

Ongoing meteor work

An investigation into the 1998 and 1999 Giacobinids by meteoroid trajectory modeling

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Calculation of the trajectories of meteoroids ejected from a comet close to Jupiter is very difficult, since the Jovian perturbations are very large. A technique for calculating the trajectories of meteoroids from Comet 21P/Giacobini-Zinner by a two-stage method is presented. The trajectories leading to the Giacobinid showers of 1998 and 1999 are calculated using the method.

1 Introduction

In recent years, the trajectory followed by dust ejected from the comet 55P/Tempel-Tuttle has been calculated, and observations of Leonids meteors match these predictions, making clear the details of the meteor shower from this comet. However, considering meteor showers from shorter period comets including 21P/Giacobini-Zinner, trajectory calculation is complicated by large Jovian perturbations. This paper presents a solution to these problems involving a two-stage calculation. In the first stage a fast outline calculation is performed, and trails which approach the earth near enough to suggest the possibility of meteors are identified. In the second stage, a calculation including planetary perturbations is performed in detail, based on the trajectories found in the first stage. In this paper, this method is applied to the comet 21P/Giacobini-Zinner, and the trajectories leading to the observed major Giacobinid shower in 1998 and their middle-scale shower in 1999 are deduced.

2 Method

The basis of this method is the same as the dust trail theory applied to Leonids in recent years. That is, as a comet passes perihelion, the method assumes the meteoroid stream to be formed by dust ejected in a direction opposite to the movement to that of the parent comet, and calculates the distribution of this dust.

2.1 First stage: outline calculation

In the first stage, the perturbations due to Jupiter were calculated only approximately, and the distribution of the whole dust trail from comet 21P/Giacobini-Zinner was investigated. Microsoft Excel(TM) was used for calculation, because it can calculate rapidly by referring to a table of positions of Jupiter through one revolution.

In the model, dust was ejected from the comet at intervals at every perihelion passage, and these particles were followed by numerical integration with the simplest Euler method at intervals of 0.5 days. The ejection velocities (positive in the direction of the comet's travel) ranged from -30 m/s to $+30$ m/s in steps of

5 m/s. Thus ejections in the same direction as that of the comet were considered along with ejections in the conventional, opposite direction. This method was repeated and an outline distribution of the whole dust trail was obtained. This ejection of dust was modeled for every perihelion passage of Giacobini-Zinner from the 1894 perihelion passage onwards, namely 16 occasions. The error per revolution in this calculation was about 0.01 AU or less in perihelion distance and about 10 days or less in the time of perihelion passage, when the known orbital elements of the parent comet were applied. It is assumed that these errors accumulate with the number of passages.

The dust trails presumed to approach the earth were identified by this method. In addition, the difference between the calculated and observed results was noted. The calculated longitude of the ascending node Ω should equal the solar longitude $\lambda_{\odot}$ at the time of the shower. (Note that the shower occurs at the descending node of the meteoroid stream, which is 180° different from the ascending node; but that Solar Longitude $\lambda_{\odot}$ is defined in geocentric co-ordinates, thus differing by 180° from the position of the Earth in heliocentric co-ordinates.)

2.2 Second stage: precise calculation

The more precise calculations including planetary perturbations were performed along those dust trajectories estimated by the first stage to approach the earth.

They were calculated using NIPE (v3.21 for MS-DOS, programmed by Mr. Naito) which is software that calculates planetary positions based on DE200. This software calculates perturbations due to nine planets and the moon. The program author quotes a calculation error of less than 1.0×10^{-14} AU per 8000 days] about the position of each planet to DE200. This amounts to 4.6×10^{-16} AU per year, or less than 5×10^{-14} AU for the entire integration for the worst case. The numerical integration proceeds in intervals of 0.125 days using the Adams-Bashforth-Moulton method. In order to calculate perturbations as accurately as possible, this method was used to calculate the position of the dust. The error per revolution of this calculation was

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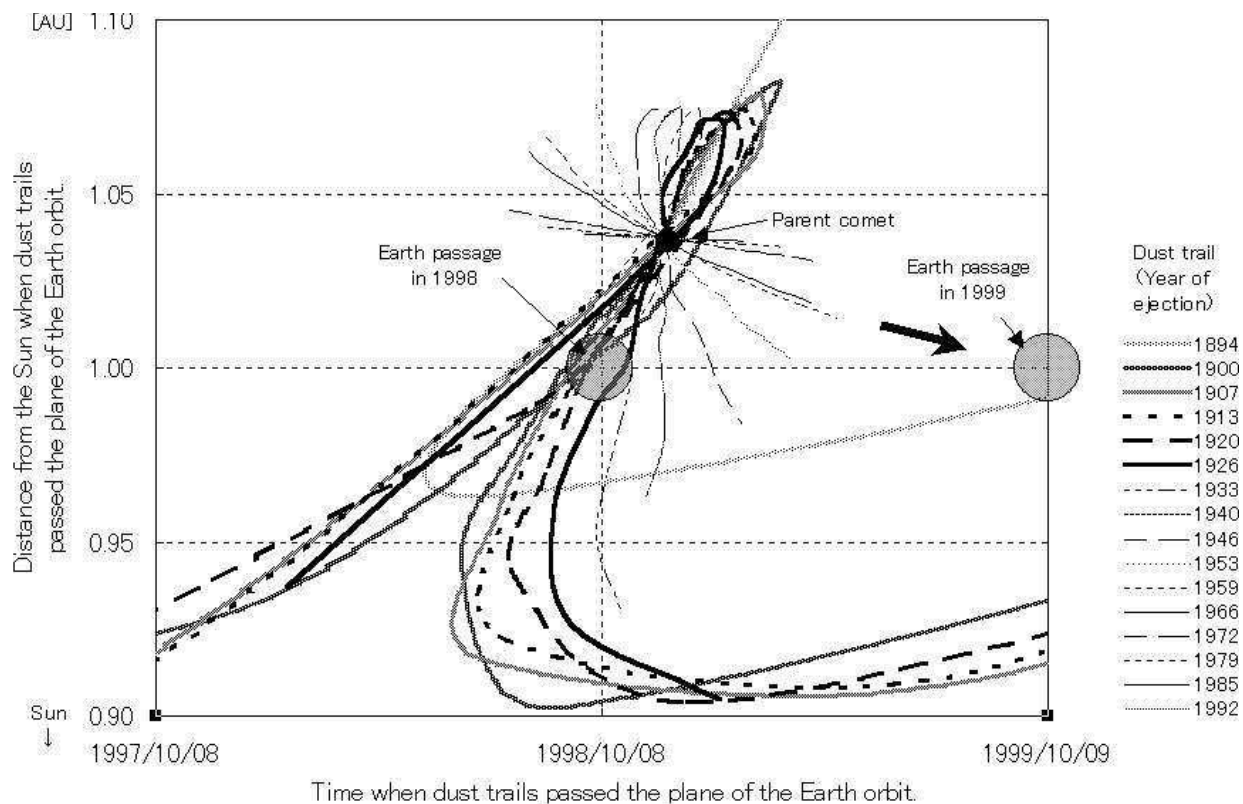


Figure 1 – Distribution of dust trails from the results of the First Step. (Shaded circles represent the Earth; their diameters are arbitrary.)

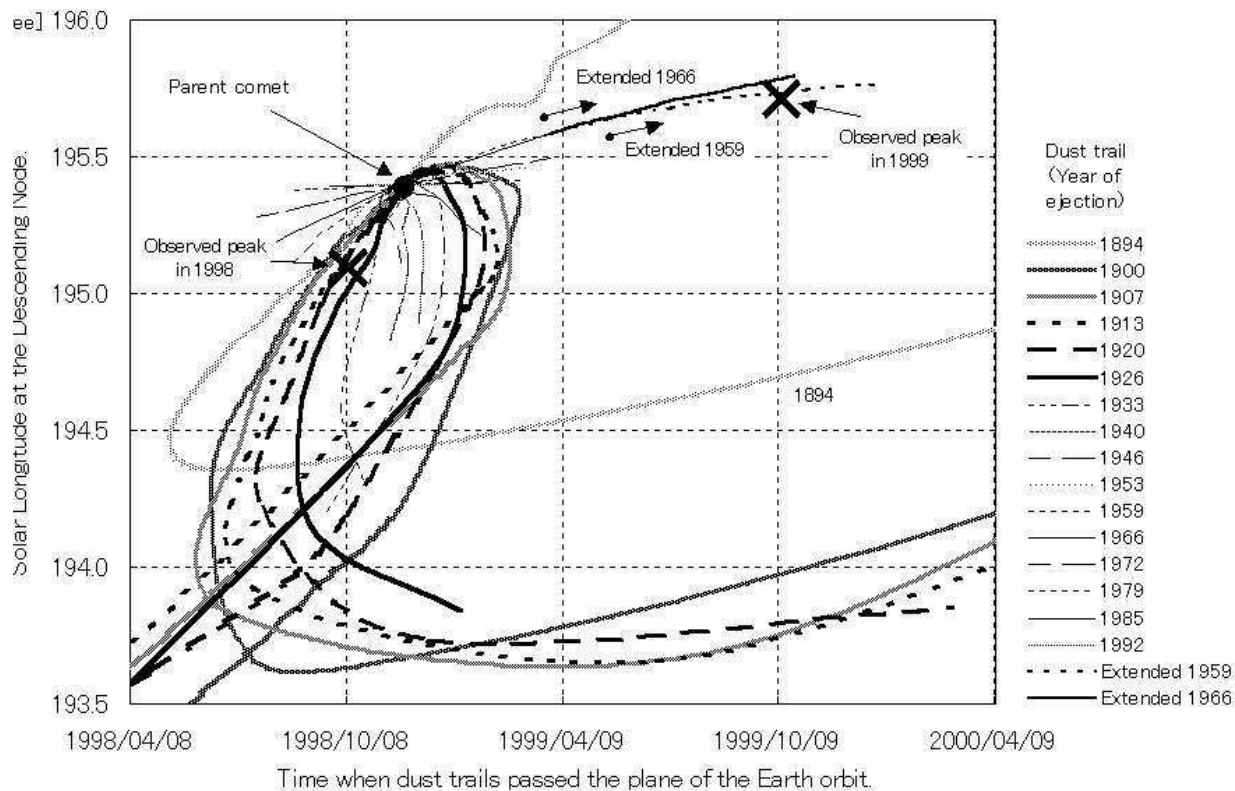


Figure 2 – Relation of the ascending node to the time of perihelion.

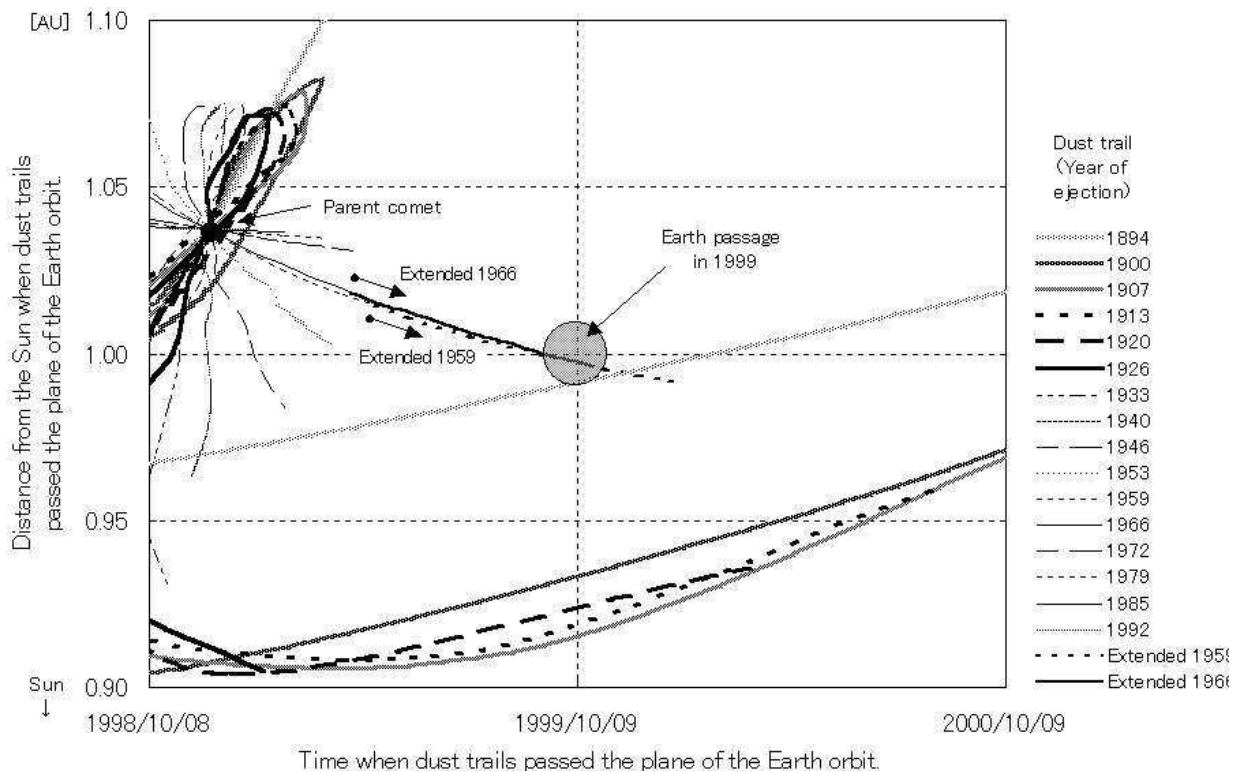


Figure 3 – Distribution of dust trails from the results of the First Step when the ejection velocity is extended to 70 m/s for the 1959 and 1966 trails. (Shaded circles represent the Earth; their diameters are arbitrary.)

about 0.001 AU or less in perihelion distance and about one day or less in the time of perihelion passage, when the known orbital elements of the parent comet were applied. These results were regarded as of sufficient accuracy.

3 Results

3.1 First stage: outline calculation

The distribution of the calculated dust trail is shown in Figure 1.

It can be seen that the trails are intricately distributed due to the large Jovian perturbations. It also turns out that several trails were likely to approach the earth in 1998. These results are summarized in Table 1.

In Table 1, material ejected with negative velocity produced large differences between the calculated and observed longitudes. This material was excluded from the second stage of the calculation. The observed peak was at $\lambda_{\odot \text{OBS}} \simeq 195.08^\circ$ in 1998 (Iiyama, 1999).

The trails not shown in Table 1 are those which tended not to approach the Earth on Figure 1, and were therefore judged not to approach it in reality.

The only trail which approached the earth closely in 1999 was that ejected in 1894. However, this trail had been excluded from the second stage calculation due to its distance from the Earth in 1998. The observed peak was at $\lambda_{\odot \text{OBS}} \simeq 195.72^\circ$ in 1999 (Iiyama, 2000). When dust with ejection velocity out of the chosen range was considered, however, it seemed likely that dust ejected in 1959 and 1966 would also approach the earth in 1999.

Table 1 – Outline calculation results of trail positions in 1998, showing ejection velocity and solar longitude $\lambda_{\odot \text{SIM}}$ at the descending node. Data marked with an asterisk were excluded from the second-stage calculations.

Year of ejection	Ejection velocity (m/s)	$\lambda_{\odot \text{SIM}}$ ($^\circ$)	
1894	+0 – +5	195.1	
1900	+5	195.2	
1907	+5	195.2	
1913	+5 – +10	195.2	
1920	+5 – +10	195.1	
1926	+10 – +15	195.0	
1933	+15 – +25	194.7 – 195.1	
1900	–20	194.0	*
1907	–25	194.4	*
1913	–25	194.5	*
1920	–25	194.2	*
1926	–25	194.4	*
1933	–30	194.3	*

It also appeared that the calculated longitude of the ascending node matched well with observation, as shown in Figure 2.

The allowed range of ejection velocities was therefore extended for these two trails and the calculation was applied. The distribution of these two dust trails is shown in Figure 3.

It turned out that these trails approached the earth in 1999. These results are summarized in Table 2.

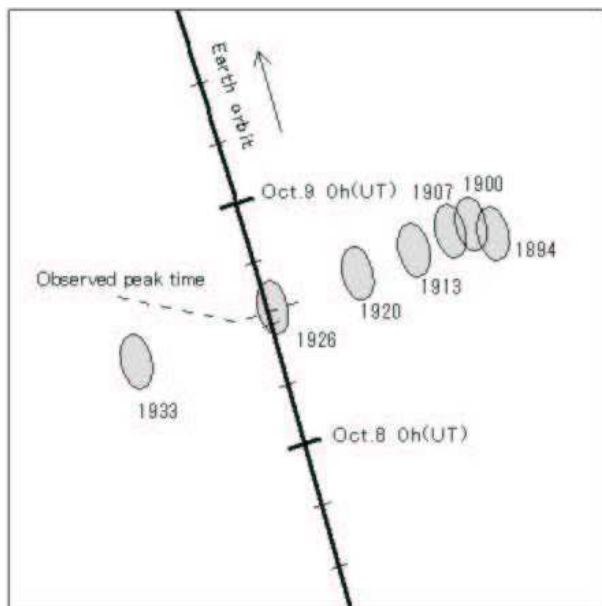


Figure 4 – Position of the trails in 1998. The radius of a trail was assumed to be 0.001 AU. The distance between the 6-hour marks is 0.0043 AU.

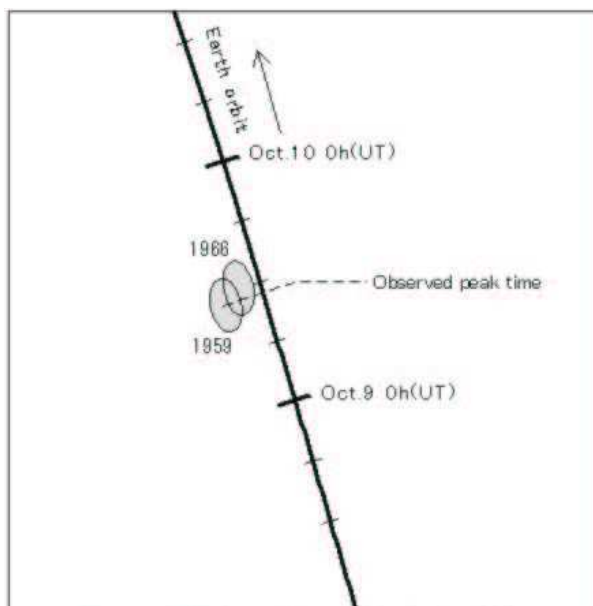


Figure 5 – Position of the trails in 1999. The radius of a trail was assumed to be 0.001 AU. The distance between the 6-hour marks is 0.0043 AU.

Table 2 – Outline calculation results of trail positions in 1999, showing ejection velocity and solar longitude $\lambda_{\odot \text{SIM}}$ at the descending node. Data marked with an asterisk were excluded from the second-stage calculations.

Year of ejection	Ejection velocity (m/s)	$\lambda_{\odot \text{SIM}}$ (°)	
1894	+5 – +10	194.7	*
1959	+60	195.7	
1966	+70	195.8	

3.2 Second stage: precise calculation

The trails shown in the first stage to approach the Earth closely were calculated more precisely. The results are summarized in Table 3 for the trails which approached the earth in 1998, and the situation is illustrated in Figure 4.

Consequently, it became clear that the trail which was ejected in 1926 intersected the earth in 1998. The ejection velocity was +10.8 m/s. The earth passed the descending node of this dust trail at $13^{\text{h}}33^{\text{m}} \pm 1^{\text{m}}$ UT on October 8, and the time of minimum approach was $13^{\text{h}}25^{\text{m}} \pm 5^{\text{m}}$, at a distance of +0.0004 AU. (For reference, the diameter of the Earth is about 0.000085 AU.) The observed peak was around 1998 October 8, $13^{\text{h}}10^{\text{m}}$ UT (Iiyama, 1999), and the result was generally in agreement to within a few dozen minutes.

The results are summarized in Table 4 for the trail which approached the earth in 1999, and the situation is illustrated in Figure 5.

It turns out that the dust trail from 1959 approached to a distance of 0.0026 AU and the one from 1966

to 0.0015 AU. The earth passed the descending node of the dust trail from 1959 at $10^{\text{h}}48^{\text{m}} \pm 1^{\text{m}}$ UT, and the one from 1966 at October 9, $11^{\text{h}}54^{\text{m}} \pm 1^{\text{m}}$ UT. The time of minimum approach of the 1959 dust trail was $11^{\text{h}}25^{\text{m}} \pm 5^{\text{m}}$ UT, and of the 1966 one $12^{\text{h}}25^{\text{m}} \pm 5^{\text{m}}$ UT on the same day. The observed peak was around 1999 October 9, $11^{\text{h}}00^{\text{m}}$ UT (Iiyama, 2000), and the time of dust trail from 1959 was generally in agreement to within a few dozen minutes.

4 Conclusion

The results of the calculations proved that the trail which caused the major Giacobinids shower in 1998 was the trail ejected in 1926. The calculated time of the peak was in agreement with observation to within a few dozen minutes. The meteor showers in 1998 often produced hourly rates of 50–100 in moonlight (Iiyama, 1999). This high rate was brought about by the trail only 0.0004 AU away.

In 1999, the observed peak time was close to that calculated from the trail ejected in 1959. But the appearance in 1999 showed a broad peak from $10^{\text{h}}00^{\text{m}}$ to $13^{\text{h}}00^{\text{m}}$ UT on October 9, so the trail ejected in 1966 might also have participated.

The ejection velocities of these two dust trails are high, +60.0 m/s and +69.5 m/s. It is important for future research that the possibility of such high ejection velocities has been demonstrated. The question of which return produced the dust ejection can also be considered, since the perihelion distance in 1959 and 1966 was smaller than the other returns, namely 0.93–0.94 AU. The meteor rates in 1999 were small (ZHR = 20–30) compared with those in 1998. This reason could be greater trail distance, or higher ejection velocity, or

Table 3 – Precise calculation results of trail positions in 1998. Distance is positive away from the Sun. In the Position column, D. Node indicates the Descending Node and Min. the minimum distance of the Earth from the trail.

Year of ejection	Ejection velocity (m/s)	Position	Date (UT)	Time (UT)	$\lambda_{\odot}^{\circ}$ (J2000.0)	Distance (AU)
1894	+1.5	D. Node	Oct. 8	15 ^h 00 ^m	195.151	+0.0161
		Min.	Oct. 8	10 ^h 25 ^m	194.966	+0.0160
1900	+5.3	D. Node	Oct. 8	16 ^h 25 ^m	195.209	+0.0148
		Min.	Oct. 8	12 ^h 15 ^m	195.042	+0.0147
1907	+6.0	D. Node	Oct. 8	16 ^h 15 ^m	195.202	+0.0135
		Min.	Oct. 8	12 ^h 20 ^m	195.045	+0.0134
1913	+6.7	D. Node	Oct. 8	15 ^h 22 ^m	195.166	+0.0108
		Min.	Oct. 8	12 ^h 20 ^m	195.045	+0.0107
1920	+8.2	D. Node	Oct. 8	14 ^h 34 ^m	195.133	+0.0066
		Min.	Oct. 8	12 ^h 25 ^m	195.049	+0.0066
1926	+10.8	D. Node	Oct. 8	13 ^h 33 ^m	195.091	+0.0004
		Min.	Oct. 8	13 ^h 25 ^m	195.090	+0.0004
1933	+15.4	D. Node	Oct. 8	11 ^h 56 ^m	195.025	−0.0094
		Min.	Oct. 8	14 ^h 35 ^m	195.138	−0.0094

Table 4 – Precise calculation results of trail positions in 1999. Distance is positive away from the Sun. In the Position column, D. Node indicates the Descending Node and Min. the minimum distance of the Earth from the trail.

Year of ejection	Ejection velocity (m/s)	Position	Date (UT)	Time (UT)	$\lambda_{\odot}^{\circ}$ (J2000.0)	Distance (AU)
1959	+60.0	D. Node	Oct. 9	10 ^h 48 ^m	195.712	−0.0027
		Min.	Oct. 9	11 ^h 25 ^m	195.740	−0.0026
1966	+69.5	D. Node	Oct. 9	11 ^h 57 ^m	195.760	−0.0015
		Min.	Oct. 9	12 ^h 25 ^m	195.782	−0.0015

both.

This method showed that dust trail calculations can be performed for a comet greatly perturbed by Jupiter. The accurate prediction of meteor showers from such a comet demonstrates the viability of this method. Finally, the influence of radiation pressure is not included in these calculations. This is because there is no function which calculates radiation pressure in NIPE. If the method is improved to include this influence, still better conclusions can be drawn.

References

- Iiyama, O. (1999), “The Report of Visual Observation in October 1998”, *Astronomical Circular (Bulletin of the Nippon Meteor Society, ISSN-0388-5852)* **678**, 4–25.
- Iiyama, O. (2000), “The Report of Visual Observation in October 1999”, *Astronomical Circular (Bulletin of the Nippon Meteor Society, ISSN-0388-5852)* **690**, 4–12.