4

THE KIRKWOOD GAPS AS AN ASTEROIDAL SOURCE OF METEORITES

H. SCHOLL and C. FROESCHLE

Zimmerman and Wetherill's proposed mechanism for the production of meteorites from asteroids has been explored by numerous numerical computations of orbits. Starting from the vicinity of the 2/1 Kirkwood gap, 30% of our orbits soon have aphelia reaching beyond, but not much beyond 4 A.U.; (3% only exceed 4.3 A.U.). These results suggest that the proposed mechanism might work, although we have not yet checked whether Jupiter's action will be large enough for those perihelia. Furthermore, our investigation has been extended to the 3/1, 7/3 and 5/2 Kirkwood gaps, and shows that these gaps should also be considered as a possible source of meteorites.

Certain classes of meteorites are presumed to originate in the asteroidal belt between the orbits of Mars and Jupiter. These meteorites are considered to be fragments resulting from collisions between asteroids that have perihelia outside the orbit of Mars. The orbits of the fragments are changed into earth-crossing orbits by some specific mechanism, and after a collision with the Earth, the fragments appear as meteorites on the Earth.

The dynamical problem is to find such a mechanism that transforms non earth-crossing orbits into earth-crossing ones. Direct collisional transfer into earth-crossing orbits generally is excluded as it requires a strong change in velocity which should produce shock effects in the meteorites that are not observed (Wetherill 1974). Therefore, other mechanisms have to be found. As is well-known, there are gaps in the frequency distribution of the asteroids' mean motions, the so-called Kirkwood gaps, where the ratio between the asteroids' and Jupiter's mean motion is close to a small rational number. If an asteroid is located in one of commensurability gaps it will be in resonant motion with Jupiter. P. D. Zimmerman and G. W. Wetherill (1973) proposed a mechanism that yields earth-crossing orbits from the Kirkwood gap which is at the 2/1 commensurability in the asteroidal belt.

The orbit of a fictitious asteroid with normal starting values placed at the 2/1 commensurability shows much stronger perturbations than an asteroid that is not in a resonant motion with Jupiter. Particularly, the eccentricity of the orbit varies strongly while the semimajor axis remains nearly constant according to Poisson's theorem. Subsequently, the aphelion of the orbit may approach closely Jupiter's orbit. Zimmerman and Wetherill base their proposed mechanism for the yield of meteorites on that effect. Two asteroids, which are close to the 2/1 commensurability, collide and break up. A fragment enters the gap and, according to the mechanism described above, approaches closely Jupiter's orbit.

While in resonant motion, close approaches to Jupiter itself will not occur. Eventually a statistically probable second collision will remove fragments from resonance and close approaches not only to Jupiter's orbit, but to Jupiter itself become frequent. Then, Jupiter's perturbations may change the fragment's orbit into an earth-crossing orbit.

There remain two problems: What starting values for the fragment in the gap yield sufficiently strong variations in eccentricity and what is the limiting value for the aphelia in order to transform orbits into earth-crossing orbits by perturbations of Jupiter?

We investigated the regions near the 2/1 commensurability for strong variations in eccentricity by numerical calculations. Our model was based on the plane elliptic restricted three body problem averaged by Schubart's method (Schubart 1964). In that model, an orbit is determined by four quantities a, e, σ, μ; a is the semimajor axis, e is the eccentricity of the fragment's orbit. μ and σ are the angles which determine the relative position between Jupiter and the fragment as well as the angle between their perihelia. The starting values for an orbit were chosen in the a, e, σ phase space defined by $3.2 \leq a \leq 3.36$ AU, $0^\circ \leq \sigma \leq 360^\circ$, $0 \leq e \leq 0.14$. The limits for a correspond to the observed limits of the gap. For further details regarding the calculations see School and Froeschlé (1974, 1975).

We calculated about 100 orbits numerically over 10,000 years to find the frequency distribution of the aphelia. According to our results, about 30% of the orbits starting in the phase space defined above have aphelia beyond 4 AU. However, after 4 AU there is a sharp drop-off in the frequency distribution curve. Only 8% of the orbits have aphelia larger than 4.1 AU and only 3% exceed 4.3 AU. No orbit was found with an aphelion larger than 4.5 AU. No significant number of orbits approaches Jupiter's orbit within 0.05 AU since Jupiter's perihelion is at about 5 AU.

We have not yet checked whether Jupiter's action will be large enough to transform these orbits into earth-crossing ones. If Jupiter's action extends down to 4 AU or less, our results support well their proposed mechanism.

Furthermore, we investigated orbits at three other Kirkwood gaps, (the 5/2, 7/3 and 3/1 commensurabilities) for close approaches with Jupiter's orbit. For the 7/3 case, no orbit had an aphelion larger than 4 AU. Therefore, the 7/3 case is excluded as a possible source for meteorites. In the 5/2 gap, a surprisingly large 30% of the orbits exceeded 4 AU. The phase space for the starting values was chosen as for the 2/1 case. We are not able to state how many orbits exceed 4.1 AU or 4.3 AU because at the 5/2 commensurability; the eccentricity varies with long periods - more than 50,000 years in several cases. As the computing time was limited, we usually stopped the calculations when an orbit exceeded 4 AU which was equivalent to a value of 0.41 for the eccentricity. Some selected orbits were integrated over longer periods of time. They yielded aphelia at 4.5 AU. Therefore, the Kirkwood gap at the 5/2 commensurability also can be regarded as a source for meteorites.

No orbit starting in the Kirkwood gap at the 3/1 commensurability has an aphelion close to 4 AU. That would require an eccentricity of 0.6. However, because of the variations in eccentricity, the perihelia of some orbits approach closely the orbit of Mars. 26% of the orbits have perihelia less than 1.9 AU, 15% are below 1.8 AU and 6% come below 1.7 AU. The aphelion of the orbit of Mars is 1.66 AU. There remains the problem of determining the zone around Mars in which Mars is able to transform these particular orbits into earth-crossing orbits.

In conclusion, we can say that in addition to the Kirkwood gap at the 2/1 commensurability proposed by Zimmerman and Wetherill, the Kirkwood gaps at the 5/2 and at the 3/1 commensurability also may be considered as possible sources for meteorites. However, we must say, that all our calculations are based on the planar restricted three body problem and therefore, calculations based on a three dimensional model might yield different results. The coupling between the variation in eccentricity and between the motion of the argument in perihelion of a fragment's orbit may prevent close approaches with Jupiter or with Mars.

ACKNOWLEDGEMENTS

We thank Dr. J. Schubart for his continuing interest. The calculations were carried out on the two IBM 370/168 of the University of Heidelberg and of the C.I.R.C.E. at Orsay respectively.

REFERENCES

Scholl, H., and Froeschlé, C. 1974, *Astron. and Astrophys.*, *33*, 455.
Scholl, H., and Froeschlé, C. 1975, *Astron. and Astrophys.*, *42*, 457.
Schubart, J. 1964, SAO Special Report No. 149.
Wetherill, G. W. 1974, in *Ann. Rev. of Earth and Pl. Sciences*, *Vol. 2*, 303.
Zimmerman, P. D., and Wetherill, G. W. 1973, *Science*, *182*, 51.