Imaging of the Signatures of the Impact Events in the Thermal Infrared

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1. Introduction

TIMMI, ESO's 10 μm instrument (for a detailed description of TIMMI see e.g. Käufl *et al.* 1992, 1994) was mounted at ESO's 3.6-m telescope from July 15 to July 31 to provide for infrared imaging with broad- and narrow-band filters in the 5 and 10 μm atmospheric windows. The purpose of the observations was twofold:

- to investigate and monitor the atmospheric consequences of the impacts (P.I. Tim Livengood, NASA GSFC, Greenbelt, Md)
- to search for global oscillations of Jupiter resulting from the impacts (P.I. Benoît Mosser, IAP, Paris)

The observing time was shared between the two programmes and the filters were chosen strategically in such a way that the data are in principle useful for both programmes.

2. Technical Details and Calendar of Observations

Impacts covered

Impact A: Impact A was observed on July 16, starting at 20:23 UT, i.e. the first images of the impact area correspond to the peak brightness at 10 μm. Photometrically these data are not the best, but the evolution of the morphology of the impact area can be very nicely studied.

Impact B: A time window of ±1 h around the predicted impact time was covered in good to acceptable weather conditions. Even after careful inspections of the data no signatures could be seen.

Impact F: This was the next impact visible over La Silla. A minute signature of the impact was detected.

Impact H: This impact was the one best covered by TIMMI (0.5 h before till 3 hours after impact) under good to acceptable weather conditions.

Impact L: This impact was observed marginally through heavy clouds. Few scientific valuable data are available from this impact.

All the other impacts could not be observed due to bad weather.

Other observations

February 28–March 4, 1994; pre-event observation of Jupiter.

July 22–July 31, 1994; with few interruptions constant monitoring of the Jovian disk with TIMMI for atmospheric effects and seismological signatures.

Scales

0.6 arcsec/pixel (≈ 2300 km/pixel) for all observations during daytime and for all observations specialized for seismology.

0.45 arcsec/pixel (≈ 1700 km/pixel) for night-time observing when studying the effects of the impacts on the Jovian atmosphere.

Filters

9.1–10.41 μm: used for seismology and sensitive to C_2H_4 and NH_3. To be most sensitive to the signatures of the effects on the atmosphere, additional filters tailored to the IR spectrum of CH_4, NH_3, C_2H_4, C_2H_6, and the standard 5 μm (M-Band) filter were used.

Observers

The observations were carried out by Tim Livengood (NASA GSFC) and Hans Ulrich Käufl (ESO) for the atmospheric effects proposal. Benoît Mosser (IAP) and Marc Sauvage (SAP/DAPNIA, Saclay) did the observations concerning seismology of Jupiter.

3. The Selection of Data Presented Here

The data shown in this article constitute a rather arbitrary selection. The number of frames obtained exceeds 100,000! Since there is a separate article dealing with seismology, the scope of this presentation is restricted to atmospheric effects, particularly also since they exceeded all expectations of the observers. A full analysis and reduction of the data will clearly take some time.

The original idea of the Livengood *et al.* proposal was to try to trace temperature changes resulting from the impacts in the Jovian atmosphere above the cloud layer. Since the abundance of infrared trace molecules in the upper atmosphere is governed by depletion through condensation, minor changes of the temperature would be amplified via the exponential behaviour of the vapour pressure to somewhat bigger abundance changes. These would be easier observable than radiance changes introduced by the temperature increase alone for constant abundances. Nevertheless, also with this amplification it was never anticipated that the impacts would create signatures of the size and strength actually observed.

In this contribution I will concentrate on

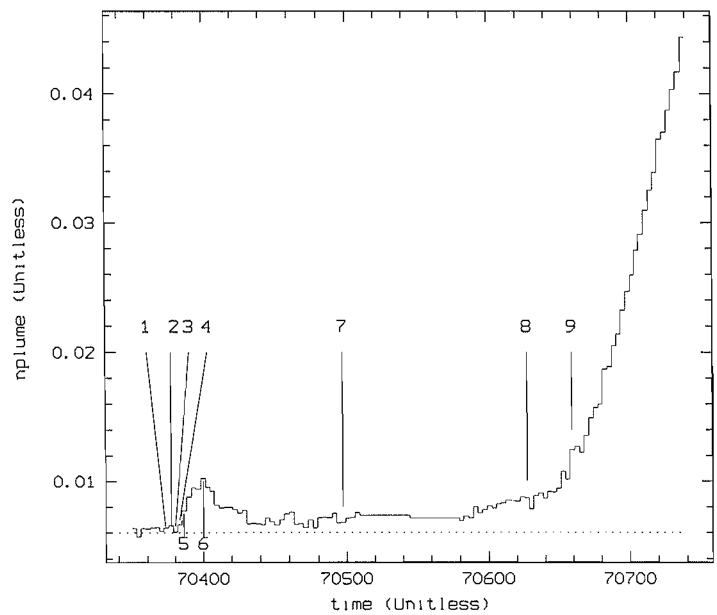


Figure 1: *Light curve for the precursor event of impact H. The time axis is in seconds since midnight (U.T.). The numbers and arrows correspond to the frames shown in Figures 2a and 2b. The light curve is normalized on Jupiter (disk-integrated), i.e. the peak of the precursor event at t = 70,400 s corresponds to ≈ 4 % of the disk-integrated signal from Jupiter in the filter pass band (9.1–10.41 μm). A dotted line shows a constant offset of the photometry. For the rapid rise on the right see Figure 3.*

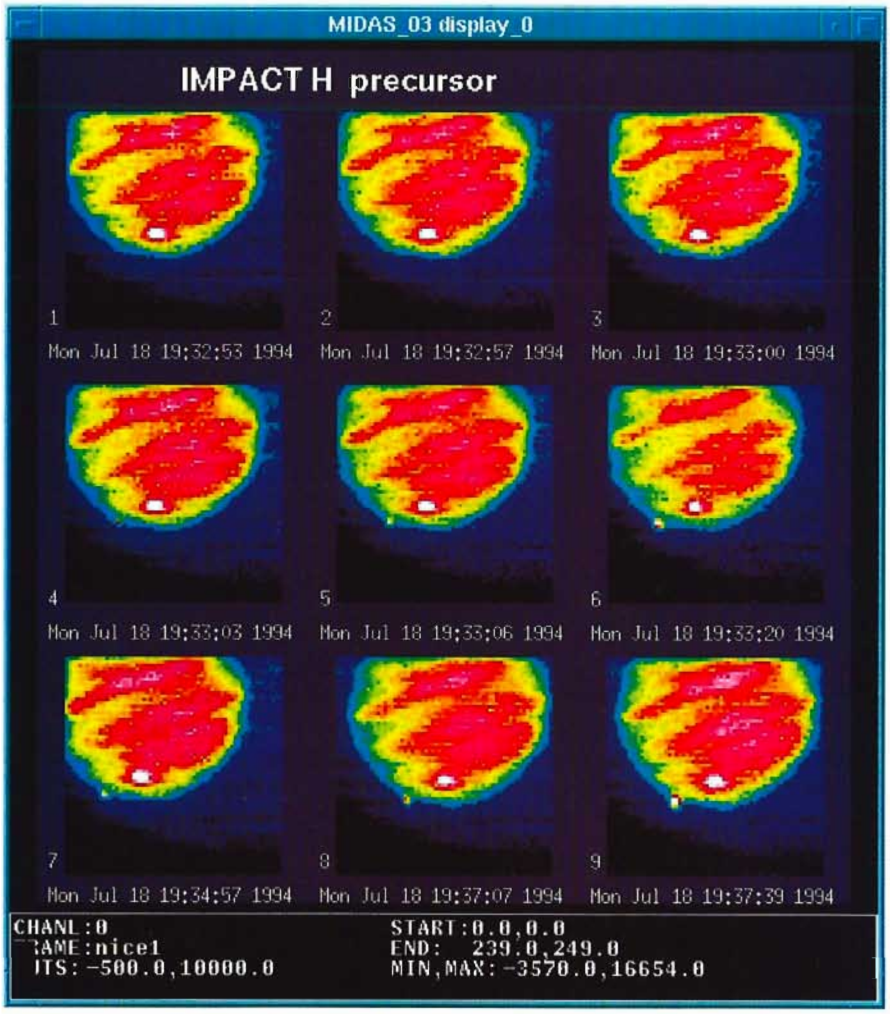


Figure 2a: *A sample of frames obtained with TIMMI (filter 9.1–10.41 μm) during the time interval of the section of the light curve shown in Figure 1. The projected size of one pixel on Jupiter is 2300 km. Between frame 2 and 3 the emission from the impact area becomes apparent. In all frames, the impact area is not resolved (i.e. smaller than 2 pixel). For the photometry of the frames see Figure 1. Impact area G (age 12 h) can be clearly seen in all frames on the Jovian disk.*

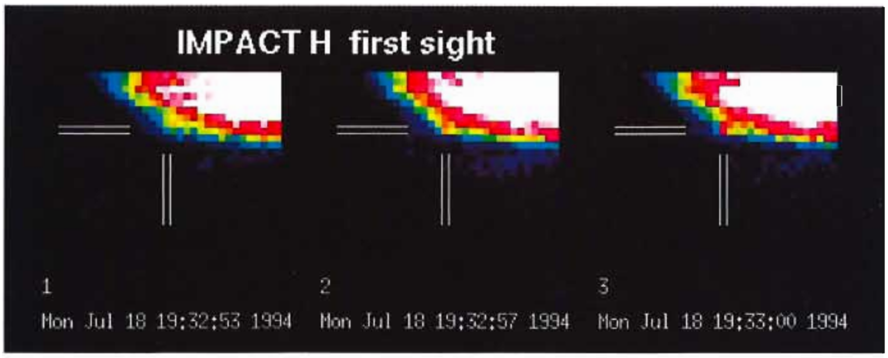


Figure 2b: *An enlargement of the first three frames obtained with TIMMI shown in Figure 2a (with compressed dynamic range). The projected size of one pixel on Jupiter is 2300 km. While subframe 1 at 19:32:53 clearly does not show an emission on the limb, subframe 2 at 19:32:57 shows a faint signature, and for subframe 3 at 19:33:00 the emission is obvious. This leads to the determination of first sighting of the impact area with an uncertainty as small as 3 seconds.*

two absolutely unexpected events: the very bright thermal emission and the very fast expansion of the impact area.

4. The Precursors of Impact H

Figure 1 shows a section of the light curve of the impact H area obtained with the 9.1–10.41 μm filter. The light curve was normalized using the Jovian disk as the photometric standard. Figures 2a and 2b give the corresponding frames. A small "blip" becomes apparent at 19:32:57 occurring typically 58 seconds after the now accepted impact time for fragment H (19:31:59 U.T., Yeomans and Chodas, private communication). This value is just at the edge of the 1 σ error estimated by these authors.

While a detailed analysis of the light curve would need to disentangle projection effects and refraction by the Jovian atmosphere, it seems clear that a thermal IR signature is visible either instantaneously or within seconds after the impact. Interesting to note is, that with respect to the time resolution of the observations (3.5 s), the rise of the thermal emission is not fully resolved. Extremely surprising is that this pre-flash decays rapidly and the strong emission sets on only 4 minutes later which probably coincides with the impact area rolling across the terminator for Earth-bound observers. Already the pre-flash achieves a surprising brightness: 4–5 % of the disk-integrated signal of Jupiter in the same filter.

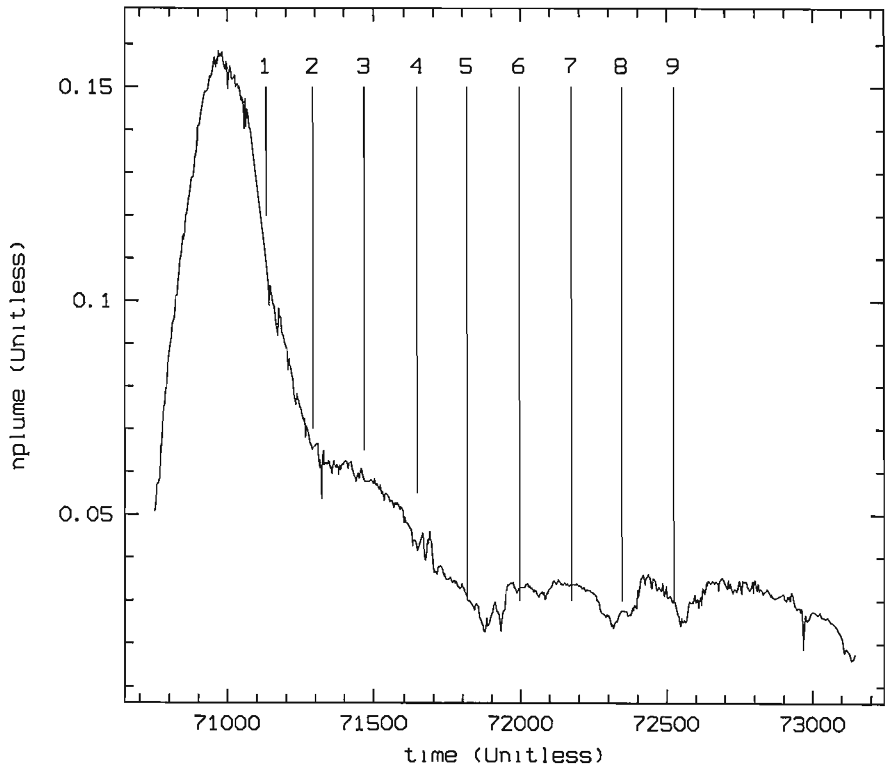
Figures 2a and 2b show a selection of frames whose location are indicated in the light curve shown in Figure 1. It should be mentioned that all thermal IR observing of bright impact events as reported from other observatories also showed this pre-cursor behaviour. Figure 2a also shows the impact area of impact G which was by then 12 hours old.

5. The Expansion of the Impact Area

Figure 3 shows the light curve of impact H during peak and decay phase. Figure 4 shows again a selection of images whose location in time is noted in the light curve. While frame 1 and 2 show the impact plume basically as a point source, frame 3 in Figure 4 shows a slight extension parallel to the limb. Because of the projection, an expansion perpendicular to the limb cannot be observed. This extension is then more and more obvious in the other frames shown in Figure 4. As can be seen in Figure 3, the apparent expansion of the impact area is coincident with the "hump" appearing in the decay of brightness. The time elapsed between impact and frame 4 in Figure 4 is 1200 seconds. The apparent size of the impact region in frame 4 of Figure 4 on Jupiter is 10,000 km. This implies an "expansion velocity" exceeding 5 km/s and could be as large as 10 km/s, depending on the size of the impact area directly after impact.

While the propagation of an atmospheric wave with 5–10 km/s is hard to understand, another scenario would easily explain the observations. If one assumes that after the impact, secondary ejecta with 15 km/s vertical velocity are thrown out of the impact site then it takes these ejecta typically 1200 seconds until they fall back on the Jovian surface.

Figure 3: *Light curve for the brightness maximum of impact H. The time axis is in seconds since midnight (U.T.). The numbers and arrows correspond to the frames shown in Figure 4. The light curve is normalized on Jupiter (disk-integrated), i.e. the peak of the event at t = 71,000 s corresponds to ≈ 15 % of the disk-integrated signal from Jupiter in the filter pass band (9.1–10.41 μm). The rise of the light curve is probably due to the rolling in of the already cooling impact area over the terminator into the Jovian hemisphere visible from Earth. Interesting to note is the bump at t = 71,500 seconds. This could be caused by secondary heating superposing the apparently exponential cooling (see text). The spikes on the curve indicate the noise of the photometric data.*



Provided these ejecta would have a tangential velocity of 5–10 km/s then the apparent expansion of the impact site could be the signature of the secondary impacts of the ejecta of the primary event. This scenario is nicely supported by the "hump" in the decay in the light curve which could be caused by the onset of a heating process (secondary impacts). If this scenario is correct, then the maximum altitude of the trajectories of the ejecta would be typically 4000–5000 km above the Jovian surface. Similar morphological behaviour was found for impact A. Additional support of the scenario sketched here comes from the fact that 30–40 minutes after the impact the rapid apparent expansion slows down appreciably.

6. Conclusion

After a very brief inspection of a minute amount of data it is already clear that these data obtained with TIMMI alone will provide substantial insight into the physical processes during the entry of the impactors. In the same way it will be possible to describe the dissipation of the energy and the depletion of the material injected into the Jovian atmosphere by the impacts. Unfortunately, the observing time allocated for the project was not sufficient to monitor the 10 μm signatures until complete fade-out.

During the last moments of observation (July 31, 3:00), nearly nine days after the last impact, the signatures of the collision were clearly observable! Following the first evaluation of the TIMMI data alone, the next step then will be to obtain a comprehensive view of the event by taking advantage of observational data obtained from other sites but especially assembling all data obtained from La Silla in a coherent way.

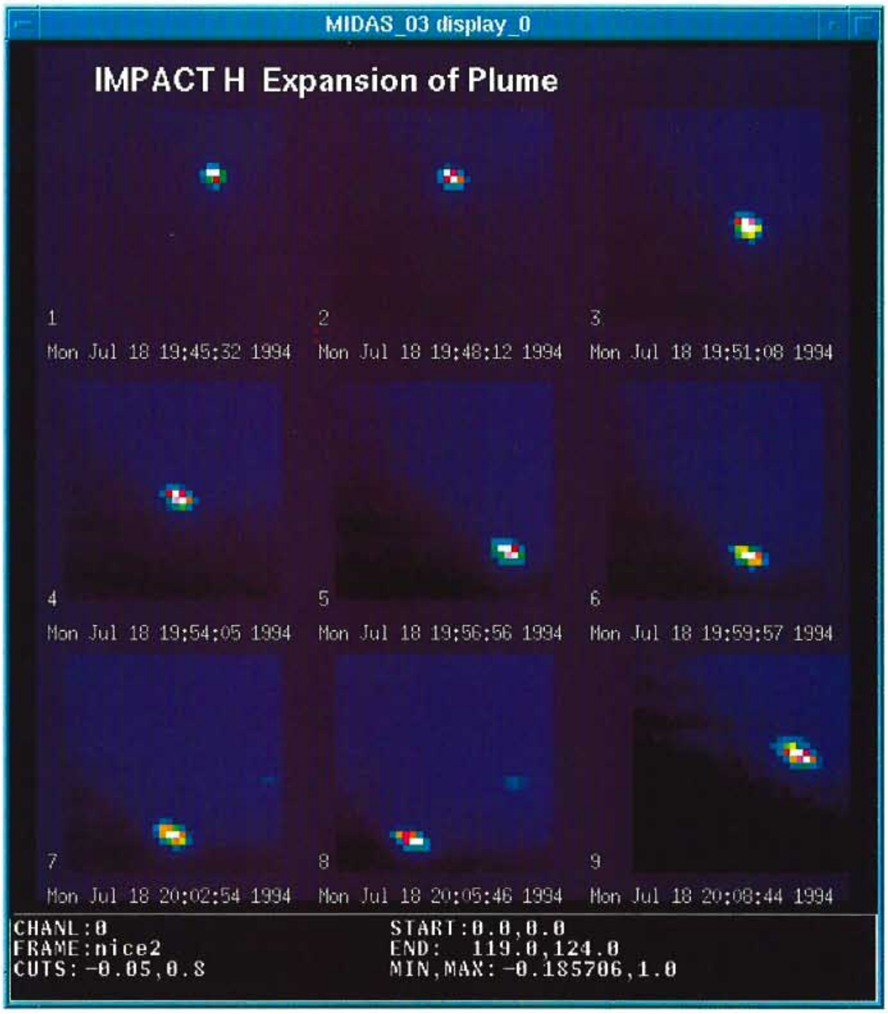


Figure 4: *A sample of frames obtained with TIMMI (filter 9.1–10.41 μm) during the time interval of the section of the light curve shown in Figure 3. The projected size of one pixel on Jupiter is 2300 km. All subframes are normalized to the brightest pixel in the impact area. While frames 1 and 2 are compatible with an unresolved point source, frame 3 is not. Frames 4–9 show a further expansion of the impact site with time. For further explanations see text.*

Acknowledgements

All these observations would have been impossible without the dedicated support of ESO's La Silla staff. I would like to mention especially E. Matamoros, J. Roucher and U. Weilenmann. This campaign was particularly difficult because of day and night-time observing since TIMMI was usually observing 18 hours and more per day. The author appreciates also valuable discussions with K. Zahnle.

References

H.U. Käufl et al. 1992, *The Messenger* **70**, p. 67.
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Near-IR Spectroscopy of Jupiter at the Time of SL-9 Impact Using NTT-IRSPEC: Emissions of CH_4, H_3^+ and H_2

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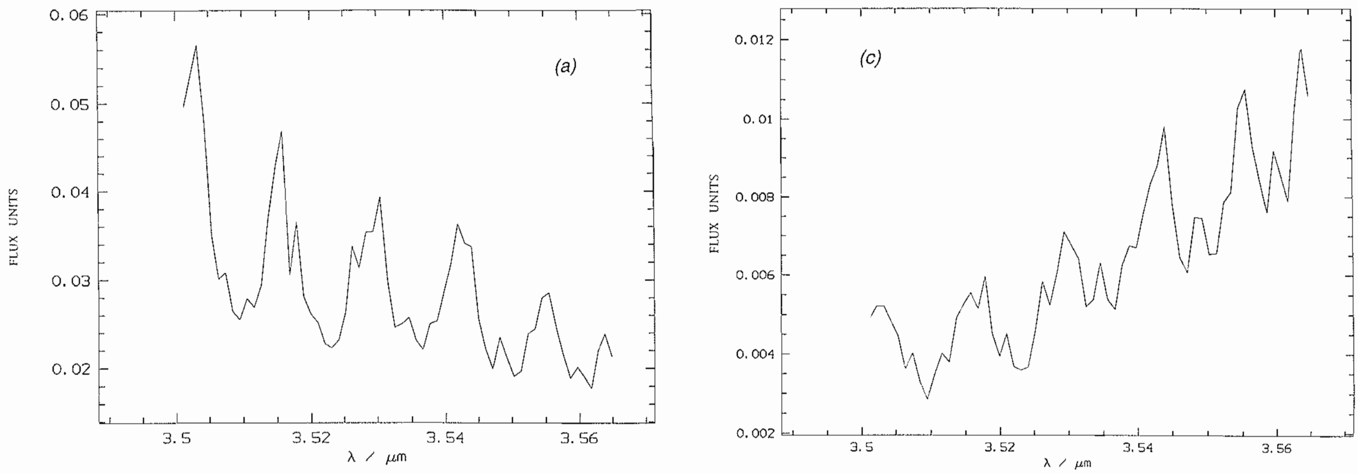
Near-infrared observations of the Jovian disk, using IRSPEC at the 3.5-m NTT, have been performed continuously from July 16 to July 28, 1994, with a final observing night on July 30/31. Data were recorded every night, with the exception of the three nights of July 18–22, lost because of bad weather.

The IRSPEC instrument is an imaging spectrometer working between 1 and 5 μm, with a resolving power ranging from 1300 to 3000. Its 4.4 arcsec slit was aligned along the parallel of impact sites (l = –44°) to monitor these sites as they were rotating with the planet. After the impacts, in the second part of the run, we monitored the entire Jovian disk by shifting the slit (still aligned with the parallels) in 9 different positions to cover the whole latitude range from pole to pole. This method allowed us to monitor systematically the impact regions and the corresponding emission regions detected at the same longitude in the northern hemi-



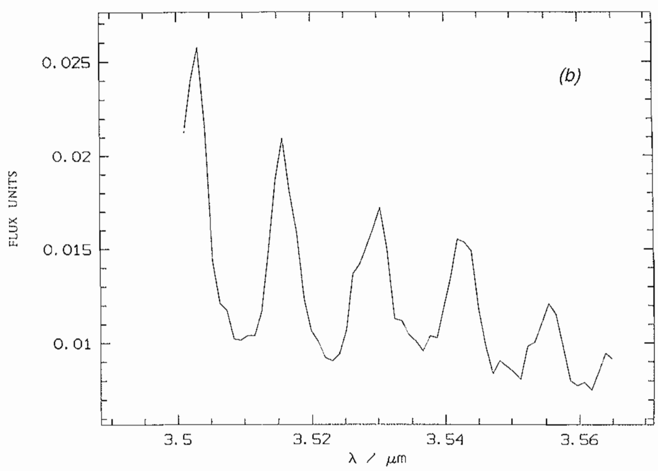


Figure 1: *CH_4 emission above the H impact site, 20 minutes after impact (July 18, U.T. 19:50). The peaks correspond to P multiplets of the ν_3 band of methane, centred at 3.3 μm (J = 14 to J = 18). (a) Central region (maximum of intensity); (b) Intermediate region (2.2 arcsec from central region); (c) Leading side of the H impact (4.4 arcsec from central region.)*