# 77. DEFORMATION OF A METEOR STREAM CAUSED BY AN APPROACH TO JUPITER

B. YU. LEVIN
*O. Schmidt Institute of Physics of the Earth, U.S.S.R. Academy of Sciences, Moscow, U.S.S.R.*

A. N. SIMONENKO
*Committee on Meteorites, U.S.S.R. Academy of Sciences, Moscow, U.S.S.R.*

and

L. M. SHERBAUM
*Astronomical Observatory, Kiev University, Kiev, U.S.S.R.*

**Abstract.** The increase in the width of a meteor stream with time is usually regarded as due to differences in the secular variations of the slightly different orbits of individual meteoroids. However, the ordinary differential planetary perturbations acting on different parts of an elliptical ring of meteoroids have a more important effect. Model calculations are presented for a filament-like stream that makes close approaches to Jupiter. They confirm the major importance of deformations of the stream by direct planetary perturbations that act even on a filament-like stream of zero thickness. The disturbed part of the stream takes the form of a bend, dispersing along the initial orbit and producing a significant decrease in the spatial density of the meteoric particles.

The increase in the width of a meteor stream, leading in time to its dispersion and ultimate merging into the sporadic background, is usually regarded as due to differences in the secular perturbations on the slightly different orbits of individual meteoroids (Ahnert-Rohlfs, 1952). Some ten years ago one of the present authors (Levin, 1956) stressed the major importance of deformation of a stream arising from the differential planetary perturbations on different parts of the elliptical ring. This differential effect deforms even a filament-like stream of zero thickness. The maximum perturbations are experienced by the part of the stream that passes the point of closest approach to the orbit of a perturbing planet simultaneously with that planet. Model calculations on the effect have been made (Sherbaum, 1970) by Cowell's method (using an electronic computer) for three similar filament-like streams that approach Jupiter closely; the streams can be regarded as three filament-like parts of the same broad stream.

TABLE I
Parameters for the streams

| | I | II | III |
|---|---|---|---|
| $a$ | 4 AU | 4 AU | 4 AU |
| $e$ | 0.5 | 0.5 | 0.5 |
| $q$ | 2 AU | 2 AU | 2 AU |
| $i$ | 8° | 5° | 4°12′ |
| $\omega$ | 30° | 52°59′ | 108° |
| $\Omega$ | 30° | 6°53′ | 311°43′ |
| $\Delta_{\min}$ | 0.154 AU | 0.327 AU | 0.511 AU |

*Chebotarev et al. (eds.), The Motion, Evolution of Orbits, and Origin of Comets*, 454–461. 

The orbits of the streams are of identical size and shape and have their perihelia in the same direction, but they differ in orientation and consequently in the distances $\Delta_{min}$ of closest approach to Jupiter (see Table I).

In Figure 1a the three orbits cannot be distinguished from one another. We have marked the part of the stream whose behaviour we have studied. Approximately in the middle of this part is situated the 'closest approach particle' (CAP) which later passes at the minimum distance from Jupiter. The distance from CAP to the ends of the

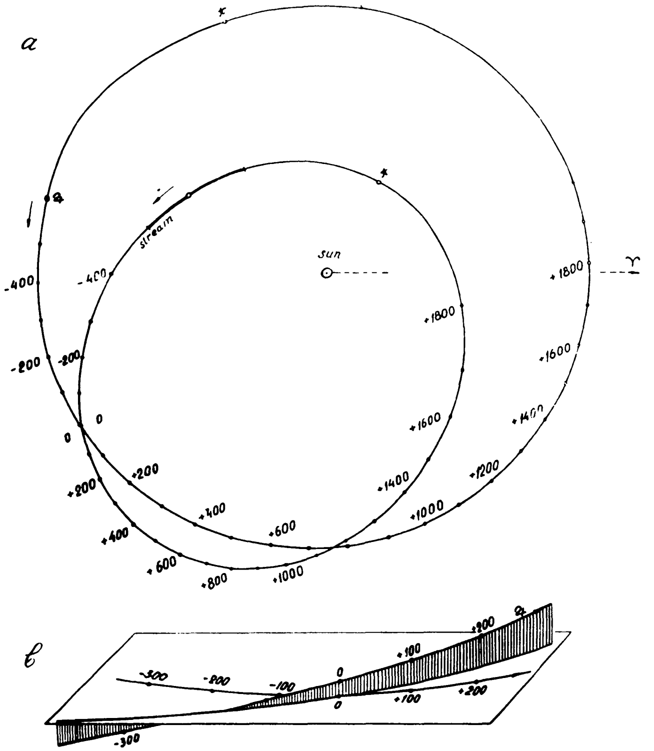


Fig. 1. (a) The orbits of Jupiter and the meteor stream. The positions of CAP (the 'closest approach particle') and Jupiter in their respective orbits are marked by dots at intervals of 100 days before (−) and after (+) the moment of closest approach (0). (b) the position in space of the orbits of Jupiter and stream I in the region of approach.

section of the stream studied is 25° in mean anomaly $M_0$ or 202 days in time. Figure 1b shows the position in space of the orbit of the first stream and that of Jupiter in the region of approach. Streams II and III pass below the first one.

Figure 2 shows for streams I and II the distances of the particles from Jupiter and the orbital elements of the particles at different moments of time before and after the closest approach to Jupiter. Because of the perturbations by Jupiter the streams are deformed, and the minimum distances from Jupiter are smaller than the $\Delta_{min}$ given above, namely 0.125 AU for stream I, 0.297 AU for stream II and 0.490 AU for stream III.

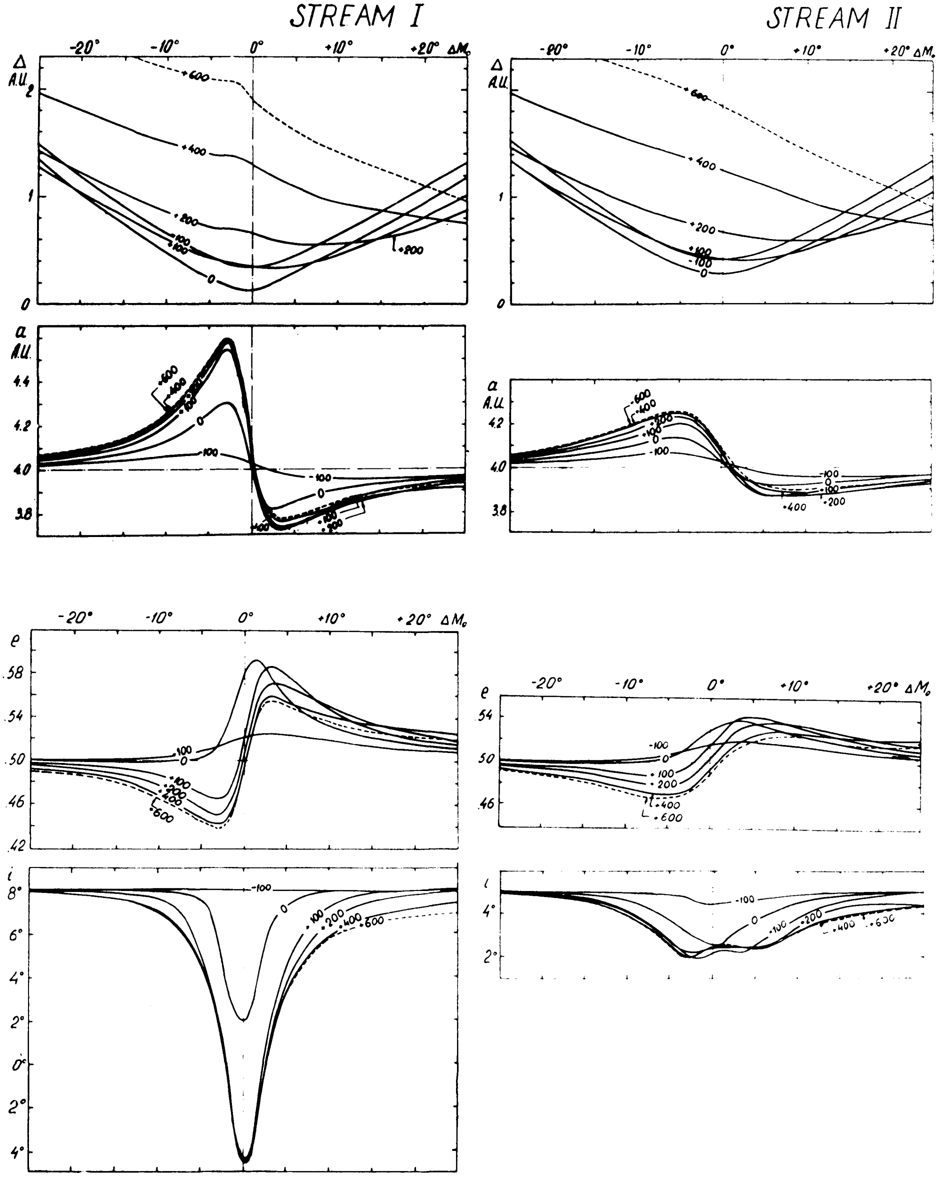


Fig. 2. The distances of particles of streams I and II from Jupiter and the orbital elements of the particles. The abscissa gives the distances of the particles from CAP in terms of the initial mean anomaly.

For the particles which come closest to Jupiter, i.e., for those situated near CAP, the changes in semimajor axis $a$ are small. This is because during the closest approach the velocity vectors of these particles are approximately perpendicular to the direction to Jupiter. Jupiter's attraction changes mainly the directions of the velocity vectors and not the magnitudes. For particles moving ahead of CAP $a$ diminishes monotonically with time, while for particles moving behind CAP it increases monotonically. The maximum and minimum of $a$ occur for particles situated 2 to 3° from CAP for stream I and at somewhat larger distances for streams II and III. In the examples calculated $a$ increases more rapidly than it decreases. At $t = -100$ days the extremal changes in $a$ for particles of stream I are smaller than 0.1 AU. At the moment of the closest approach of Jupiter to the perturbed stream ($t = 0$) these extremal changes of $a$ reach 0.3 AU, and then during the 100 days after approach they rise to 0.54 AU.

The changes in eccentricity $e$ are, roughly speaking, opposite in phase to the changes in $a$. There is a minimum of $e$ for particles moving behind CAP and a maximum for those moving ahead. At $t = +400$ days the extremal values of $e$ for stream I are 0.44 and 0.55. For particles near CAP the velocity vector turns first in one direction and then the other. Thus, before the closest approach $e$ increases, and after the approach it returns almost to the original value of 0.5.

The changes in inclination $i$ for the particles in stream I are substantial. At the time of closest approach the inclination of particles close to CAP changes at a rate of about 10′ per day. The total change in $i$ within 600 days after closest approach reaches 12°.5; the value of $i$ goes through zero, and there is thus an interchange of the ascending and descending nodes. This interchange of nodes is depicted here by passage below the line $i = 0$; the motions of the particles remain direct.

The orbital elements change rapidly during the period of closest approach (from $-100^d$ to $+100^d$), but the variations subsequently become more gradual. At $t = 400$ or $500^d$ after closest approach the perturbations become much smaller than before, and the further changes in the elements are about 0.1 to 0.01 of those accumulated previously. By that time Jupiter is more than 0.7 to 0.8 AU from all parts of the stream.

The changes in $a$ and $e$ for particles in streams II and III during the period of their approach to Jupiter are similar but markedly smaller than for stream I. The changes in $i$ are also small.

Before being perturbed by Jupiter the particles moved one after another along the same orbit. After the perturbations they move along different orbits. Although the orbital elements have already changed substantially by the time of closest approach the particles continue to be situated near the original orbit. But gradually a bend develops in the stream.

Figure 3 shows the portion of stream I that suffers the greatest perturbations. The bends represent the instantaneous locations of particles that are about to move along different trajectories. At the time of closest approach the most perturbed particles form a small bend directed towards Jupiter. They deviate from the initial orbit by less than 0.1 AU. At the top of the bend are the particles closest to CAP. The deformation increases with time and becomes more and more pronounced after Jupiter has moved away from the stream and only slightly influences its motion. The form of the bend changes. Particles which followed CAP have increased velocity: during the first stage of the development of the bend they outrun CAP, while the particles that moved ahead are decelerated and lag behind.

The deformations of streams II and III are similar to those described above for stream I, but they are smaller and develop slowly.

The further development of the bend in stream I is determined mainly by the changes occurring in orbits of individual particles during a short time around closest approach. For streams II and III the development of the bend after closest approach is somewhat more complicated because of the larger relative role of the previous and subsequent small perturbations by Jupiter.

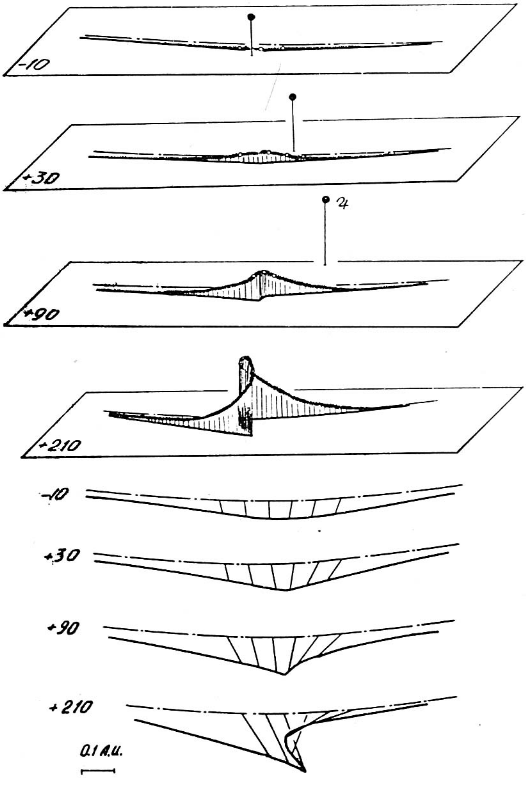


Fig. 3. The portion of stream I that suffers the greatest perturbations. The arc considered is 23° in terms of the initial mean anomaly. The four upper diagrams represent the locations of the bend with respect to the plane of the initial (unperturbed) orbit at various times, while the four lower ones are their projections on that plane.

Figure 4 shows the development of the bends of all three streams during one revolution, while Figure 5 illustrates subsequent spatial positions of the bend in the first stream relative to the plane of the initial orbit. The diagrams show the CAP and two points that were initially situated at $\pm 1\overset{\circ}{.}2$ in terms of the initial mean anomaly. At the beginning these particles are situated close to one another. Under the perturbations by Jupiter they start to deviate together from the initial orbit, but in the course of time they drift apart because of the differences in their orbits.

https://doi.org/10.1017/S0074180900006926 Published online by Cambridge University Press

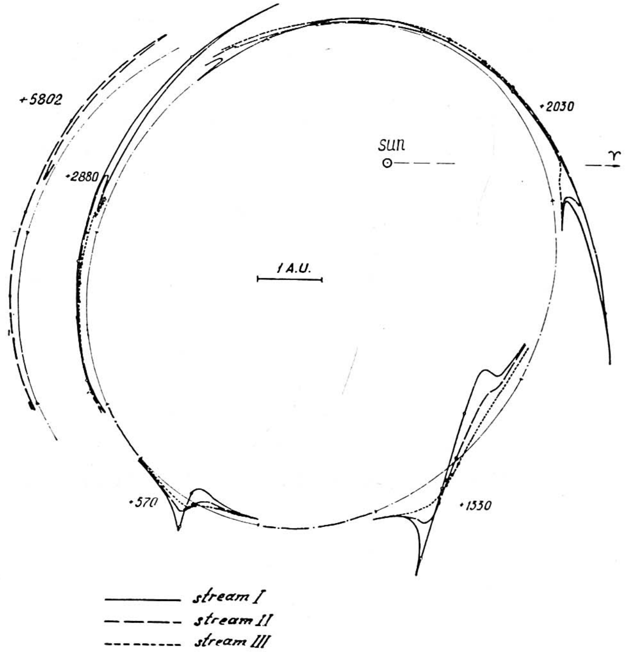


Fig. 4. Development of the bends in the streams during one revolution, projected on to the ecliptic plane. The corresponding unperturbed sections of the stream (50° in length in terms of the initial mean anomaly) are shown by a thin line.

The deviations of particles from their unperturbed positions are of the same order of magnitude both in the plane of their initial orbit and perpendicular to it. Differences in the orbits lead to rapid changes in the size and form of the bend. As already mentioned, the development of the bends in streams II and III proceeds in a similar way, but more slowly. In Figure 4 the bend in the stream II is shown after two revolutions ($t = +5802^d$).

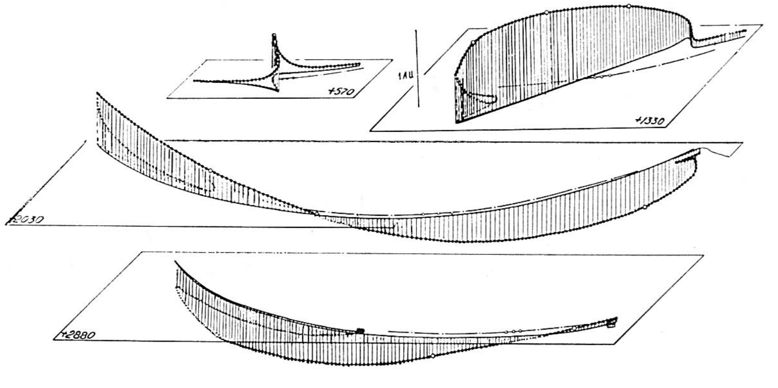


Fig. 5. Development of the bends in stream I relative to the plane of the initial orbit.

The linear density of particles in the bend rapidly diminishes. For stream I it decreases by more than an order of magnitude during one revolution. Due to the large dependence of the perturbations on the distance to Jupiter, there are corresponding increases in the distances between particles in the bends on neighbouring filamentary streams. Consequently, in the examples calculated, i.e., for a stream closely approaching Jupiter, the spatial density of particles in the perturbed section decreases after one revolution by 3 to 4 orders of magnitude, and it continues to decrease during subsequent revolutions. Near the point of closest approach, however, the simultaneous passage of different parts of the bend can lead to temporary increases in density.

It must be noted that the subsequent extensions of the bends already formed is accompanied by the production of 'younger' bends during the regular passage of Jupiter near the point of closest approach. After several revolutions the particles of stream I will thus have dispersed over a region up to 2 AU in width. This dispersion is much larger than that resulting from ejection of particles by a cometary nucleus (see Figure 6). Actually, Jupiter disperses not only the initial stream but also the bends

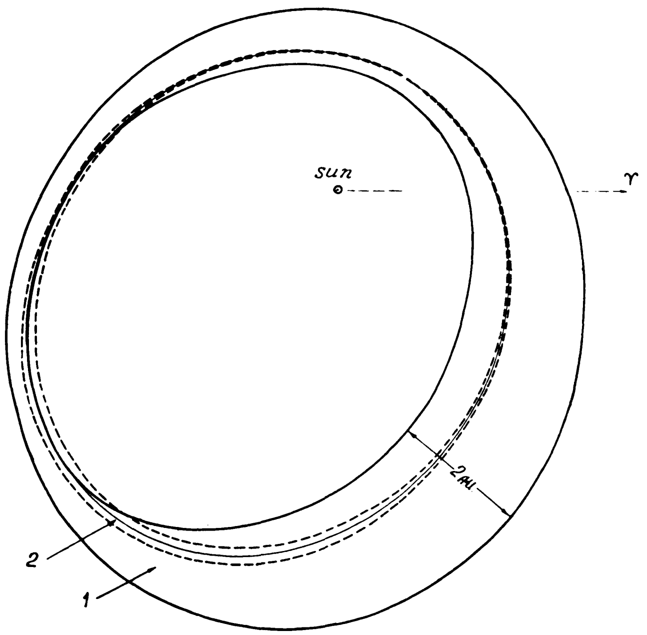


Fig. 6. Region 1 is that occupied by particles of stream I after a single approach to Jupiter. Region 2 is that occupied by particles ejected isotropically (at a velocity of 0.1 km $s^{-1}$) from a cometary nucleus near perihelion (the true ejection velocities are possibly smaller than this).

already formed, and therefore the dispersion of particles proceeds more rapidly and over a larger region of space.

Dispersion occurs rapidly even for a stream which does not have close approaches to Jupiter. Ordinary small perturbations also produce bends (see Figure 7). Because of the larger inclination ($i = 30°$) this stream does not approach Jupiter's orbit any closer

https://doi.org/10.1017/S0074180900006926 Published online by Cambridge University Press

than 0.74 AU. Nevertheless, the point of intersection illustrated describes complicated loops increasing in size with time. To each revolution there correspond 2–3 loops. During the third or fourth revolutions the loops are already about $10^6$ km in extent, and by the tenth revolution they extend up to $20 \times 10^6$ km.

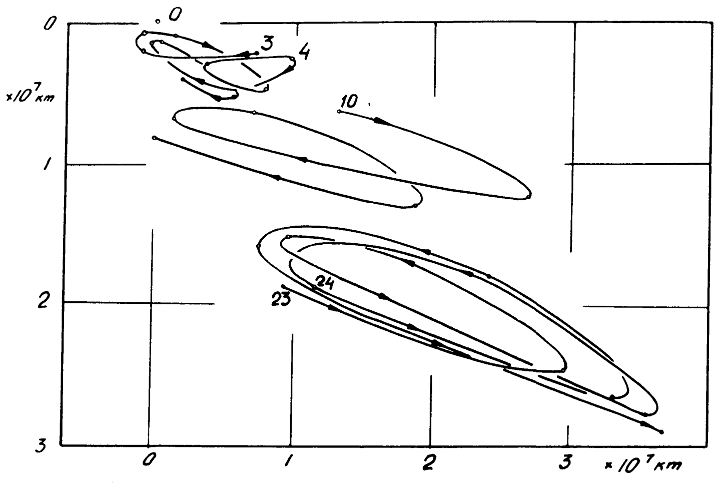


Fig. 7. The displacement with time of the point of intersection of a filament-like stream ($a=4.5$ AU, $e=0.5$, $i=30°$, $\omega=100°$, $\Omega=9°$) with a plane perpendicular to the stream at a point situated 90° from the initial perihelion.

## References

Ahnert-Rohlfs, E.: 1952, *Veroeffentl. Sternw. Sonneberg* **2**, 38.

Levin, B. Yu.: 1956, *Fizicheskaya Teoriya Meteorov i Meteor noe Veshchestvo v Solnechnoj Sisteme*, Akad. Nauk SSSR, Moscow. (See also Levin, B. Yu.: 1961, *Physikalische Theorie der Meteore und die meteoritische Substanz im Sonnensystem*, Akademie-Verlag, Berlin.)

Sherbaum, L. M.: 1970, *Vestn. Kiev. Gos. Univ. Ser. Astron.* No. 12.

## Discussion

*Yu. V. Evdokimov:* How many meteors were used in your calculations and why should they initially have the same orbit?

*B. Yu. Levin:* We considered 16 points located at equal intervals in mean anomaly. Meteors leaving the nucleus of a comet with almost zero velocity will initially have practically the same orbit but will be at different distances from the comet.

*Yu. V. Evdokimov:* In our calculations on the Draconids we used meteors which correspond very closely to the real ones. It seems to me that even if the meteors leave the comet with small velocities, they do not have the same orbit.

https://doi.org/10.1017/S0074180900006926 Published online by Cambridge University Press