# SATELLITES OF MINOR PLANETS: A NEW FRONTIER FOR CELESTIAL MECHANICS*

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**Abstract.** Most minor planets have satellites. This observation is predicted to have a major impact on the theory of minor planets, comets, and meteors.

On June 1978 the minor planet 532 Herculina occulted a star four magnitudes brighter than itself. One visual observer of the event in California reported a five second secondary occultation 90 seconds earlier than the main event, which itself lasted 20 seconds. This same secondary event also showed up in a photoelectric trace of the event taken at Lowell Observatory in Arizona, making it the first confirmed observation of such a secondary occultation [1]. This led to renewed interest in numerous earlier reports of secondary events in conjunction with occultations of stars by other minor planets.

As of October 1978, there was a total of 23 reported secondary events; and at least one of these had been reported for each of the eight minor planets which had been observed to occult a star [2]. In determining the cause of these secondary events, the following features are noteworthy: Intensity drops generally correspond to total occultations of the star's light, rather than partial occultations, as for the rings of Uranus. These drops are often several magnitudes, insuring that visual timings by experienced observers can be relied upon, and that atmospheric turbulence is an inprobable cause. The confirmed secondary of Herculina was shown to be co-moving through space with Herculina, virtually ruling out a chance alignment of distant asteroids. Ordinary stars near the ecliptic, when monitored photoelectrically, do not show occultation events when not near an asteroid; nor are such secondary events ever seen during lunar occultations. Although most observers have monitored the star for 10–20 minutes before and after the occultation, the farthest secondary event to date was four minutes away, and the vast majority have been within 1.5 minutes of the main event.

Based on the preceding, it was suggested to the AAS Division of Planetary Sciences in October 1978 that minor planets apparently have satellites [3]. Moreover, based on the result that eight out of a possible eight minor planets apparently had such satellites, as seen by observers who were not strategically located for the purpose, the implication was taken that such satellites are both numerous and commonplace. This led to a major post-conference observing effort in connection with the occultation of a star by 18 Melpomene on 11 December, 1978. The results, still unpublished, may be approximately summarized as follows: the

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main occultation was recorded by three photoelectric and several visual observers in the Washington, D.C. area. In addition, there were three photoelectric and three visual reports of secondary events seen by observers outside of, but within 1000 km of, the main occultation path. None of these are apparently the same object. However, the photoelectric traces near Washington showed clearly that the star was a previously unknown close double star complicating the interpretation. Since Melpomene was, for this purpose, a randomly-selected asteroid, it tended to confirm that satellites are a feature of most minor planets.

The limit for the radius of gravitational stability for these systems is set by the Sun [4], and is approximately 100 times the diameter of the parent asteroid. The most significant disrupting force is tidal friction, which can alter the orbits drastically on time scales from 100 to 10,000,000 years, with the result that many former satellites will now be resting on the surfaces of their primaries. These forces will also permit a direct determination of the dynamical ages of these systems when orbits can be determined for the satellites, for example, by Space Telescope; and should enable a quick choice to be made between the primordial and the recent planetary breakup [5] hypotheses of the origin of minor planets.

The realization of the probable multiple-body nature of minor planets can be applied to comets and meteors as well. For the latter, it can explain why fireballs often break up in the Earth's atmosphere above 100 km, where the shearing forces are still negligible. For comets, the idea of satellites in orbit around a nucleus can explain a host of puzzling anomalies, such as why split comets do not trace back exactly to a common point, why initial separation velocities of split components are usually 1 m/s or less, and why multiple nuclei are sometimes observed in non-splitting comets. The gravitational sphere of influence concept also helps us understand why comets have comas at such great heliocentric distances, and why coma diameters actually *decrease* as comets approach the Sun.

In conclusion, although the idea that minor planets might have satellites was unexpected, it is now supported by a considerable body of observational evidence; it helps in the understanding of numerous puzzling features of minor planets; and it has quite significant implications for the origins of minor planets, comets, and meteors.

## References

[1]. See summary in 1978, *Sky and Telescope* **56**, p. 210.
[2]. Binzel, R. P. and Van Flandern, T. C.: 1979, *Science* **203**, p. 903–905.
[3]. Van Flandern, T. C.: 1978, *Bull. Amer. Astr. Soc.* **10**, p. 599.
[4]. Szebehely, V.: 1978, *Cel. Mech.* **18**, p. 383.
[5]. Van Flandern, T. C.: 1978, *Icarus* **36**, p. 51–74.