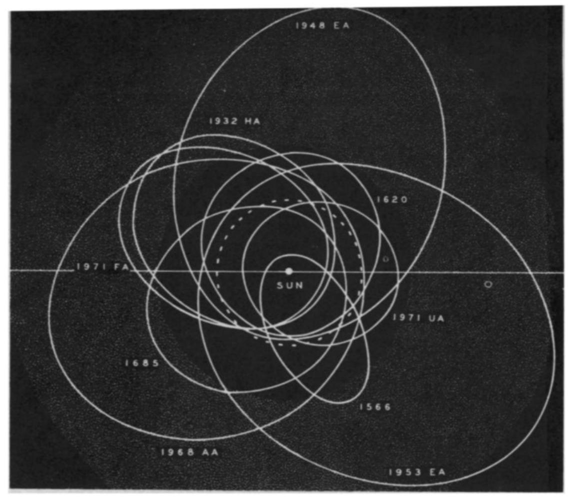
Toro! Toro! Toro!

A "Great Campaign on Toro" was mounted by a number of astronomers on the occasion of that asteroid's most recent passage near the earth



Smithsonian Astrophysical Observatory

Orbits of earth-grazing asteroids. Toro is 1685. Earth's orbit is dashed. Speckling is asteroid belt.

by Dietrick E. Thomsen

The asteroid Toro appears to live in a complicated orbital resonance with Venus and the earth (SN: 9/16/72, p. 186). One of the consequences of the relationship is that Toro makes passages close to the earth. The passages give astronomers a rare opportunity for close-up study of an asteroid.

In August 1972 Toro came within 13 million miles of the earth. Observations made on that occasion are presented in the August 1973 ASTRONOMICAL JOURNAL.

The most basic items of information to determine about Toro or any other asteroid are its size, shape and rotation period. Even when it was closest, Toro was a faint object, a point of light of between twelfth and thirteenth magnitude. To get the geometric and dynamical data astronomers study the variation in Toro's brightness over the time of the observations. Changes in brightness can result from a combination of the motion and shape of the asteroid or from variations in the reflectivity of the parts of the surface exposed to sunlight as the asteroid rotates.

The direction of the asteroid's axis of rotation could not be precisely determined, and this uncertainty causes difficulties in interpreting the light variations. But J. L. Dunlap, Tom Gehrels and M. L. Howes of the Lunar and Planetary Laboratory of the University of Arizona conclude that Toro could be a cylinder with hemispheric ends, 3.2 kilometers across at the middle and between 7.5 and 10.5 kilometers long. An alternative is an ellipsoidal shape the same width but somewhat longer. The rotation period is 10 hours 11 minutes.

From the asteroid's reflectivity and the color and polarization of the reflected light, Dunlap, Gehrels and Howes conclude that its surface texture is very similar to that of the moon.

Another important question about asteroids is: What are they made of, and what can that tell us about relationships among the bodies of the solar system? In Toro's case answers were sought by Clark R. Chapman of the Planetary Science Institute in Tucson and Thomas B. McCord and Carle Pieters of Massachusetts Institute of Technology. They used the 50-inch telescope at Kitt Peak National Observatory. They examined the spectrum of the reflected light to determine the substances present.

Toro appears generally reddish in color, but its spectrum differs in detail from the spectra of other reddish asteroids. Toro's spectral curve has a steep slope in the ultraviolet bending into a flat slope in the near infrared. None of the other reddish asteroids measured by Chapman, McCord and Pieters have such a sharp bend in the visible portion of the spectrum. "Thus Toro's major spectral reflectance characteristics are unusual among asteroids," they say.

An absorption band between 0.95 and 1.00 micron wavelength in Toro's spectrum is attributed to doubly ionized iron almost certainly in the mineral called pyroxene. Chapman, McCord and Pieters suggest that the mineral is in the form orthopyroxene and is mixed with olivine. Such a composition is similar to that of the L class of chondrite meteorites. The classes L5, L6 and perhaps L4 make particularly good matches. It happens that these classes make up nearly half of all stony meteorites that reach the earth. The correspondence between meteorites that hit the earth and an asteroid that crosses the earth's orbit suggests that perhaps the Apollo asteroids (Toro's class) are the source of the L chondrites or else that the asteroids and the meteorites have some other common source.

Radar beams were successfully bounced off Toro on the nights of Aug. 9 and 10, 1972, by R. M. Goldstein, D. B. Holdridge and J. H. Lieske of the Jet Propulsion Laboratory. The round-trip time of flight was 135 seconds. The radar was able to set only a lower limit on Toro's radius: 1.7 kilometers. The more Toro's radius exceeds this number, however, the smoother its surface must be. Combining optical and radar data, Goldstein, Holdridge and Lieske conclude that the asteroid has an irregular rocky surface slightly smoothed by a mantle of loose material.

The final question regards the future (and the past) of Toro. Toro's motion appears to be in a resonance controlled alternately by Venus and by the earth. Will the asteroid stay in the resonance, and will the resonance enable it to escape destruction by collision with a planet or ejection from the solar system? Trying to find out J. G. Williams of JPL and G. W. Wetherill of the University of California at Los Angeles calculated Toro's orbital elements for the longest period yet reported: 500 B.C. to 4500 A.D. In general Toro appears to be locked onto earth between 500 B.C. and 2960 A.D. Between 2960 and 3470 A.D. it will be in transition. After, Toro locks on Venus.

Whether Toro can avoid colliding with earth or Venus depends on fine calculations of positions at the times when Toro crosses their orbits. From the calculations so far done, it appears that Toro approaches at least to within 3 million miles from the earth and 8 million miles from Venus.

As long as it is in the resonance, Toro seems unlikely to crash into the earth or Venus. Eventually the influence of Mars will knock it out of the resonance, and then a close encounter with a planet may cause either a crash or the ejection of Toro from the solar system. In general an asteroid of Toro's sort has an expected lifetime of 10 million to 30 million years against either of those eventualities. Mars is expected to knock Toro out of the resonance in 1 million to 3 million years. This period is too small a fraction of the expected lifetime for the resonance to affect Toro's lifetime very much.

Toro comes close again in 1976, but its magnitude then will be only about 15. The next chance for work of the present quality will be in August 1980 when Toro comes almost as close as it did in 1972. □