THE IMPACT OF COMET SL9 WITH JUPITER: IR OBSERVATIONS AT TIRGO

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October 8, 1994

Abstract.

Infrared images of Jupiter have been obtained on 5 nights before, during and shortly after the period of the impacts of the fragments of comet Shoemaker-Levy 9 (1993e) with the giant planet. Long lived bright spots produced by the impacts have been measured and analyzed. By measuring the intensity variation of the spots as a function of Jupiter rotation we show that these spots are likely constituted by large and thin clouds of dust located above the methane layer. The IR relative albedos has been also measured for some of these spots.

Key words: Jupiter, Comets, Comet Shoemaker-Levy 9, Infrared

1. Introduction

One of the most spectacular consequence of the impact of the fragments of comet Shoemaker-Levy 9 (1993e) with Jupiter has been the large luminosities released at infrared wavelengths during the events. Even more surprising were the long term effects produced in the atmosphere of Jupiter: large spots that appeared bright at IR wavelengths regions and dark in the visible and whose nature is still puzzling. In this paper we report IR observations of these spots and analysis of the data taken on July 24. Some relevant parameters of the spots will be deduced from measurements and a possible interpretation will be given.

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Earth, Moon and Planets **66**: 83–89, 1994.

2. Observations

Jupiter was observed in the IR with the italian TIRGO (Telescopio InfraRosso del GOrnergrat) telescope, a 1.5 m diameter, f/20, Cassegrain telescope located on the Swiss Alps (Gornergrat) at about 3200 m of altitude.

The telescope was equipped with a camera (ARNICA, from ARcetri Near Infrared CAmera) with a detector NICMOS3 (Lisi et al., 1993).

TABLE I

log of the Observations

Date 1994	Time (UT)	Filter $\lambda(\mu m)$	Exposure Time (s)	Visible Impact Sites of fragment
July 17	20:23	2.35	180	A+E, C
July 17	20:33	1.58	135	A, C
July 17	20:43	2.35	180	A, C
July 17	20:51	2.35	180	A, C
July 17	20:59	2.35	180	A, C
July 17	21:08	2.35	180	A, C
July 22	21:12	2.35	270	G, L, W+K
July 22	21:24	1.64	135	G+D, W+K
July 23	20:52	2.35	180	E, H, Q1, R+S+G+D
July 23	21:02	1.64	180	A, E, H, Q1, R+S+G
July 23	21:10	2.12	180	A, E, H, Q1, R+S+G
July 24	19:33	2.35	180	K, C, A, E, H
July 24	19:44	1.64	180	K, C, A, E, H
July 24	19:55	2.12	202	K+W, C, A, E
July 24	20:22	2.35	180	K+W, C, A, E
July 24	20:33	1.64	180	K, W, C, A, E
July 24	20:44	2.12	202	K, W, C, A, E
July 24	20:53	2.35	180	K, W, C, A, E
July 24	21:02	1.64	90	K, W, C, A, E
July 24	21:08	2.12	108	K, W, C, A, E
July 24	21:14	1.64	90	K, W, C, A, E

The sampling on the sky was equivalent to 1 arcsec^2, with a coverage of more than 4x4 arcmin^2. Four narrow band filters have been used, at 1.64 μm, (FWHM=0.016 μm), 2.12 μm (0.021 μm), 2.35 μm (0.060 μm), and 1.58 μm (0.010 μm). The filter at 2.35 μm is centered on a strong methane absorption band in the spectrum of Jupiter, and is very effective in reducing the luminosity of the planet, enhancing the contrast with the luminous spots; with this filter, beside the spots, only the polar caps of the planet are still visible with our integration times. The filters at 1.64 μm and at 2.12 μm also correspond to absorption bands of methane and hydrogen respectively, but are less effective in suppressing the radiation from the planet; and finally, the filter at 1.58 μm was chosen to measure the continuum. This filter has been used only once because the planet was too bright to allow a good quality measure of the emission from the spots.

A set of observations of Jupiter were also recorded on July 15, one day before the first impact, to have a sort of "calibration" of Jupiter in steady state. In table 1 the log of the observations made during and after the impact time is reported. Bad weather conditions prevented any observations in other days between July 17 and 22.

Since in the field of view (FOV) of the camera at least one of the Galilean satellites was always present, they have been used as photometric standard to calibrate the impact sites in intensity. In this way it has been possible to calibrate the data also in poor photometric conditions or at very large airmass, as sometime happened. In any case also IR photometric standard stars were recorded during good photometric nights.

Typical observation with one filter included a sequence of nine 20 seconds coadded exposures of Jupiter and satellites interleaved with eight exposures on the sky, taken at 8 arcmin of distance in symmetric directions. Typical sequence in each filter lasted generally less than 10 minutes.

3. Data

For each sequence of observation a standard data reduction procedure has been applied. In particular the median of the 8 sky images, normalized to one, was used as flat field to correct each Jupiter images. Then, after the subtraction of the sky and a re-centering of the 9 images, a final image was obtained as median of these. Since all the observations were made several hours after the impacts, there were no short time scale phenomena that could be washed out by averaging. The displacement of the impact zone, due to planet rotation, was at worse less than one pixel between the first and the last frame of a sequence. The revolution of the satellites could have been a problem since their displacements were large, even 3 arcsec in the 10 minutes of duration of a sequence of images for the satellite Io at conjunction or opposition. In these cases the intensities of the satellite were measured in the frames before the average and then a mean value was computed.

As already mentioned the intensity calibration of the luminous spots have been made using the Galilean satellites as standard. Mainly Io and Europa were used, because they were always present on the frames. Their intensities, within the passbands of our filters, were obtained from published data (Clark & Cord, 1980 and Tittemore and Sinton, 1989).

To check the photometric quality of the data, the intensity ratio of the two satellites was computed for each sequence: it was constant within ± 5 % in all the frames and in agreement with published data.

The relative intensities of the bright spots produced by the impacts were measured in a frame resulting from the subtraction of the relative images of the quiescent Jupiter taken on 15 July before any impact. The intensity of the frame to be subtracted was re-scaled to match the one to be analyzed. The procedure worked well for the images taken in the methane bands at 2.35 μm, leaving a small residual in the cap regions, much smaller than the spots themselves. The low residual values imply also that, within our precision, the relative intensities of the two caps did not vary during the period of the impacts. The image subtractions in the other bands did not work so well leaving larger residual because the intensity of the quiescent emission of Jupiter was much higher with respect to that of the impact sites. The residual intensity around the spots in the subtracted frames was used to evaluate the error of the measurements.

4. Analysis

All the luminous spots at the impact sites that we could observe were old, because bad weather conditions prevented us from observing at the time of the events. Their life varied from a minimum of 5 hours for impact E on July 17, to a maximum of about 200 hours for impact A on July 24. Since the lifetime of radiative thermal emission produced by the impacts is much shorter, and is of the order of tens of minutes (Zahnle and Mac Low, 1994), the most likely explanation of the nature of the spots that we observed is that they are due to solar radiation reflected by clouds of dust particles condensed in the stratosphere of Jupiter (Field et al. 1994). Since the lifetime of these clouds seems long, much longer than the rotation period of the planet, they likely did not evolve, or evolved very little, during the period of observation in one night.

Assuming that the emission is scattering of solar radiation, one of the most important parameters that can be measured is the IR albedo of the bright spots. However, since the spots are not measured always at the same phase angle with respect to the line of sight $\theta(t)$, it is necessary to disentangle any geometrical or absorption effect introduced by the rotation of Jupiter. For that purpose, we used the observations of the night of 24 July, that spanned more than 2 hours. Moreover, on that night all the luminous spots were old enough to be sure that any thermal emission had already decayed at the time of our observations.

To recover the time dependence of the luminosity of the spots with the rotation of Jupiter we plot the relative luminosity of one spot in the three filters as a function of time for the observations of night 24. The data points

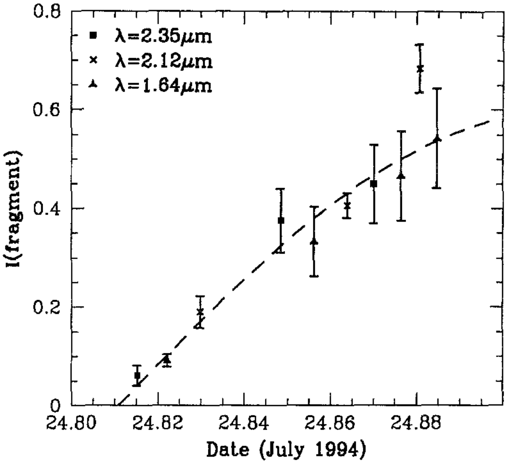

Fig. 1. Relative intensity of fragment K+W vs time

are normalized to those measured at 1.64 μm. In figure 1 values for the double spot K+W is drawn. The data points are all in agreement, except one, and they follow quite well the line overplotted in the same figure. This is a cosine function of time with a period equal to the period of rotation of Jupiter and the phase equal to that of the impact site K+W.

That means that the intensity variation with time is in agreement with a geometrical effect produced by the phase angle of luminous spots that have a depth much smaller than the other two dimensions and that is optically thick in IR. Optical thickness less than one, at least in one dimension, or large extension of the spot as compared to Jupiter can introduce deviations from this cosine dependence, especially for angles close to the limb.

However we can exclude that the spot sites were below the methane atmosphere because their intensities would depend on the extinction, i.e. on the mass of the methane traversed which depends on the angle θ. Since the methane absorption coefficients are different in the three bands, also the intensity ratios should be strongly dependent on the angle θ (i.e. time), which is excluded by figure 1.

The intensity variation of an older spot, that generated by fragment E, during the same night is flatter and it does not follow the same cos θ law. The flatness can be explained with an optical thickness smaller than one along its depth. The optical thickness in this case increases with θ while the projected area decreases. This is also in agreement with the much lower luminosity of this spot with respect to the other one. However, the time

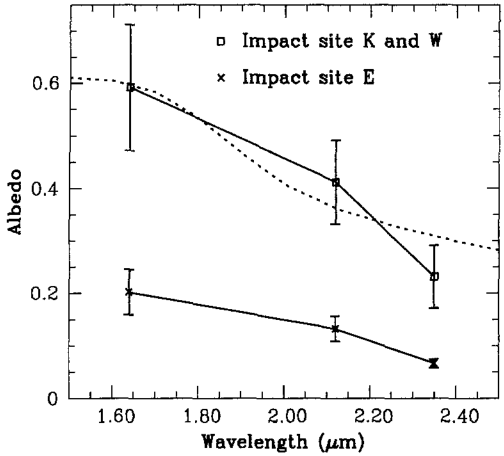

Fig. 2. Relative albedo of impact sites K+W and E vs wavelength

evolution of the intensity of this spot at the three wavelengths has the same behavior indicating that also this spot is located above the methane layers.

In figure 2 the IR albedo of the spots K+W and E, normalized to the same angle θ, are plotted. Even if at the time of the observations the spots had large differences in luminosity and age, the two curves have a remarkable similar shape with the relative albedo decreasing towards longer wavelength.

How does the dust cloud hypothesis compare with our albedo data? Field et al. (1994) conclude that the clouds are possibly made by silicate grains with a sizes about 1 μm, and have an optical depth of about 0.3. As an exercise, in figure 2 we have overplotted the albedo (optically thin case) of a cloud of silicate dust made of 1 μm grains (Ferrara, 1994). The curve is in fairly good agreement with the data; the three data points however do not constitute a statistics large enough to draw any firm conclusion. To improve the analysis it seems worth to investigate the behavior at longer wavelengths, in order to check whether this model is still consistent with the data.

Acknowledgements

We thank A. Ferrara for the useful discussions and the theoretical computation of the albedo for silicate grains.

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