Orbit Uncertainties, Keyholes, and Collision Probabilities

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Last year, asteroid 1997 XF11 was much in the news when orbit calculations indicated that it might make an extremely close approach to the Earth in 2028, and when the suggestion was made that a collision in that year was possible. Using observations available on March 11, 1998 (an 88-day data arc), it could be shown that the collision probability in 2028 was essentially zero. Pre-discovery observations found the next day only served to confirm this result. But was it possible to rule out a collision in the years after 2028, using only the 88-day-arc solution? New, nonlinear techniques for analyzing orbit uncertainties were necessary to answer this question. The resulting analysis of this reduced-arc case showed non-negligible collision probabilities for several subsequent years. Embedded within the 2028 uncertainty region were many narrow "keyholes" through which the asteroid could be perturbed onto collision trajectories. The highest collision probability for this hypothetical 1997 XF11 case was $\sim 10^{-5}$.

This year, two real cases with non-negligible collision probabilities have been identified. The first of these, 1999 AN10, is remarkably similar to the case of 1997 XF11. Within its uncertainty region, keyholes were identified which could lead to impacts in the years 2044, 2046, or 2039. As additional observations became available, the impact probability rose as high as $\sim 10^{-6}$, but pre-discovery observations were found which moved the prediction away from these keyholes, and impact is now not possible before 2076. The other potential impactor, 1998 OX4, has a very short arc and is currently lost; its impact probability is $\sim 10^{-7}$. A side effect of the increasing discovery rate for Near Earth Objects and the new nonlinear orbit uncertainty analysis techniques will be a growing number of asteroids with at least temporarily non-negligible impact probabilities.