A Spiral Meteor Train

Shigeno, Y.; Toda, M.; Kobayashi, M.

Abstract

A spiral meteor train was successfully observed and photographed at two stations. The spiral was 4.17 ms in period and 461 m in diameter. We calculated the centrifugal acceleration and atmospheric drag of the meteoroid, and found that it is not the meteoroid but only the emitted gas which is making a spiral motion. A non-linear meteor trail may be curved or branched, if not spiral. We attempted a dynamic study. Since a meteoroid has a very large kinetic energy, compared to the force received from the atmosphere, its motion is not changed greatly.

A Spiral Meteor Train

Yoshihiko Shigeno, Masayuki Toda, and Masato Kobayashi

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1. Introduction

Meteor trails are usually linear, but some trails were reported to be non-linear. Beech [1–3] collected many reports and analyzed non-linear meteors mainly using naked-eye observations in the 1800s. A non-linear meteor may have a trail of a curved, spiral, branched, or combined shape. The data classification results of non-linear trails are as follows:

1. About 0.5% of the meteors were non-linear.
2. Of the non-linear meteors, 60% were curved and 40% were spiral.
3. These phenomena were observed for meteors of various durations, magnitudes, and colors.

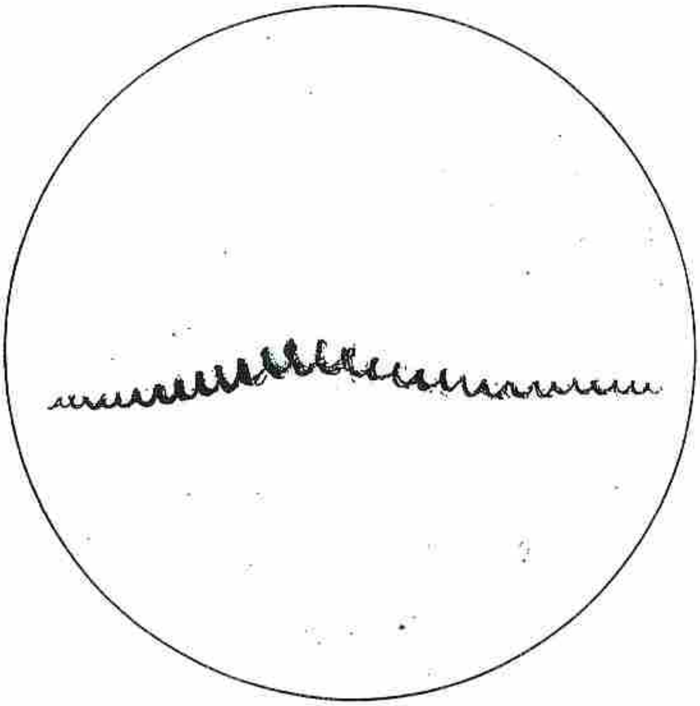

Figure 1 – Kunihiko Suzuki observed this Orionid spiral meteor train through 9×35 binoculars at 18^h14^m UT on December 22, 1982, from Mt. Tsukuba, Japan. The drawing shows the train 10 s to 15 s after the meteor appeared.

Beech explained these phenomena with the magnus effect and torque-free precession in hydrodynamics. A revolving baseball draws a curve, while a revolving football draws a spiral. However, he says he has never seen a non-linear meteor on a photograph. Shigeno [4] never saw a non-linear meteor either, although he made double-station observations and measured more than 1000 meteors recorded by photography and TV. *Sky and Telescope* [5] published an example of a photographed spiral meteor trail. Suzuki [6] sketched a spiral meteor train which he observed with binoculars. Figure 1 shows this sketch. To check this phenomenon, Toda has continued photographic observations. On November 17, 1997, Toda successfully observed a spiral meteor train in the Leonids. This is a double-station observation, together with Kobayashi. Based on this meteor train observed at two stations, our report analyzes a spiral shape and discusses the mechanism of a non-linear meteor trail.

2. Observation

Figure 2 shows the photograph of a spiral meteor train where the train becomes spiral in the middle and returns to linear again. This meteor train was not observed at both stations, although this one appeared two minutes after the double-station meteor analyzed here. Figure 3 shows the photo of the double-station observation. Since the meteor train was about 250 km away from the stations, we were not able to determine the fine structure, but the spiral shape could be measured.

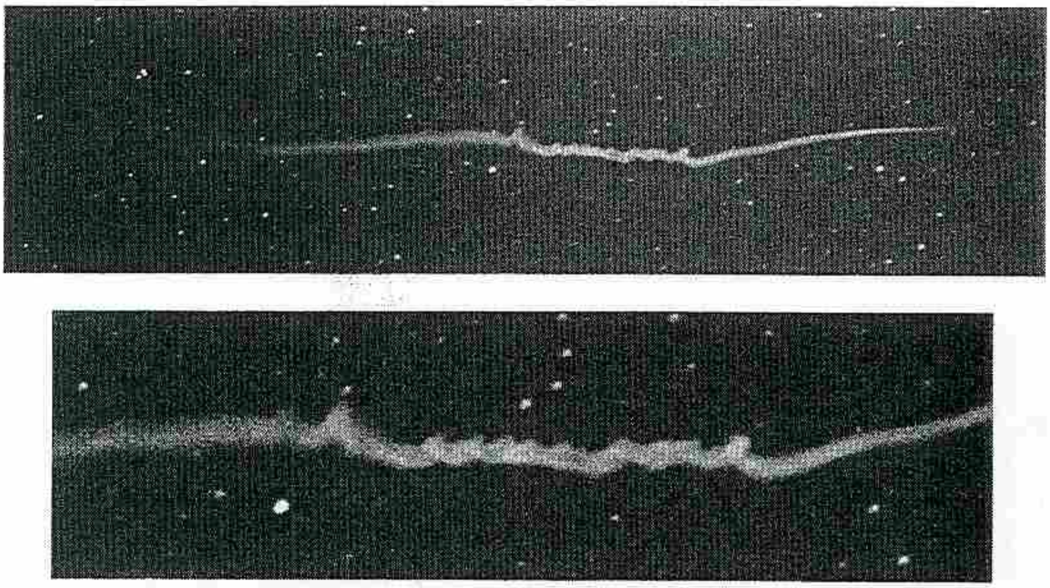

Figure 2 – A magnitude −3 Leonid meteor appeared at $17^{\rm h}44^{\rm m}47^{\rm s}$ UT on November 17, 1997. The photograph taken by M. Toda shows the meteor train from $17^{\rm h}44^{\rm m}56^{\rm s}$ to $17^{\rm h}45^{\rm m}00^{\rm s}$ UT, as well as an enlargement. The photograph was taken with a Nikon F4s, $f = 200$ mm, $f/2.0$, on Fuji HR1600 film.

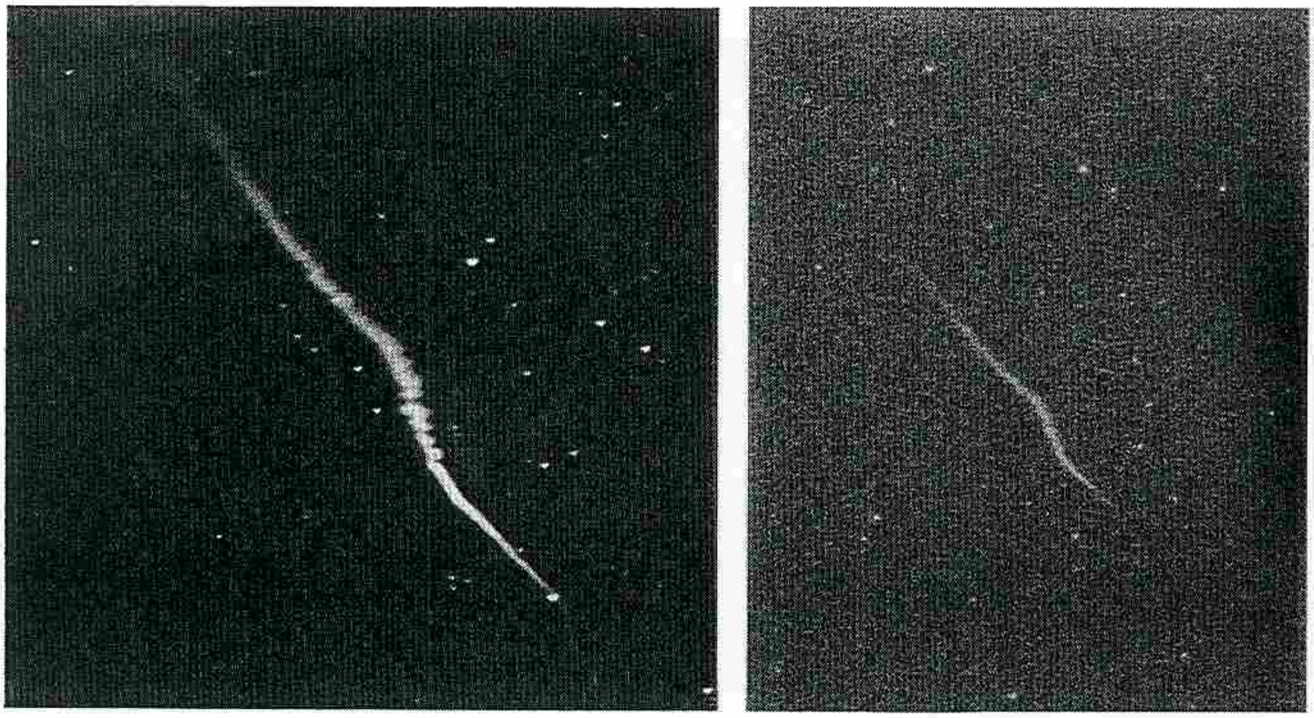

Figure 3 – This magnitude −4 Leonid meteor appeared at $17^{\rm h}42^{\rm m}26^{\rm s}$ UT on November 17, 1997. *Left*: Meteor train photographed by M. Toda from $17^{\rm h}42^{\rm m}35^{\rm s}$ to $17^{\rm h}42^{\rm m}39^{\rm s}$ UT, with a Nikon F4s $f = 200$ mm, $f/2.0$, on Fuji HR1600 film. *Right*: Meteor train photographed by M. Kobayashi from $17^{\rm h}42^{\rm m}36^{\rm s}$ to $17^{\rm h}42^{\rm m}40^{\rm s}$ UT, with a Nikon F3 $f = 85$ mm, $f/1.4$, on Konica GX3200 film.

Table 1 lists the measurement results. The distance between the two stations was 72.0 km. The train began at a height of 102.2 km and the spiral at 97.7 km. The first measured point of the spiral was at a height of 95.0 km. The spiral disappeared at a height of 92.8 km and the train ended at 89.1 km. In Table 1, the distance in the direction of motion between two spiral cycles is $L_{\rm s}$, the spiral cycle time is $P_{\rm s}$ (with an assumed Leonid velocity of 72 km/s, according to Lindblad [7]), and the spiral diameter is $D_{\rm s}$. As a result, the spiral was found to draw circles of 461 m in diameter at 4.17-ms cycles.

Table 1 – Positions of the meteor train. Location of observer 1: Mt. Fuji, halfway-point; location of observer 2: Mt. Yatsugatake. For explanation of the symbols, please refer to the text.

	λ (° E)	φ (° N)	h (km)	L_s (m)	P_s (ms)	D_s (m)
Obs. 1 location	138.79861	35.33333	1.420			
Obs. 2 location	138.36694	35.87813	1.049			
Train begin	140.92983	34.23761	102.202			
Spiral begin	140.89171	34.23332	97.701			
Spiral 0	140.86089	34.23217	94.987			
Spiral 1	140.86057	34.23110	94.680	331	4.59	438
Spiral 2	140.86023	34.22999	94.358	345	4.79	439
Spiral 3	140.86001	34.22923	94.140	234	3.26	405
Spiral 4	140.85970	34.22821	93.845	317	4.41	488
Spiral 5	140.85941	34.22722	93.560	306	4.25	561
Spiral 6	140.85911	34.22623	93.275	306	4.25	493
Spiral 7	140.85881	34.22521	92.984	314	4.36	504
Spiral end	140.85857	34.22442	92.755	247	3.43	358
Train end	140.81869	34.22507	89.100			
Spiral mean				300	4.17	461
Spiral SD				39	0.54	64

3. Discussion

If a spiral is assumed to be the result of a rotational movement of a meteoroid around an external axis, the centrifugal acceleration becomes

$$r\omega^2 = 3.1 \times 10^8\ \mathrm{m\,s^{-2}}, \tag{1}$$

where r is the "orbital" radius and ω is the angular velocity. The radius of the spiral is half the diameter D_s of the spiral minus half the diameter of the train. In our case this amounts to (461 m − 185 m)/2. This calculation ended in an unreasonable large value for the centrifugal acceleration.

Then, the drag that the meteoroid received from the atmosphere was calculated. The absolute magnitude of the meteor was determined from the observed magnitude of −4 to be −5.5. By using the formula of Nagasawa [8], the meteoroid mass was calculated to be 5.8 g. The meteoroid density was 0.6 g/cm^3 [9] and the meteoroid diameter was 26 mm. Recently, Babadzhanov [10] determined the density of the Leonids to be 2.5 g/cm^3, but this result does not change the conclusion of this report.

To calculate the atmospheric drag F, the following formula of Barger and Olsson [11] was used:

$$F = -0.5 \times C_\mathrm{D} \times S \times \varrho_\mathrm{a} \times V^2 = -2.2\ \mathrm{kg\,m\,s^{-2}}. \tag{2}$$

Here, C_D is the drag coefficient (assumed value $C_\mathrm{D} = 1.0$), S is the cross-section area of the meteoroid, ϱ_a is the atmospheric density (1.6×10^{-6} kg/m^3), and V is the meteor velocity (72 km/s). The value of C_D is 0.4 when a sphere moves through the atmospheric density at the ground. However, it is assumed $C_D = 1.0$, because the atmospheric density is very low in the height level considered here. As to ϱ_a, the atmospheric density at 94 km high was calculated using Terada's formula [12] derived from the U.S. Standard Atmosphere [13]. Strictly speaking, equation (2) pertains only to a meteoroid moving at a sub-sonic velocity through the atmospheric density at the ground, but is usable for the purpose of this report.

From this drag force, the meteoroid receives an acceleration of $-380\ \mathrm{m\,s^{-2}}$. The meteor velocity decreases by about 38 m/s if this acceleration acts for 0.1 second. This value is plausible as an atmospheric acceleration. Compared to the atmospheric drag in equation (2), the acceleration in (1) is too large. This means that the meteoroid itself was not moving along a spiral trajectory. So we have to assume that only the gas of the meteoroid train was in a spiral. This reminds us of the spiral jet of a comet (Sekanina [14]), although the mechanism may be different. The spiral train forming mechanism is discussed here.

The Knudsen number, Kn (Nanbu [15]) can be calculated as follows:

$$\mathrm{Kn} = \lambda / L = 2.2, \tag{3}$$

where λ is the mean free path (56 mm) in the atmosphere at 94 km height and L is the object size (26 mm). If the Knudsen number is 0.01 or higher, the atmosphere is regarded as a thin gas. This means the spiral train was formed synchronously with the rotation of the meteoroid.

However, since the gas emitted from the meteoroid seems more dense than the atmosphere, a whirl is generated behind the meteoroid. The whirl turns as the meteoroid revolves while emitting gas spirally. In this case, the revolution velocity of the meteoroid is faster than that of the spiral train.

If we assume that the thickness of the gas flow immediately after the meteor is equal to the cross-section of the meteoroid, and take into account the path length of the meteor, which is 16.7 km, we obtain a gas density of $6.6 \times 10^{-4}\ \mathrm{kg/m^3}$, about 400 times the atmospheric density.

We cannot tell which of the above cases the current observation belongs to. The fact that the spiral begins and ends along the trail may give a hint to the solution. In the remainder of this article, we discuss curving and branching meteors.

We first consider the possibility of a meteor trail to be bended by a force orthogonal to the direction of the above meteor. For example, a force of $580\ \mathrm{kg\,m\,s^{-2}}$ gives a velocity of 10 km/s after 0.1 second. Since the atmospheric drag is as in formula (2), however, such a great bending is not possible. As the atmosphere is a thin gas at high altitude, a bending force hardly occurs, even when the meteoroid is revolving.

How about a branching meteor trail? In Figure 4, one rotating meteoroid splits into two parts which moves in different directions. To change the direction of a Leonid meteor (72 km/s) by 15°, for example, the meteor must be moved at a rate of 19.3 km/s perpendicularly to the direction of the meteor. Two mass points immediately before the splitting are 2 cm away and revolve around each other. The number of revolutions needed for a tangential speed of 19.3 km/s is 3.1×10^5 per second. If the mass at each mass point is 1 g, the centrifugal force involved is $3.7 \times 10^7\ \mathrm{kg\,m\,s^{-2}}$. This force is large enough to split the meteoroid well before the aforementioned high number of revolutions is reached. Therefore, we cannot say that splitting by revolutions causes the meteor trail to branch.

Another possible cause for branching is the explosion of the high-temperature meteoroid. However, it is difficult to see how an an explosion yielding accelerations of several tens of kilometers per second does not produce jetting.

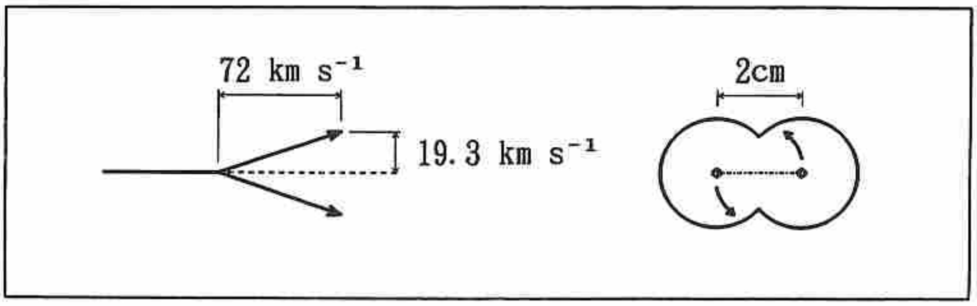

Figure 4 – The branching meteor trail.

Shigeno witnessed a split fireball at $14^h30^m14^s$ UT on August 12, 1975. The fireball was a slow sporadic meteor of magnitude -1. The red meteor lasted for 7 seconds. A single light spot split into a leading light spot and a following light spot on the same trail. Although this meteor was photographed, the photograph does not show splitting, because both light spots continued to follow the same trail.

The phenomenon observed by Shigeno can be explained as follows:

1. the leading light spot is the body of the meteoroid; and
2. the following light spot is a cloud of particles separated from the main body.

The atmospheric drag decelerates a decomposed meteoroid drastically. With equation (2), the diameter of particles decelerating 10% in 0.1 second is calculated. If the meteoroid density is 1 g/cm^3, the atmospheric density (ϱ_a) is $2 \cdot 10^{-5}$ kg/m^3 (altitude: 80 km), and the meteor velocity V is 20 km/s, then the particle diameter is 0.3 mm.

4. Conclusion

Roughly speaking, the atmospheric pressure at 100 km height is about one millionth of that on the ground. The velocity of the meteor is about 1000 times that of a baseball. Since the atmospheric drag is directly proportional to the the square of the velocity, the meteor receives almost the same drag as a baseball does. However, since the kinetic energy per unit of mass is about one million times bigger, the atmospheric drag cannot change the meteoroid motion greatly.

Is a curve or bend of a meteor trail an illusion? When you draw a straight line with a pen, your arm muscles extend and contract continuously. However, since your muscles extend or contract not smoothly but intermittently, the line becomes zigzag. Many of you may have encountered this experience. If you keep tracking a moving meteor with your eyes, the eye muscles extend and contract intermittently and do not move the eyes smoothly. This may end in the zigzag observation of a meteor.

This report clarified the spiral shape of a meteor train and indicated that a meteoroid may be revolving. Rather many meteor trains may be spiral-shaped, although not many spiral meteor trains have been observed. If a spiral train is photographed with a low-resolution camera, the photos may show fine light and shade repeatedly. Because of the long exposure, the spiral train will be photographed in the form of many stripes.

A study on other curved or bended meteor trails ended in a pessimistic conclusion. A meteor further splitting and branching into two trails could not be explained at all. Curving, bending, or branching meteor trails require further studies.

Acknowledgment

This report was compiled with cooperation from Messrs. Mitsuru Terada, Hiroyuki Shioi, and Isshi Tabe, reflecting opinions from Mr. Satoshi Takahashi about hydromechanics and comments from Dr. Ko Nagasawa. We would like to express our great appreciation.

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Observational Results

SPA Meteor Section Results: March–April 1998

Alastair McBeath

News and results submitted to the *SPA Meteor Section* from March and April 1998, are discussed. March 15 produced a notably brilliant meteor for south-west England. Relatively few observers recorded any Lyrids because of poor weather, but radio and some visual data support a broad maximum on April 22, without an obvious sharp peak. Some confirmation of two Virginid radiant areas previously found was possible during March and April, and another weak radiant was suspected during early March. Some low early η-Aquarid rates were detected in late April.

1. Introduction

Weather conditions seem to have been generally unfavorable during these two months, and many observers struggled to see anything at all, at least in the northern hemisphere. In South Africa, conditions seem to have been much better, permitting Tim Cooper to carry out some very useful monitoring of several minor showers, most notably the Virginids. Table 1 shows the overall observing tallies possible.

Table 1 – Visual, photographic, and radio hours' totals, and visual meteor numbers recorded in each month, including a partial breakdown of meteor types.

Month	Visual	VIR	LYR	ETA	SAG	Meteors	Photo	Radio
March	$76^{\mathrm{h}}.7$	48				409	112^{h}	2633^{h}
April	$92^{\mathrm{h}}.8$	22	200	17	31	721	7^{h}	3054^{h}

Photographic observations came from *Arbeitskreis Meteore* (*AKM*) members Ina Rendtel, Jürgen Rendtel, Roland Winkler, and Jörg Strunk, all in Germany, with one trail so far discovered on their all-sky fireball patrol negatives, a fireball on April 19-20. Along with all the *AKM* details here, these were extracted from the *AKM*'s journal Meteoros, issues 4 and 5 (1998), thoughtfully submitted by Ina Rendtel.