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Discovery of a Possible Impact Spot on Jupiter Recorded in 1690

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Abstract

Upon surveying old drawings stored in libraries we discovered a dark spot drawn by G. Cassini in 1690 December. The size and visibility of this spot were similar to those produced by the impacts of Comet D/Shoemaker-Levy 9 in 1994. During the 18 d observational period, this spot was stretched mainly in the east–west direction by a zonal wind. Considering this circumstantial evidence together with a result of simple simulation of the time variation, we conclude that this spot was possibly produced by the impact of a single astronomical object around 1690 December 5.

Key words: Comets: general — Historical records — Impacts — Planets: individual (Jupiter) — Solar system: general

The impacts of fragments of Comet D/Shoemaker-Levy 9 (hereafter, SL 9) in 1994 produced large, dark spots on the surface of Jupiter. The size of the largest spot G was about 26000 km diameter (Hammel et al. 1995). These spots could be easily recognized, even using a small telescope, due to their large size and darkness. These spots were thought to be made by dust grains, which were ballistically ejected by the impact explosion (Zahnle 1996), and fell into the stratosphere (Banfield et al. 1996). Possible candidates of the dust grains in these spots are silicate formed in the cooling phase of the impact plume (Hasegawa et al. 1996), or amorphous carbon materials (Höfner, Wuchterl 1997) or HCN-polymer (West et al. 1995). Although the origin of the dust grains is not clear, these spots were so dark that visual observers could easily follow the deformation of these spots with time due to the zonal wind. The final elongated length of the deformed spots for visual observers was several-to-ten-times larger than the original size before the solar conjunction in 1995 November. After this conjunction, visual observers recognized not the individual spots, but a zonal lane of almost uniformly darkened at the impact latitude, which was made by the widely spread dust grains by the zonal wind. No intrinsic atmospheric phenomena in Jupiter was known to produce such large dark spots (Rogers 1995; Peek 1958). Although the detailed physical characteristics of the impact spots are being studied, we can expect that another cometary collision, if any, should make similar dark spot on the surface.

It is also important to search for similar records of such spots among the historical observations, not only to clarify the frequency of such impacts, but also to add other information concerning such impact phenomena. Because Jupiter has been continuously monitored for almost 400 yr, ever since the innovation of astronomical telescopes, similar impact spots may have been recorded among the historical data. Several surveys of historical records have been carried out until now (Hockey 1994, 1996; O'Meara 1996). Table 1 summarizes the results of 8 candidates of possible impact-related spots before the mid-19th century. However, none of these candidates has matched the impact spots of SL 9. Nos. 1 and 2 are the well known Hooke's and Cassini's spots, respectively, which were interpreted as similar phenomena to the Great Red Spot (Hockey 1994). No. 3 seems to be a regular spot, which appeared in the South Equatorial Belt (Hockey 1994). Three dark spots of No. 4 observed by W. Herschel in 1778 were also interpreted as atmospheric phenomena (Hockey 1994, 1996). No. 5 was also some possible small regular spots, which soon disappeared. No. 6 is interpreted as an elongated feature, called "barges", which occasionally appeared between the North Tropical Zone and North Equatorial Belt. No. 7 was apparently white spots. No. 8 was a huge dark spot spread over one fourth of the Jovian disk, and may be the most probable candidate for an impact-related spot in this table. However, it is unfortunate that there was only one observation of this spot, which resulted in an

Table 1. Candidates of the possible impact-related phenomena studied so far in the historical records.

No.	Observed year	Observer	Phenomena	Possibility of impact spot	Reference
1................	1664	R. Hooke	Dark spot	none	Hockey(1994)
2................	1665–1713	G. Cassini	Dark spot	none	Hockey(1994,1996)
3................	1689	G. Cassini	Dark spot	small	Hockey(1994,1996)
4................	1778	W. Herschel	Dark spots	small	Hockey(1994,1996)
5................	1785–1788	J. Schroter	Dark spots	small	Hockey(1994,1996) O'Meara(1996)
6................	1834–1835	J.V. Mädler W. Beer G. Airy	Dark spots	small	Hockey(1994)
7................	1834–1857	W. Dawes W. Lassell	White spots	none	Hockey(1994)
8................	1839	J. South	Dark spot	small	O'Meara(1996)

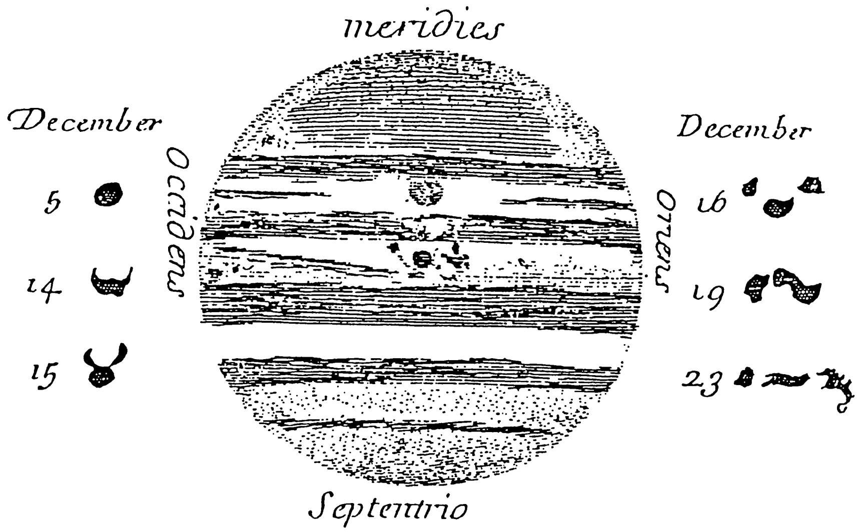

Fig. 1. Discovered drawing of Jupiter in 1690 December by G.D. Cassini, which was reported in "Nouvelles découvertes sur le globe de Jupiter" in 1692.

uncertainty in the duration of this feature. There are no candidates of impact-related spots after the mid-19th century, either. Although several spot-like features were recorded during this period, all of them are interpreted as being purely atmospheric phenomena (Rogers 1995; Peek 1958).

For further research, we surveyed historical drawing preserved deep within the Library of Paris Observatory, and discovered the drawing of a possible impact-related spot in 1690, which had been overlooked. This drawing, shown in figure 1, was drawn by the famous astronomer Giovanni-Dominique Cassini (1625–1712), who spent most of his life observing Jupiter and Saturn. He found the so-called Cassini's permanent spot in 1665, and continued its observation until 1687. He also found a difference in the rotation periods at different latitudes. His derived periods are 9h56m and 9h51m for the middle latitude and equator, respectively, which are consistent with recent well-defined periods. This fact is sufficient to prove that he was one of the most reliable, excellent visual observers. A detailed description of this observed spot appeared in the text of "Nouvelles déscouvertes dans le globe de Jupiter" which is preserved in the Library of the Paris Observatory. He stated that he was surprised to find a new spot on 1690 December 5.

Several characteristics of this spot are extremely similar to those of impact spots of SL 9. (I) This spot appeared abruptly as a round, dark spot on December 5.

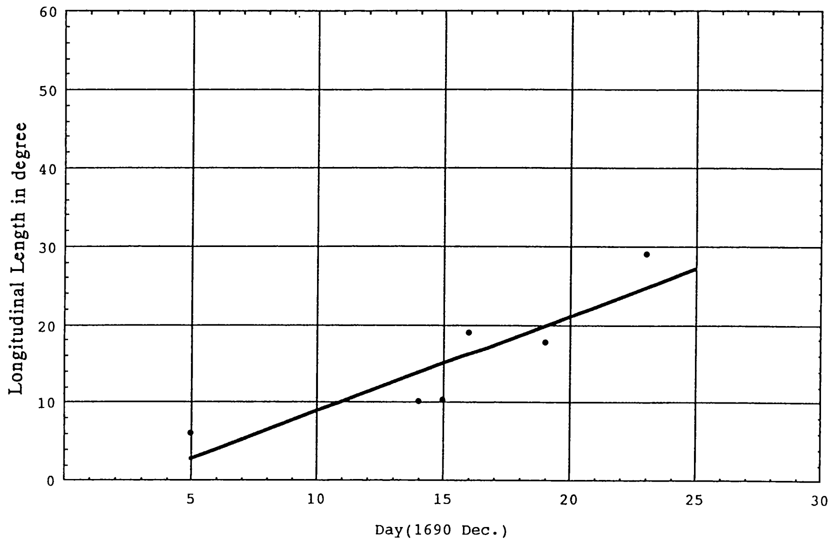

Fig. 2. Observed growth of the longitudinal length of the possible impact spot in 1690. The growth rate is approximately fitted by $L = -1.67 + 0.61\,T$, where T is the elapsed time in the unit of date from 1690 December 0.

(II) The apparent diameter of this spot, estimated from his drawing, is about 6°, or 7500 km, which is comparable to those of impact spots of class 2a (fragments A, C, E, and H) (Hammel et al. 1995). (III) The spot was the most distinct feature on the Jovian disk due to its darkness. (IV) Its evolution was followed for 18 d until December 23, and its longitudinal length extended continuously with time up to about 29° (see figure 2). (V) The lifetime of the visibility of this feature was more than 18 d. This value is also comparable to that of class-2a spots by visual observers (from 9 d for spot A to 35 d for spot H) (Rogers 1996).

The strongest evidence for convincing us is the recorded time variation of over 18 d. Such a long-term evolution was never found in other candidates given in table 1. Figure 3 shows a sequence of the deformation of the observed spot with time. The spot became crescent shape, and extended to about 10° in the longitudinal direction after 10 d from its appearance. Immediately after this epoch, it was seen as fragmented dark patches. Then, 14 d after the appearance, two patches merged again to one long filament-like structure. The final situation after 18 d shows three narrow patches lying in the longitudinal direction. The eastern patch clearly shows the effect of wind shear or of an unseen atmospheric structure, such as vortexes. Such an evolution is similar to the H impact site observed by HST (Hammel et al. 1995; Beebe 1996). The average growth rate of the elongation was 0.°6 per day, which corresponds to 8.6 m s^{-1} of the zonal wind shear at this latitude.

In oder to realize that such a time variation is just due to zonal wind shear, we carried out a simple simulation, the result of which is also shown in figure 3. We assume that the initial spot was produced by the ejecta of the impact, and applied the wind speeds measured by the Voyager spacecraft (Limaye 1986). Although the vertical wind shear may be one of the reasons for the time variation of the spot morphology, the primary effect is the zonal wind shear. Therefore, we neglected the vertical wind shear in this simulation. Because of the uncertainties of the position of the spot, the initial center position of the spot in this simulation was changed from the equator to ±5° in latitude, and the wind speed was reduced by 0–50% based on Voyager's data. Among the simulated results, the best-matched simulated-pattern to the observed time evolution is that the latitude of the center of the spot is +1.°5, and that the reduction rate of the wind speed is 30%. The wind velocity of Voyager's data is that at the top of the ammonia cloud, which is actually different from that of the stratospheric wind. Indeed, the impact-site evolution in the case of SL 9 indicated a lower wind speed than that of Voyager's data (Banfield et al. 1996). The 30% reduced value of the wind speed seems to be consistent with the early observations in 1994. This result suggests that the spot is affected due to the stratospheric wind. Although the detailed morphology of the observed time variation, such as fragmentation of the pattern or curved structure, cannot be realized by our simple simulation, it is clear that the global structure and dimension can be interpreted simply by the zonal wind shear.

On the Jovian surface, the round feature of such a large

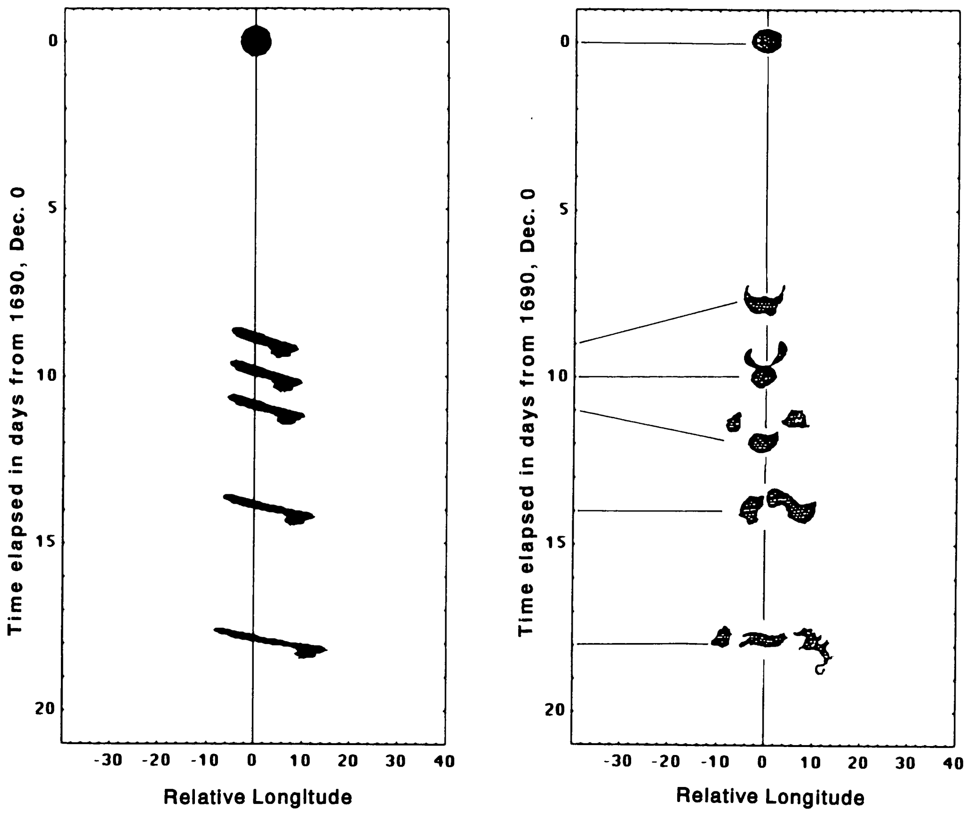

Fig. 3. Time evolution of the spot. The right-hand panel is the strip sketch of the observations by Cassini, and the left-hand panel is the result of our simple simulation fitted to the observed length (see text).

scale during the initial stage should be only a vortex. Some vortexes indeed show spot-like features, and we cannot discriminate the atmospheric spots from impact-related spots without long-term follow-up observations. Because there was no long-term follow-up of any candidates in table 1, none of them are accepted as being impact spots. The spot of this study is the only case having a record of long-term evolution of the longitudinal extension. There is no known example where a vortex extends in the zonal direction. Moreover, there is no atmospheric phenomena showing such evolution, not only at the equator, but also at any latitude of Jupiter (Rogers 1995; Peek 1958). On the basis of the observed size, shape, darkness, and especially evolution of this spot, we conclude that this spot was probably produced by the impact of a single astronomical object, the size of which was comparable to those of fragments A, C, or E of SL 9. Because there was no other spot during the studied period, the impact body may have been a single object. The parent body may not have been fragmented like SL 9 before the impact. It may have directly crashed into Jupiter without any tidal disruption, even if it came through a similar trapping phase of the complex orbital evolution, as in the case of SL 9 (Chodas, Yeomans 1996).

We also tried to determine the possible parent object of this impact in a published cometary catalogue (Marsden, Williams 1996), which resulted in negative detection. However, this fact does not deny the possibility that this spot was caused by an impact, because it was natural that small, faint objects such as fragment A of the SL 9 could be easily missed in the 17th century due to the poor instrumental situation. There is no structure such as an outer crescent shape of the impact ejecta observed in larger fragments of SL 9. The completely round description of the initial spot may suggest that the parent body was entered to Jovian atmosphere at an almost perpendicular direction. However, it may have been due to the poor spatial resolution of classical telescopes together with the poor observing conditions during the winter season in Paris. It is impossible for us to extract any more information concerning the impact body than that described here. Concerning the frequency of such impacts, some theoretical studies indicate that Jupiter would experience such a collision of 1-km size short period comets once every 950 yr (Nakamura, Yoshikawa 1995), about 500 yr (Nakamura, Kurahashi 1996), or 240 yr (Kary, Dones 1996). The collisions of smaller comets are thought to be more frequent. Although the appearance of this spot was only 300 yr before the 1994 impact event, it is within the statistical range of a possible occurrence.

This discovery of a possible impact spot also reminds us of the importance of data archives, which may produce new insights to science for the future. The library work in the Paris Observatory is a typical example of the excellent effort to preserve such historical records. The drawings may even result in significant findings in the future. It should be stressed that we should take care of archiving astronomical data for the astronomers of the next generation.

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