Asteroid 1950 DA's Encounter with Earth in A.D. 2880

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Initial analysis of the numerically integrated, radar-based orbit of asteroid (29075) 1950 DA indicated a 20-minute interval in March 2880 during which the 1.1-km object might have an Earth impact probability of 0.33%, (+0.17 on the Palermo hazard scale -- the first such potentially positive event). These preliminary values were supported by both linearized covariance mapping and Monte Carlo methods. The dynamical models, however, were limited to gravitational and relativistic point-mass effects on the asteroid by the Sun, planets, Moon, Ceres, Pallas, and Vesta. Subsequent extended modeling that included perturbations likely to affect the trajectory over several centuries (thus decrease impact probability) has not excluded the encounter.

Covariance based uncertainties remain small until 2880 because of extensive astrometric data (optical measurements spanning 51 years and radar measurements in 2001), an inclined orbit geometry that reduces in-plane perturbations, and an orbit uncertainty space modulated by gravitational resonance.

This resonance causes the orbit uncertainty region to expand and contract along the direction of motion several times over the next six centuries rather than increasing secularly on average, as is normally the case. As a result, the 1950 DA uncertainty region remains less than 20,000 km in total extent until an Earth close-approach in 2641 disrupts the resonance. Thereafter, the same uncertainty region extends to 18 million km along the direction of motion at the Earth encounter of 2880.

We examined 11 factors normally neglected in asteroid trajectory prediction to more accurately characterize trajectory knowledge. These factors include computational noise, Galilean satellite gravity, galactic tides, Poynting-Robertson drag, major perturbations due to the gravitational encounters of the asteroid with thousands of other asteroids, an oblate Sun whose mass is decreasing, planetary mass uncertainties, acceleration due to solar wind, radiation pressure and the acceleration due to thermal emission of absorbed solar energy.

Each perturbation principally alters the along-track position of 1950 DA, either advancing or delaying arrival of the object at the intersection with the orbit of the Earth in 2880. Thermal radiation (the Yarkovsky effect) and solar pressure were found to be the largest accelerations (and potentially cancelling in their effects), followed by planetary mass uncertainty and perturbations from 64 perturbing asteroids.

The Earth approach distance uncertainty in 2880 is determined primarily by accelerations dependent on currently unknown physical factors such as the spin axis, composition, and surface properties of the asteroid, not astrometric measurements. As a result, no specific impact probability is quoted here.

Two different types of impact probabilities can be considered when unknown physical parameters dominate orbit uncertainties. The first, IP_α, a "true" impact probability, would derive from an estimation process in which observations were used to solve for all relevant physical parameters (spin, mass, thermal conductivity, etc.), thus providing a nominal value and probability density for each which could then be sampled. IP_α is not presently computable for 1950 DA. For the second type, IP_β, the dynamics, nominal values and probability models are guessed. The result would reflect those "best model" assumptions and would differ from IP_α.

1950 DA's trajectory dependence on physical properties also illustrates the potential for hazard mitigation through alteration of asteroid surface properties in cases where an impact risk is identified centuries in advance. Trajectory modification could be performed by collapsing a solar sail spacecraft around the target body, altering the way the asteroid reflects light and radiates heat, thereby allowing sunlight to redirect it over hundreds of years.

The next radar opportunity for 1950 DA will be in 2032. The cumulative effect of any actual Yarkovsky acceleration since 2001 might be detected with radar measurements obtained then, but this would be more likely during radar opportunities in 2074 or 2105. Ground-based photometric observations might better determine the pole direction of 1950 DA much sooner.

Reference: Giorgini, J., et al, *Science* **296**, 132-136 (2002).
http://neo.jpl.nasa.gov/1950da
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