A REVIEW OF DYNAMICAL EVIDENCE CONCERNING A FORMER ASTEROIDAL PLANET

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This paper is a brief review of results presented elsewhere (Van Flandern 1977, 1978). The conclusion of these results is that at least the comets, and probably also the asteroids and meteorites, originated in the breakup of a major planet in the present location of the asteroid belt, at an epoch of just 5×10^6 years ago. Although there are many "well-known facts" about the solar system which seem to contradict this conclusion, these contradictory "facts", upon closer examination, are often not so convincing as we have been inclined to assume; in each instance so far suggested there is a plausible alternative interpretation of the data which is supportive of the breakup hypothesis. A compelling contradictory argument has not yet surfaced. In view of this, and in consideration of the strength of the arguments favoring the hypothesis, it will be necessary to judge the conclusion on the merits of the case, without the intervention of the a priori decision that it cannot be true.

Even with that granted, it must be admitted that two aspects of the hypothesis are very surprising. First, specific mechanisms for disrupting a large planet are unknown, and there is little in the evidence to suggest what the mechanism may have been. However, this ignorance is not a very good counterargument. Ramsey (1950) has discussed core instability conditions which could result in the explosion of terrestrial-sized planets. Stellar explosions are accepted by all, though not yet well understood theoretically. Recent work by Oort (1976) shows that even entire galaxies are observed to be exploding. It would therefore seem fair to point out that explosion is a fact of life in the observable universe, despite our discomfort with the contemplation of its applicability to the type of celestial body on which we reside.

R. L. Duncombe (ed.), Dynamics of the Solar System, 257–262.

The second puzzling aspect of the hypothesis is the recentness of the event. Since Copernicus we have learned not to place ourselves in a special location, or a special time, in the universe. However, it is possible that the solar system has had a rich and varied history. What event robbed Venus of its rotational angular momentum? How did Saturn's rings form? What tilted Uranus on its side? What event disrupted the satellite system of Neptune? When were the Martian satellites captured? There may have been a great many individually unique events in the solar system's history, of which the breakup of an asteroidal planet may have been only the most recent, and therefore the most easily reconstructed.

What, then, is the evidence? Because of planetary perturbations, principally by Jupiter, only two types of orbits can survive several million years after an explosion: low eccentricity orbits, as for the asteroids; and nearly parabolic once-around orbits, as for the very long-period comets. Oort (1950) discovered the remarkable property that many comets are in orbits having periods of revolution of 5×10^6 years, yet are known to be making their first return to the inner solar system! In a breakup origin, although comets with all periods are produced, only those with periods just equal to the time interval from the breakup to the present can be making first returns today. Hence the epoch of the event: $(5.5 \pm 0.6) \times 10^6$ years ago. These comets exhibit a strong bias in the directions of their perihelia. (Throughout this section, refer to Van Flandern 1977 and 1978 for specifics). While such a perihelion direction bias is inevitable in an explosion because of the "Sun-selecting influence", it is difficult to explain in any other uncontrived way. In particular, perihelion directions are very difficult to perturb, either by passing stars or galactic tidal forces. The comet perihelion distance distribution is likewise in agreement with a breakup origin, but is not reconcilable with the usual theory that this distribution must have been produced by passing stars. When the effects of galactic tidal forces and, statistically, passing stars are removed from the comet orbits in a five-million-year backwards integration, the tendency for the orbits to cluster (i.e. intersect at a point at that epoch) is truly remarkable. In every case where a measure is possible, the comet orbits have the distribution predicted by a breakup event.

Asteroid orbital elements display "explosion signatures", similar to artificial satellites which exploded in Earth orbit. Moreover, Bensusen and Van Flandern (1978) have discussed a statistically significant tendency for the orbits of the two largest asteroid families to intersect in a common point at an epoch of about $5x10^6$ years ago. At no other epoch is the tendency to cluster statistically significant.

Meteoritic evidence consists of the very young cosmic ray exposures ages, such as for H-group chondrites, which cluster near $4x10^6$ years old; chemical differentiation; isotopic anomalies; nondispersal of meteor shower radiants; the high frequency of meteorities with high geocentric velocities, and a great deal more. The physical and chemical evidence will not be reviewed extensively here.

In summary, there exists a great deal of dynamical, as well as physical and chemical, evidence that a large planet broke up in the asteroid belt $5x10^6$ years ago. Although this hypothesis is inconsistent with the interpretation of the comet, asteroid, and meteorite data, there do not seem to be any irreconcilable conflicts with the data itself. Indeed the hypothesis provides fresh insights into many solar system anomalies, some of which have been most awkward to explain by the conventional hypotheses.

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DISCUSSION

Scholl: 1) A good test for your theory would be a numerical calculation backwards of all the observed minor planets.

2) Why do we observe so few asteroids in the Kirkwood gaps and in the region between the Hecuba gap and the Hilda group?

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Van Flandern: Thank you for your suggestion of an integration; I think it is a very good idea, although somewhat expensive.

The problem of the origin of the Kirkwood gaps is often still considered as unsolved. The planetary break-up model adds one new, interesting idea which has the potential to lead to an explanation; namely, that the initial asteroid orbits for any given semi-major axis had initially a relationship between eccentricity and longitude of perihelion (because initially all orbits intersected in a point). The dynamical consequences of such a relation have not yet been explored.

Kozai: I am afraid that even Williams' theory is not sufficient to compute positions of orbital planes of asteroids several million years ago.

Van Flandern: In general you are certainly correct. We confined our study to orbital planes of asteroids in the Eos and Koronis families, which have very similar elements within each family. We then looked only for a clustering of family members relative to one another. The result could be an artifact, but I think it is interesting that the only statistically significant clustering in each family occurred at $(4.8 \pm 0.1) \times 10^6$ years ago.

Kresak: I do not see how the distribution of meteor orbits can lend support to your hypothesis. The observed distribution pattern is due to (1) meteor showers, which are definitely of recent origins and mostly associated with existing short-period comets; (2) a strong prevalence of direct motions among the sporadic meteors; (3) a strong selection effect favoring the observation of meteors with high geocentric velocities; and (4) the fact that all optical observations are made at nighttime, and most of them are from the northern hemisphere. Even the best velocity measurements are unable to distinguish the intermediate-period meteors, like the Perseids or the Orionids, from the long-period ones. The relative contribution of long-period meteors is very small anyway. This is conceivable because solar radiation pressure would sweep out from the solar system all meteor-sized particles released by a "new" comet, so that they never return and cannot be observed outside the comet's tail.

Van Flandern: Sporadic meteors have several peaks in their semi-major axis distributions, one in the asteroid belt, and one at "large" (but not well-determined) semi-major axes somewhere between 20 AU and infinity. If these semi-major axes are really as large as for the long-period comets, this would favor the breakup

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model. Again, the distribution of radiants of shower meteors is not as dispersed as is expected, suggesting a relatively recent origin for their parent bodies (less than 10^6 years).

Weissman: I would like to offer one dynamical and one physical argument why your hypothesis is incorrect. On the distribution of perihelion directions and distances, I would say that there is no good statistical evidence that any preferred perihelion direction exists. The observational selection effects are quite complicated and no work I have seen has ever adequately accounted for them all. Moreover, in dealing with a statistical process like the perturbation of comets in the Oort cloud by passing stars there is no reason why we should not expect large fluctuations in the flux and directions of new comets when their periods are on the order of four million years and we only have good orbital data covering perhaps a 250-year span.

Concerning the perihelion distances of the comets, there is a shortage among small q comets but that shortage comes from a loss of "old" comets evolving to small semi-major axes and not the "new" comets from the Oort cloud. I will explain the reason for the loss of the older small q comets in my paper tomorrow. There is, however, no evidence that is statistically significant for a shortage of Oort cloud comets at small perihelia. Even if your hypothesis were correct the stellar perturbations on just a single five million year period orbit would destroy any record of the initial perihelion distribution of the material. The perturbations are sufficiently great to spread the comets over the complete range of observable perihelia, and in fact most comets would be perturbed out of the planetary region altogether.

On the physical side there is the evidence from the study of meteorites concerning their histories. The vast bulk of meteorites, the ordinary and carbonaceous chrondrites, are samples of primitive solar system materials. They were formed 4.5 billion years ago and since that time have not been heated or shocked to any significant degree. They have never been part of any planetary sized body and could not have undergone the catastrophic event you claim for your hypothetical planet. It is not possible for such undifferentiated, high in volatile content material to have survived for most of the history of the solar system as part of any major sized body.

By spectral reflectance measurements it has been shown that most asteroids are at least covered with material very similar to the ordinary and carbonaceous chondrites. Most of the asteroid belt in fact appears to be carbonaceous chondrites, the most primitive of the meteorite classes. The comets form a natural extension of the meteorite groups as having even more volatiles and thus being yet more representative of solar nebula material prior to the accretion of the planets. To hypothesize that all the meteorites, asteroids and comets have a 90 earth mass planet as a common parent body is totally inconsistent with all the physical evidence which has been accumulated on the meteorites.

Van Flandern: Although we cannot exactly remove the effects of observational selection on the perihelion directions of new comets, we can at least know that they operate in the sense that, when the true distribution is reconstructed, the asymmetry is greater (not less). Its statistical significance has been confirmed by many authors. No one has suggested a mechanism whereby such a strong asymmetry could have been produced by stellar encounters.

On the perihelion distance distribution, it is true that these may be changed by one, or even several, astronomical units. Therefore, I do not insist that these cut off at 2.8 AU, or vanish at the Sun; only that the general trend to diminish in number as one approaches the Sun should be preserved, as observed. Near the Earth's orbit, and after using Everhart's criteria to correct for observational selection, the observed distribution of perihelion distance of new comets is inconsistent with the uniform distribution required by the "Oort cloud" model at the 95% significance level. Many of Weissman's remarks about meteorites, concerning which neither of us is an expert, disagree with my reading of the literature. Authorities such as Brown, Patterson, Heezen, Glass, and many others have suggested a planetary origin for meteorites, particularly chondrites. The argument that they could not have been part of a much larger body is based on cooling rates, and <u>assumes</u> no active thermal processes other than the Sun's. These cooling rates are in agreement with a possible origin inside a planet large enough to have an internal heat source.

I have used the argument about the compositional similarities of comets, asteroids, and meteorites as one which favors a common origin for these bodies. Weissman's last statement should be modified to read, ". . . totally inconsistent with <u>the existing interpretation</u> of all the physical evidence." As I have pointed out, much of this evidence can be reinterpreted in a way which is at least consistent with, and often quite supportive of, the breakup hypothesis.

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