COMETS AND THE MISSING PLANET

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ABSTRACT. Integrating backwards in time in the circular restricted three-body problem Galaxy-Sun-Comet, for both the real long-period comets and fictitious random sets of orbital elements, we have confirmed van Flandern's conclusion that there is a statistically-significant clustering of the orbits of real long-period comets, in heliocentric direction, some $5 \times 10^6$ years ago. The clustering is also significant in heliocentric distance, and is more marked if it is assumed that the comets have gone round the Sun more than once since the epoch of maximum clustering. We suggest that the "event" discovered by van Flandern is not the explosive disruption of a planet formerly in the asteroid belt, but the latest in a series of minor catastrophies, such as the collisional break-up of a pair of large asteroids.

In a series of papers (1,2,3) one of us has developed dynamical arguments leading to the conclusion that there once existed, in the region of the asteroids, a massive planet which subsequently disrupted. T.C. van Flandern (4,5) has claimed that the statistics of the orbital elements of long-period comets gives direct evidence that such a planetary disruption took place about 6 million years ago. His conclusion was based on (a) the distribution of orbital elements at the present time, and (b) the clustering of long-period comet orbits at a critical time in the past, as discovered by numerical integrations of the comets' orbits backwards in time, allowing for the perturbation by the non-uniform field of the Galaxy.

In this paper, we are concerned only with the evidence under (b). We have repeated van Flandern's calculations, using a different integration technique. We have also carried out integrations for some sets of fictitious comets, whose orbital elements were chosen at random. We wish to decide in what respects, if any, the real long-period comets differ, in their orbital characteristics, from the fictitious (random) sets.

The present orbital elements of 60 long-period comets, corrected for planetary perturbations during the apparition of observation to give pre-counter values, have been listed by van Flandern (4). We adopted the same
orbital elements for our "Real" comets. Our "Random" sets of elements were generated using a pseudo-random-number generating program. The only restriction placed upon the elements was that the perihelion distance, \( \ell \), should lie between 0.5 a.u. and 4.5 a.u. These limits correspond roughly to the range found in van Flandern's sample, since he rejected all real comets whose pre-encounter value of \( \ell \) was less than 0.5 a.u. on the grounds that for such comets non-gravitational perturbations would be significant. In this paper, for reasons of economy, we display the results of only one of our random sets.

Integrations (backwards in time) were performed using a library program for the solution of the circular restricted three-body problem. The program uses adjusted time-steps, and integrations were found to be reversible over a time of \( 10^6 \) years with a precision better than 0.1° in angle and 0.001 in \( \ell \). The mass and distance of the galactic center were taken to be \( 2.32 \times 10^{11} \) solar masses and 11.7 kpc respectively. With these values, in the restricted problem Galaxy-Sun-Comet, the correct galactocentric solar angular velocity \( \Omega = 25 \) km \( s^{-1} \) kpc\(^{-1} \) (6) and the correct gradient \( \partial \Omega / \partial R = -3.2 \) km \( s^{-1} \) kpc\(^{-2} \) (7) are obtained.

If the hypothetical planetary disruption occurred \( T \) years ago, the periods of those long-period comets actually observed within the last few centuries must be very close to \( T/n \), where \( n \) is an integer, since \( T \approx 10^7 \) years ago (2; vide 3). On the grounds that the pre-encounter aphelion distances of long-period comets tend to cluster about 50,000 a.u., whereas the post-encounter aphelion distances do not, van Flandern [following Marsden and Sekaninan (8)] argues that for the selected comets \( n=1 \). It is therefore of interest to note that the period of any comet observable near perihelion, with an aphelion distance of 50,000 a.u., is \( \approx 10^7 \) years. However, the actual aphelion distances are poorly determined for such long-period comets. van Flandern therefore integrates his orbits backwards for various assumed values of \( T \), taking \( n = 1 \) for each value of \( T \).

In the plots of our integrations, given in Figure 1, the upper left-hand number is the value of \( T \) in years, and the upper right-hand number the value of \( n \). All the plots show the comets' heliocentric coordinates on Mollweide's Equal Area Projection [which is not the same projection as that used by van Flandern (4)]. The zero of ecliptic longitude is taken to be the direction of the vernal equinox at the present time, taken to be fixed in an inertial frame. The zero of galactic longitude is taken to be the direction of the center of the Galaxy, as seen from the Sun, at the time \( T \) years ago, allowing for a constant angular velocity of the Sun around the center of the Galaxy, in an inertial frame, of \( \Omega = 25 \) km \( s^{-1} \) kpc\(^{-1} \).

When the integration backwards of a comet, for a time \( T \), is begun, it is assumed that the osculating period of the comet at the present epoch is \( T \). This will not be precisely true, so that if the times of integration were taken to be exactly \( T \) for all comets, the various comets would, at that time, be in different phases of their orbits. Since the orbits are nearly rectilinear, this means that the orbital elements of the different comets would not be strictly comparable. In a few cases, we actually found