THE IMPACT OF FRAGMENT "L" OF COMET SL–9 ON JUPITER

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Abstract. Filtergrams of high spatial and temporal resolution were obtained in the methane band centred at 892 nm during the impact of fragment L of comet Shoemaker–Levy 9 on Jupiter. The light curve shows two maxima of an emission ball observed above the limb shortly after the impact. The second maximum was the brightest and had a short life time of about 90 seconds. During it's life, the apparent height of the emission ball declined towards the surface of Jupiter; the amount of displacement is larger than the expected effect caused by Jupiter's rotation. About half an hour after the impact, a domelike feature became visible when the location of the impact rotated into the illuminated hemisphere of Jupiter.

Key words: Jupiter – comets – Shoemaker–Levy 9 – impacts

1. Observation Method

The impact of fragment "L" of comet "Shoemaker–Levy 9" on Jupiter was observed on July 19, 1994 with the solar vacuum tower telescope (VTT) of the Kiepenheuer–Institut on Tenerife. The VTT has an aperture of 70 cm and a focal length of 45 m; with its focal ratio of 64 it is well suited for planetary observations. 235 images in the near infrared methane band at 892 nm (the FWHM of the filter is 31 nm) were taken at the prime focus of the VTT every 20 seconds with a CCD–camera operated in a 512×512 pixel mode. This methane band is a common tool in observations of Jupiter and its satellites, because it provides information from high layers of the jovian atmosphere and the absorption of methane leads to a reduced intensity of the disk (Jewitt et al., 1981). Our series started at 21:36:08 UT and ended at 22:54:14 UT. The exposure time was 2.5 s, and one pixel of the CCD corresponds to 0.175 arcsec, the jovian diameter on the chip was 220 pixels. The spatial resolution varied between 0.5 and 1.5 arcseconds due to seeing effects.

2. Observational Results

2.1. Emission ball

Fig. 1 documents some important stages of the impact event. At 22:20:52 UT, four minutes after the "accepted impact time" based on GALILEO–images (Yeomans and Chodas, 1994), we recognized a first brightening above the (dark) southeast limb of Jupiter. This feature increased its brightness until a first maximum was reached after 5 minutes. The decline in brightness of the first emission ball was interrupted at 22:31:52 by a sudden bright flare with a lifetime of 90 seconds. The size of the initial ball and the secondary flare were only slightly above our spatial resolution. Hence it was not possible to determine whether the two features were of different intrinsic size, but the two events were cospatial within 0.5 arcsec. The

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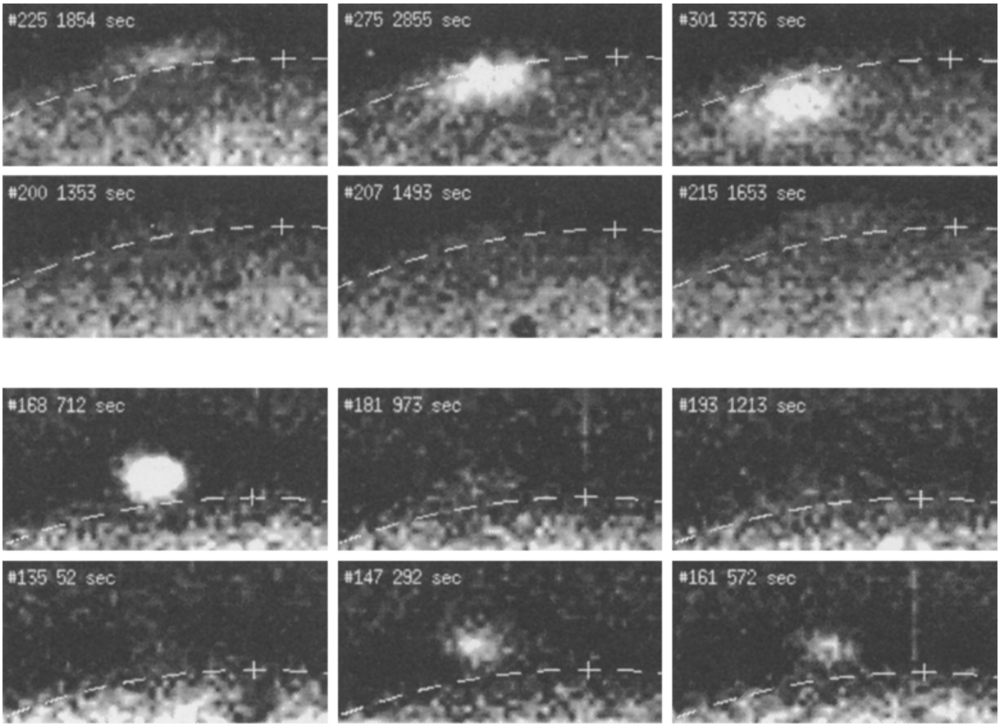

Fig. 1. Selected images of the impact region. The size of each box is 8.7 × 4.4 arcsec or 33 × 16 Mm at Jupiter's distance. Contrast has been enhanced by unsharp masking. Time increases from lower left to upper right and is indicated as seconds after 22:20 UT in each box together with the exposure sequence number. The dashed curve is an ellipse outlining the jovian limb. The centre and inclination of this ellipse were fitted to the illuminated part of the limb, the other parameters were set to their nominal values. Note the cross on the ellipse serving as a fixed point relative to the centre of Jupiter's disk. The lower set displays the emission ball phase, the upper set the occurrence of the patchy impact cloud.

flux of this flare was $(3.4 \pm 0.2) \times 10^{-4}$ of Jupiter's total flux in the methane band. This feature became almost invisible 19 minutes after it's first brightening.

2.1.1. *Light curve of emission ball*

The light curve of the emission ball is displayed in Fig. 2. The flux of the emission ball was sampled radially within an area of 3 × 2.5 arcsec enclosing the initial emission ball. The position of this sampling area remained fixed relative to the centre of Jupiter's disk. The background flux — mainly scattered light from Jupiter — was sampled in two adjacent areas of the same size and radial distance from disk centre, and its average was subtracted from the flux inside the ball area. The size of the sampling area was chosen large enough that no flux of the ball is lost even in moments of bad seeing. Due to image motion and blurring a varying amount of direct or scattered light from the jovian disk entered the sampling area. This effect

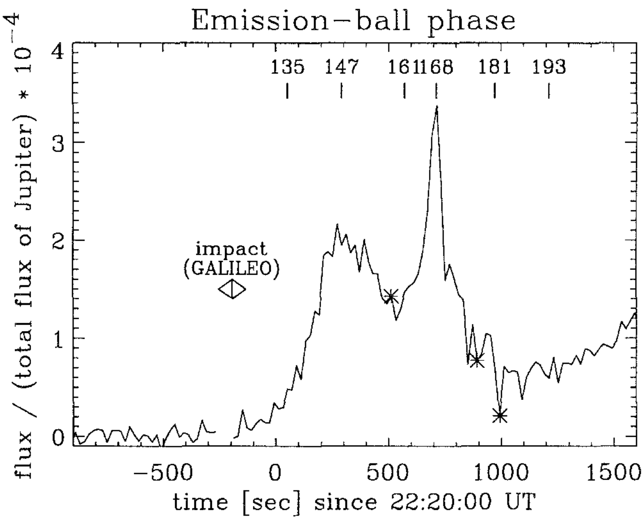

Fig. 2. The development of the brightness of the light ball. The ratio of spatially integrated excess flux to the total flux of Jupiter's disk is plotted. Asterisks mark bad data, the diamond indicates the time when GALILEO detected a short intense flash; the data belonging to the images of Fig. 1 are indicated together with their exposure sequence numbers. The brightness increase after UT 22:20 + 1200 sec is due to the patchy cloud entering the sampling region.

was minimized by subtraction of the background flux from two adjacent areas of the same size and radial distance from disk centre. Atmospheric transparency variations were compensated by dividing the ball's flux by the total flux of Jupiter for each exposure. The remaining scatter of the light curve can be estimated from the first 700 sec of the time series before the impact event.

2.1.2. Motion of emission ball

The projected position of the emission ball was measured by calculating the "centre-of-gravity" of all image pixels exceeding a specified intensity level and forming a connected region around the approximate ball location. The coordinates are relative to the jovian disk centre. There are no indications of a rising motion of the emission ball during the early phase of its existence. From a linear least square fit of 39 reliable positions with an estimated individual accuracy of 0.2 arcsec we find a systematic displacement of 0.4 ± 0.1 arcsec within 800 sec. The direction is nearly that of the jovian rotation. However, we cannot rule out that the motion is along the radial direction towards the jovian limb (the angle between the two directions is 43 degrees). Fig. 3 shows the radial component of the motion. Assuming that the impact occurred 6 degrees behind the limb at 22:17 UT and that the ball formed straight above the impact point, rotation will account only for an apparent displacement of 0.05 arcsec within the lifetime of the emission. Unless the longitude

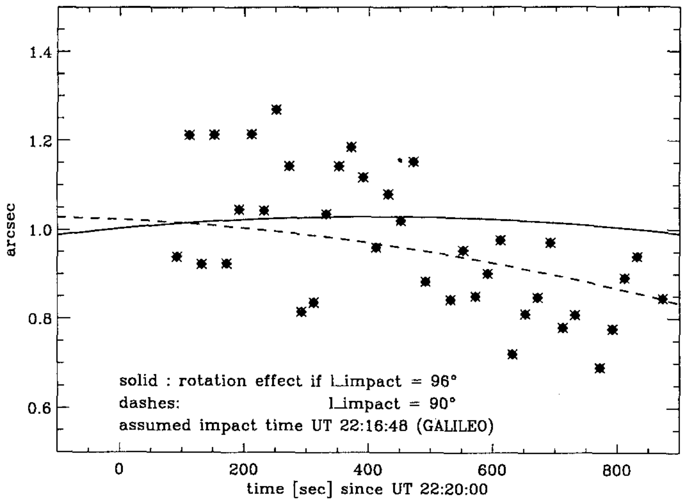

Fig. 3. Apparent motion of the emission ball ("center of gravity" of it's light distribution) towards the jovian limb.

of the ball's footpoint at impact time was near 90 degrees (6 degrees west of the predicted impact site), which seems very unlikely, most of the detected systematic motion of the emission centre must be intrinsic (1.9 ± 0.5 km/sec perpendicular to the line of sight). It should be emphasized that we see a displacement of the intensity distribution which does not necessarily imply matter motion.

2.2. Patchy cloud

About 26 minutes after the impact, at 22:43 UT, an extended brightness enhancement appeared at the limb. Eight minutes later, it had a domelike appearance extending about 0.5 arcsec (2000 km) above the limb. It moved with Jupiter's rotation into the Sun–illuminated part of the disk and got more or less the shape of a foreshortened circle with a diameter of 3.5 arcsec. This structure could be identified with the typical dark impact signature observed in the visible light. It's light curve — actually the *excess* of brightness compared to the surroundings — is shown in Fig. 4. This brightness excess was measured by sampling the flux inside a rectangular box of 4.4×2.6 arcsec that *moved* in accordance with the jovian rotation. The cloud was projected onto the illuminated part of the jovian disk, therefore the background was determined by averaging the flux at the corresponding disk positions of 35 exposures obtained before the impact event. Due to the very inhomogeneous intensity distribution inside and outside the sampling area, and because no *simultaneous* background references exist (contrary to the case of Fig. 2), seeing and pointing errors affect the data much more than in the emission–ball case.

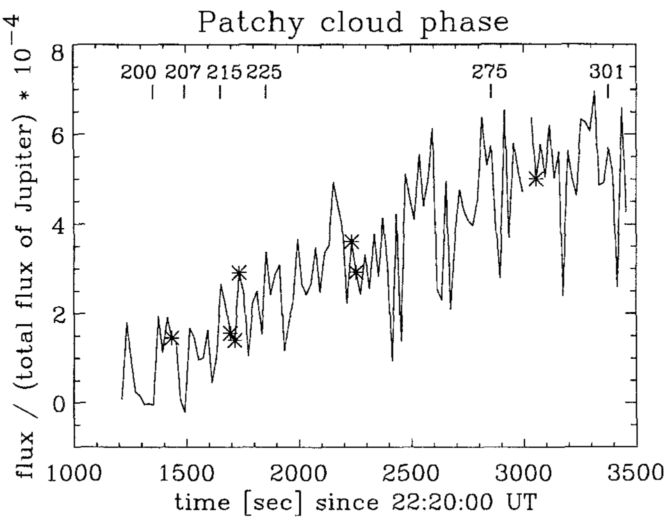

Fig. 4. The development of the excess brightness of the patchy cloud. Meaning of symbols same as in Fig. 2.

3. Concluding Remarks

The GALILEO spacecraft detected a short flash about 6 degrees behind the SE-limb at UT 22:16:48. We assume, that this flash indicated the impact. From the time difference of 250 sec between the impact and the first brightening of the emission ball seen at 892 nm, and from it's location above the limb of Jupiter we conclude that this compact emission ball is not the "explosion cloud" of the impact itself but was created after the impact in the higher atmosphere of Jupiter (2500 — 4000 km above optical depth $\tau = 1$ at 892 nm). The most remarkable phenomenon is the short-lived second maximum in the light curve of the emission ball. It's rise and decay time-scales of 45 sec are in contrast to the much slower evolution of the first maximum (250 sec and 850 sec for rising and decaying phase, resp.). Obviously, the two emission maxima are produced by different processes. The extended ("patchy") cloud became visible when the assumed impact site crossed the terminator. This indicates that the cloud was located in layers deeper than the emission ball and was not radiating intrinsicly (at 892 nm) but had to be illuminated by the sun to become visible.

References

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