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Very short arc orbit determination: the case of asteroid 2004 FU_{162}

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Abstract. We show the utility of the *Systematic Ranging* technique by analyzing the orbit determination of asteroid 2004 FU_{162}, which passed approximately 6400 km from the surface of the Earth on March 31, 2004. The limited observations introduce strong nonlinearities that must be accounted for when estimating the actual encounter distance.

Keywords. Orbit determination, ranging, impacts

On March 31, 2004, an interesting object, eventually designated 2004 FU_{162}, was detected by the telescopes of the LINEAR survey (Stokes *et al.* 2000). The position of 2004 FU_{162} was measured four times over a 44 minute time interval, revealing a proper motion of several degrees per day. Thus 2004 FU_{162} was recognized as a probable near-Earth asteroid, and the next day the measurements were flagged and forwarded to the Minor Planet Center. There the object was briefly posted to the World Wide Web for confirmation, but it was soon realized that it had already passed into the daylight sky and was no longer observable. However, it was already evident that this 5–10 meter object had passed very near the Earth, in fact far closer than any previous asteroid discovered beyond our atmosphere. However, 2004 FU_{162} was never reobserved and searches for earlier observations proved fruitless.

In this paper we will consider the orbit determination challenges posed by the paucity of observational information available for 2004 FU_{162}. The few observations and very short data arc lead to substantial nonlinearity, making conventional covariance analyses inappropriate. In this case, although the least squares orbit determination does provide a nominal orbit, the confidence limits on the nominal solution are dominated by nonlinearities. Because of this, estimating the statistics of the close approach distance is not straightforward.

The techniques used for this analysis are thoroughly explained elsewhere (Chesley 2004). For brevity, only a summary will be included here. The method, here called *Systematic Ranging*, was originally proposed in an as yet unpublished manuscript by Tholen & Whitely (2002). Their basic idea exploits the fact that the range r and range rate $\dot{r}$ of a just-discovered object are poorly constrained, while the sky position and motion is directly measured. This suggests fixing r and $\dot{r}$ at realistic values and taking the best-fitting orbit given those constraints. In this way one systematically explores a raster in $(r, \dot{r})$-space, finding the best-fitting orbit and conditional uncertainty at each point. The RMS of the fit residuals for each raster point gives an indication of the quality of the fit, and standard chi-square probability theory can be used to derive confidence regions and even probability densities in the $(r, \dot{r})$-space.

The term Systematic Ranging is intended to contrast with an alternate procedure, dubbed Statistical Ranging (Virtanen *et al.* 2001), which is based on the Monte Carlo technique. The key difference between the two approaches is that with Statistical Ranging the $(r, \dot{r})$ values are selected randomly. Also, the technique randomly samples one pair

Table 1. 2004 FU_{162} Nominal Orbital Elements (J2000.0).

Epoch	2004 March 31.0 TDB
Semimajor axis	1.005 ± 0.010 AU
Eccentricity	0.342 ± 0.029
Long. of Ascending Node	$11^\circ.1235 \pm 0^\circ.0053$
Arg. of perihelion	$289^\circ.24 \pm 0^\circ.27$
Inclination	$2^\circ.40 \pm 0^\circ.24$
Mean anomaly	$289^\circ.8 \pm 1^\circ.1$
Absolute magnitude	28.7 ± 0.3

NOTE: Formal uncertainties are not particularly meaningful in the presence of strong nonlinearities. They are listed here as a general reference only.

observations and their observational errors, rather than obtaining the best-fitting sky motion that is consistent with all of the observations, given the the selected $(r, \dot{r})$.

The astrometry for 2004 FU_{162} was published on MPEC 2004-Q22 (2004); the following results assume 1 arcsec uncorrelated gaussian noise. The range of possible orbits (Fig. 1) permitted by the observations is really quite narrow considering the short interval of observations. With greater than 99% confidence, 2004 FU_{162} is an Earth-crossing asteroid with modest inclination and a diameter somewhere between a few meters and a few tens of meters. The best-fitting orbit, which does converge under general differential corrections, has an RMS of $0''.149$ and is detailed in Table 1.

The particulars of the close approach of 2004 FU_{162} are depicted in Fig. 2. Here we can see that the nominal close approach distance was just $2R_\oplus$ from the geocenter, or a scant 6400 km from the surface. The time of the encounter—give or take about an hour—is 2004 March 31.65, around 8 hours after the last observation. Close approach distances ranging from impact to $10R_\oplus$ can be found within the 99% confidence region. The probability of impact, derived using the fully nonlinear Systematic Ranging approach, is 0.33%†.

It is interesting to note that the nominal deflection of the asteroid due to perturbation of the Earth was substantial, approximately 20°. The pre-encounter elements are listed in Table 1; the post-encounter elements are notably altered‡, indeed the category of the object was changed from Apollo to Aten by the approach.

Figure 3 reveals how the encounter distances for 2004 FU_{162} are distributed. The median distance is $2.8R_\oplus$ and the 99th percentile distance is $9R_\oplus$. The probability that 2004 FU_{162} passed closer than $7.8R_\oplus$, the record-setting flyby distance set by 2004 FH a few weeks earlier, is 97.5%.

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† There was a well-publicized bolide impact on the east coast of Australia around 2004 March 31.4, but the timing and circumstances of that event appear to be wholly inconsistent with the close approach of 2004 FU_{162}.

‡ Post-encounter semimajor axis, eccentricity and inclination are 0.827 AU, 0.392 and 4.16°, respectively. The longitude of perihelion changed from 300° to 331°.

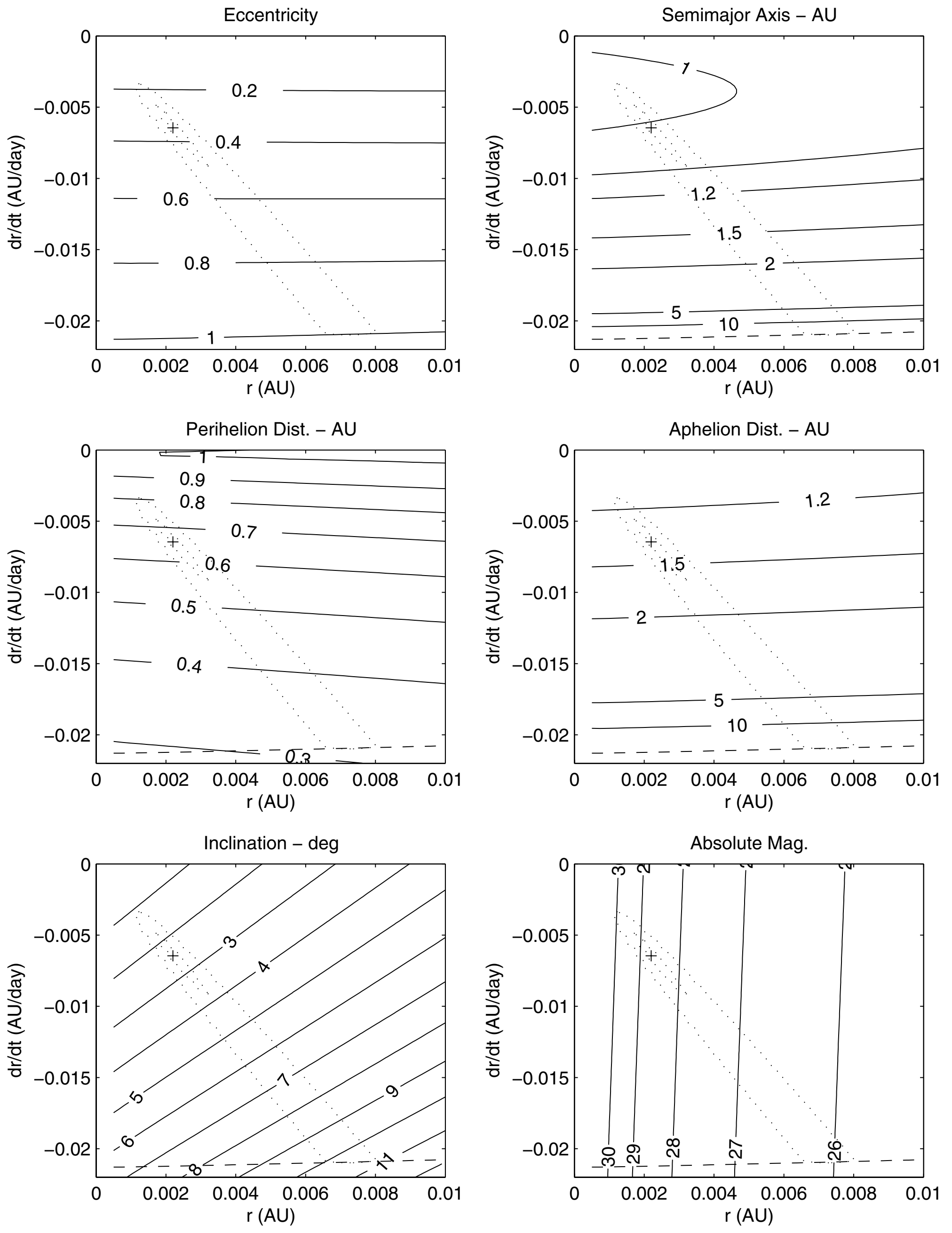

Figure 1. 2004 FU_{162} orbital distribution in the $(r, \dot{r})$-plane. Dashed curves replicate the hyperbolic limit shown at upper left. Dotted curves depict the 50% and 99% confidence regions, assuming 1″ astrometric noise. The best-fitting solution is marked with a +-sign.

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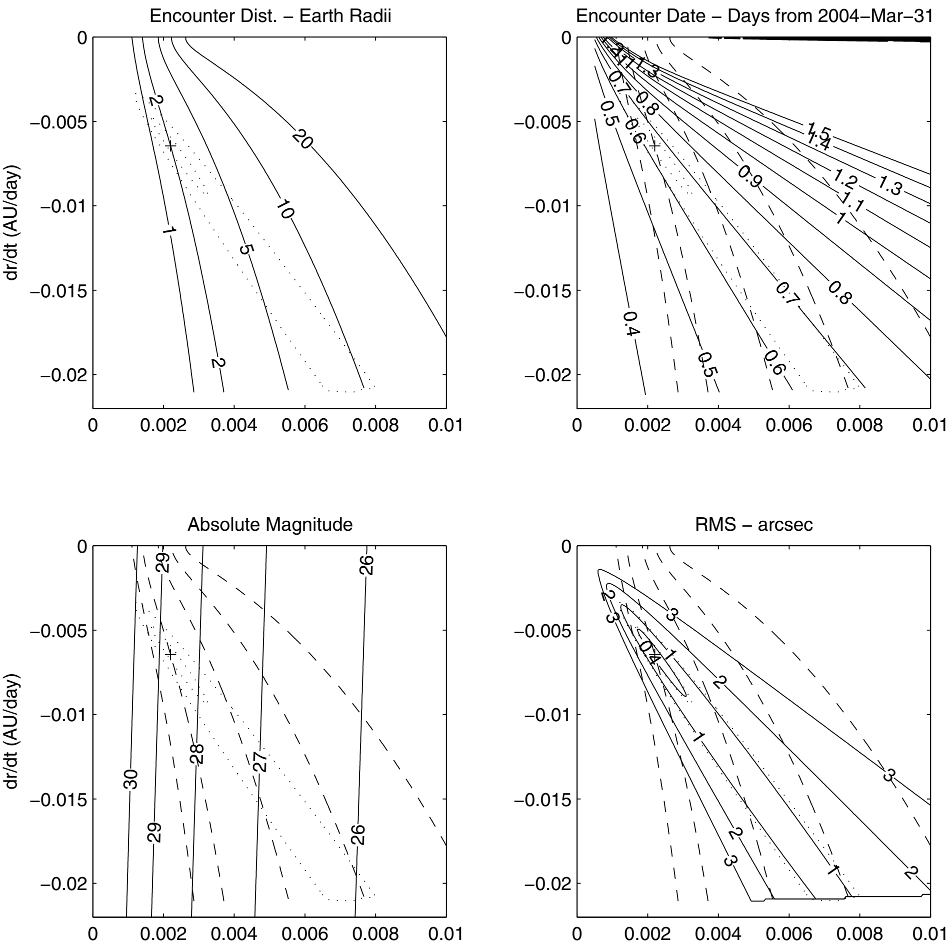

Figure 2. 2004 FU_{162} close approach data. Dashed curves replicate the encounter distance curves shown at upper left. Dotted curves depict the 50% and 99% confidence regions, assuming $1''$ astrometric noise. The best-fitting solution is marked with a +-sign.

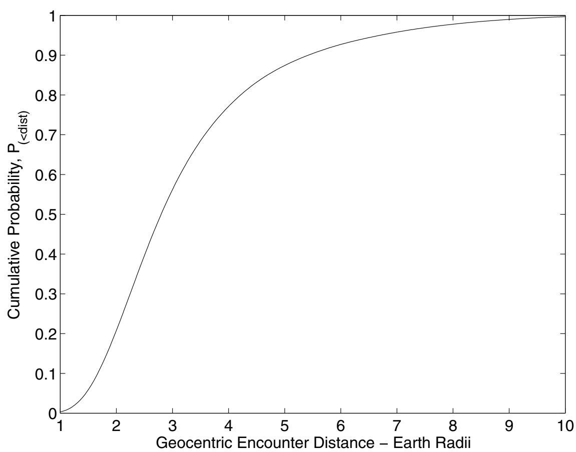

Figure 3. Probabilistic distribution of encounter distances for 2004 FU_{162}.

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