Near-IR Lightcurves of the Impacts of SL9 Fragments E, S, T and U

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Abstract

The impacts of SL9 fragments E and S, T, U were monitored on 17 and 21 July 1994 with the MAGIC IR camera at the 3.5m telescope of the Calar Alto observatory in Spain. Fragments E and S showed prominent impact plumes, but no precursors above noise level. The actual impacts of fragments T and U could not be detected in our data. Some post-impact lightcurves of spots E, C and K+U are presented.

1 Observations and Data Reduction

During 16-22 July 1994, the impact period of comet Shoemaker-Levy-9 (SL9) on Jupiter, IR observations of the events were performed with the MAGIC camera mounted to the 3.5m telescope of the Calar Alto Observatory in Spain. MAGIC is designed for imaging and spectroscopy in the 1-2.5 μm wavelength range (Herbst et al., 1993 and 1994). For the Jupiter imaging the camera was equipped with standard JHK and special Jupiter filters (J. Spencer, 1994, private communication; we used filters at 1.5 μm, 1.58 μm, 1.7 μm with red leak blocking by H filter, 2.3 μm). The chosen image scale of 0.328 arcsec/pixel provided a 84$\times$84 arcsec field of view on the 256$\times$256 pixels NICMOS3 detector.

With this pixel resolution beam switching for sky level subtraction could be performed with Jupiter (diameter 38 arcsec) still fully in the field of view. During daytime observations a Lyot stop for reduction of the effective aperture was inserted into the beam in order to avoid detector saturation. Flux calibration was achieved by nighttime standard star observations (stars BS7504B and BS5868). The absolute flux calibration of daytime observations still has to be considered as preliminary. In addition to the imaging observations we have also collected spectroscopic data of the impact regions which are described by Herbst et al. (1995).

The typical exposure times for the Jupiter images were 3 to 10 seconds, the beam switching cycle length varied from 2 to 5 exposures. During the impact events and during periods of excellent seeing we occasionally saved individual read-outs of 0.1 to 0.3 sec exposures in order to achieve high time resolution and/or to partially "freeze" seeing variations for better spatial resolution on the Jupiter disk.

The data reduction process applied to the images comprised flat fielding, bad pixels removal, extinction correction and sky level subtraction. The conversion coefficients for the flux calibrations were determined by using the standard star observations and the known

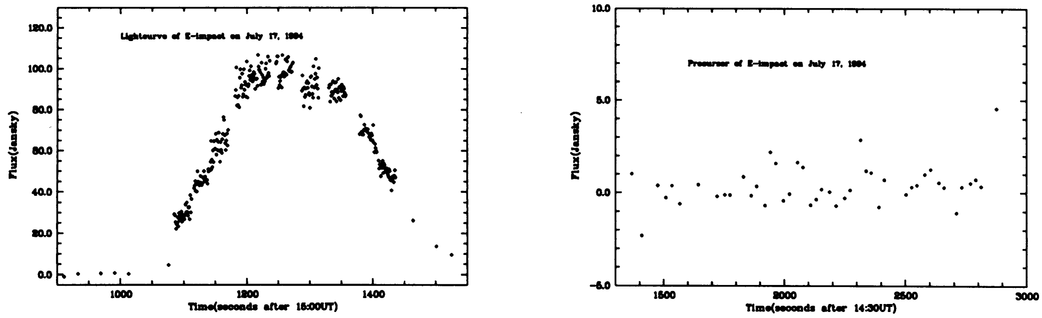

Figure 1: Preliminary 2.3 μm lightcurve of the E impact on 17 July 1994 a. Lightcurve of the plume appearance at the limb. b. Lightcurve of the impact limb before plume appearance (the last dot in the plot indicates the begin of the brightness increase from the plume)

transmission curves of the filters. For the lightcurve measurements we used apertures of 10-20 pixels radius (depending on the flux level and spot extension; the aperture was centered on the impact regions). The background sky was averaged from several locations outside of Jupiter disk. In a similar way the lightcurves of Galilean satellites, if present in the frames, were determined.

2 Results from Two Observing Days

Clear sky above Calar Alto allowed observations during all 11 SL9 impacts predicted to be visible from southern Spain, i.e. impacts A, E, H, L, P1, P2, Q2, Q1, S, T, U. Pre- and post-impact data of Jupiter were collected daily by continuous imaging until about 40 min before Jupiter set (telescope elevation limit). For an overview of the SL9 impact observations with MAGIC see also Herbst et al., 1995.

In the following we concentrate on the description of our 2.3 μm imaging observations of 17 and 21 July 1994, the days of impacts E and S, T, U, respectively.

2.1 17 July 1994: E impact

On 17 July 1994 fragment E was predicted to impact on Jupiter around 15:05:31 UT. Post-impact analysis by Yeomans and Chodas (see West, 1994) led to an "accepted" impact time of 15:11:00 UT $\pm$ 4 minutes for E. Calar Alto IR imaging of Jupiter started on 14:50 UT with continuous 2.3 μm methane filter monitoring. Because of the daytime sky the images were very noise and, by the time of the E event, only the polar cloud layers of Jupiter were - weakly - visible in the images as well as the Galilean moon Europa shortly after transit egress.

The first clear signal of the E impact was recorded in a 9 sec exposure starting on 15:17:49 UT (see Fig. 1a). From about 15:18:06 UT fast read-outs (0.3 sec) were saved in order to achieve high time resolution. The flux from the impact region increased rapidly (by 0.62 Jansky/sec) until the maximum level of approx. 100 Jansky was reached around 15:20:10 UT. At that time the impact cloud was about 25 times brighter than Europa. The maximum

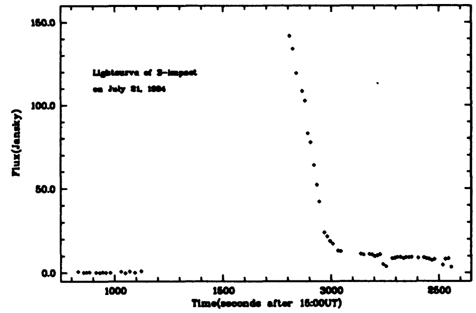

Figure 2: Preliminary 2.3 μm lightcurve of the S impact on 21 July 1994

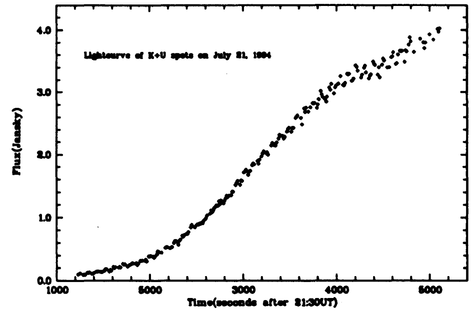

Figure 3: 2.3 μm rotation lightcurve of the K+U complex on 21 July 1994

phase lasted for about 100 sec, then the brightness decrease began with a decay rate of 0.40 Jansky/sec. The brightness of the impact region turned over to the only slowly variable rotation lightcurve at about 15:27 UT (when we changed filters to 1.7 μm). Later in the night we obtained some further 2.3 μm images of Jupiter. From that we conclude that the flux of the E spot remained constant over a wide range of its rotation across Jupiter disk.

Evidently, the lightcurve of the E impact exhibits the typical behavior of the initial plume when rotating into the field of view. This is concluded from the analogy of the E impact lightcurve with those of other events (see e.g. Hamilton et al., 1995; Herbst et al., 1995), i.e. from the approximately 7 min delay between accepted impact time and first impact light detection, from the about 2 min rise time to maximum and the slower decay of the brightness within about 3 min. In other words: when the impact cloud rotated into the field of view some 5 to 10 min after the explosion we first measured the heating of the Jovian atmosphere by the maybe still expanding blanket of explosion ejecta (increasing brightness), then we followed the radiative cooling of the impact area (maximum and decreasing brightness).

We also performed a careful search for precursor events in our E impact data. Aperture photometry of the region on Jupiter, where the impact plume occurred, revealed no clear indications for precursors above noise level. Furthermore, visual inspection of the individual images also led to "negative" results. However, since the pixel brightness of the A impact precursor was considerably fainter than that of the Jovian polar clouds, it is easily possible that the signal of an E precursor, if present at all, is embedded in the noise variations of our daytime observations. Comparison with E impact lightcurves of other observers may help to identify a noise peak in our data as potential precursor flash of the E event.

2.2 21 July 1994: S,T,U impacts

For the Calar Alto visibility window of Jupiter on 21 July 1994 fragments S, T and U were accepted to impact around 15:15 UT ($\pm$ 5 min), 18:10 UT ($\pm$ 7 min) and 21:55 ($\pm$ 7 min), respectively (see West, 1994).

Our monitoring of the S event was hampered by interruptions due to technical problems with the MAGIC read-out electronics. Therefore, we could collect only some 2.3 μm images between 15:14 to 15:19 UT. Continuous imaging started at about 15:30 UT. During the first short sequence no clear signal from impact phenomena (precursor, initial plume) could be

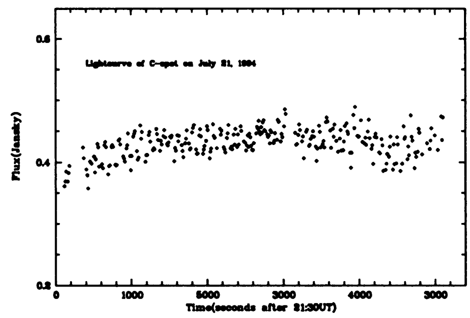

Figure 4: 2.3 μm rotation lightcurve of the C spot on 21 July 1994

detected above noise level (see Fig. 2). Visual inspection of the impact limb in our images confirm this statement. However, by about that time the S fragment splashed into Jupiter very close to the cloud complex of impacts D and G (Sekiguchi, 1994).

With the resumption of our continuous monitoring around 15:30 UT the initial plume had already passed peak brightness (see Fig. 2). According to Sekiguchi (1994) the plume appeared over the limb at 15:21:30 UT (with a precursor around 15:15:50 UT). Our measurements (Fig. 2) cover only the brightness decay of the S plume (peak brightness occurred at 15:28:50 UT; Sekiguchi, 1994).

The two other impacts (fragments T and U) monitored from Calar Alto during 21 July 1994, remain mysterious. We have not seen a clear signal in our 2.3 μm images, neither from T nor from U. Both fragments should have been exploded right inside bright old spots, i.e. T into the E and F complex, U into the K spot. In Fig. 3 we show as an example the lightcurve of the K and U complex starting from about 21:47 UT, i.e. shortly before the U impact. Only the moderate and slow brightness increase due to rotation of the old spot into the field of view is found. However, the presence of an old impact cloud at the Eastern limb during explosion of an impacting fragment does not necessarily prevent the detection of fireballs, as was demonstrated for instance by the S impact of the same day (see above).

In Fig. 4 the rotation lightcurve of the old C impact region is plotted as it was measured from our 2.3 μm images of 21 July 1994. The spot (on its 12th revolution after impact) appeared with a strong central condensation and had an extension of about 17000 km both in longitude and latitude. Limb darkening of spot C was measurable until about 45 degree from the meridian (see Fig. 4).

3 Conclusions

From 4 impacts monitored in the 2.3 μm methane filter on 17 July 1994 (E fragment) and 21 July 1994 (S, T, U fragments) 2 fireballs (E and S) show a remarkable similar lightcurve, while 2 impacts (T and U) remained totally undetected. Precursors for E and S, if present at all, were masked by the data noise in our daytime observations. There are marginal indications for the presence of secondary peaks, so called "shoulders" as detected by Richichi et al. (1994, private communication) for the L impact, during the brightness decay of the E and S plumes which will be investigated carefully in the future.

The non-detection of T and U could either mean that these fragments were too small to produce a noticeable impact flash. An alternative interpretation might be that their explosion was totally covered underneath the overlying clouds from the old impacts. Therefore, a search for changes in the structures of the old impact regions E+F and K seen in images before and after the T and U impacts, respectively, may further constrain the question whether or not an impact explosion for T and U took place.

In the future one may also extend flux measurements as done by Ortiz et al. (1995) to the full sample of the impact spots on Jupiter in order to learn more about the properties of the cloud particles and on similarities and diversities for the various clouds. Rotation phase lightcurves of the spots (to get an idea what is meant one may combine Fig. 3 and Fig. 4 which cover the rotation phase from the Eastern limb to the meridian, however, for two different sites) may be very useful for the physical modeling of the particulates in the spots. Studies of the long-term development of the clouds can reveal characteristics of the Jovian wind system at the impact latitude.

4 References

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