Imaging of Comet SL-9 in the Gunn Photometric System

G. CHERNOVA and K. JOCKERS, Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, Germany

Comet Shoemaker-Levy 9 was observed with the focal reducer of the MPI for Aeronomy attached to the ESO 1-m telescope from April 25 to May 1, 1994, when the comet was very close to opposition. The aim of the study was to determine the brightness and colour distribution of the individual nuclei and their dust tails. These observations therefore did not directly address the impending collision. Instead, we wanted to study the fragments of a parent comet and the dust surrounding them, in order to compare this dust, which probably was liberated only during the break-up, with the dust of other comets observed at Jupiter's distance, e.g., comet Schwassmann-Wachmann 1. As the cometary fragments all come from the same parent nucleus, colour differences between individual nuclei would indicate an inhomogeneous nucleus.

More than 100 useful individual frames were obtained between April 27 and May 1 in the G, R, and I bands of the intermediate-band photometric system of Thuan and Gunn (unfortunately, our lens optics does not allow to use the common wide-band photometric systems). For each night, all useful images of one colour are combined into a single image, free from stars, in order to increase the signal-to- noise ratio.

The night of April 27/28 has already been evaluated and Figure 1 shows the resulting G-band image in a false colour display. Nucleus A(21) is on the top left and nucleus W(1) at bottom right. The following Gunn G magnitudes have been derived (the fluxes are taken in square boxes of 5×5 pixels, i.e. 8×8 arcsec, corresponding to $21{,}000 \times 21{,}000$ km at the comet): 20.6 ± 0.4 A(21), 20.0 ± 0.3 B(20), 20.2 ± 0.3 C(19), 19.3 ± 0.15 E(17), 19.6 ± 0.20 F(16), 18.4 ± 0.09 G(15), 18.8 ± 0.11 H(14), 18.5 ± 0.09 K(12), 18.9 ± 0.12 L(11), 19.1 ± 0.17 P2(8b), 19.3 ± 0.15 R(6), 18.9 ± 0.11 S(5), 19.5 ± 0.17 W(1). The nuclei P1, Q1 and Q2 are too close together to measure their flux individually in 8×8 arcsec boxes. The Gunn G magnitude of P1, Q1 and Q2 together, measured in a square box of 11×11 arcsec is 17.7 ± 0.08. At the time of these observations the phase angle was less than 0.2 degrees, so some opposition brightening must be present.

Within the noise limits the nuclei all have the same colour. Figure 2 shows the colour difference in magnitude per pixel, Gunn G – Gunn R, as a false-colour image. At the bottom left part of the image there is no emission and the image represents only noise. About half of the pixels have cyan colour, corresponding to zero value, given by MIDAS to the logarithm of a negative argument. The individual comet fragments have a similar colour, and there seems to be a colour trend into the tails. Such a trend is expected, as the dust particles are likely to be sorted by the solar light pressure into different sizes in different tail regions, and different dust sizes may give differ-

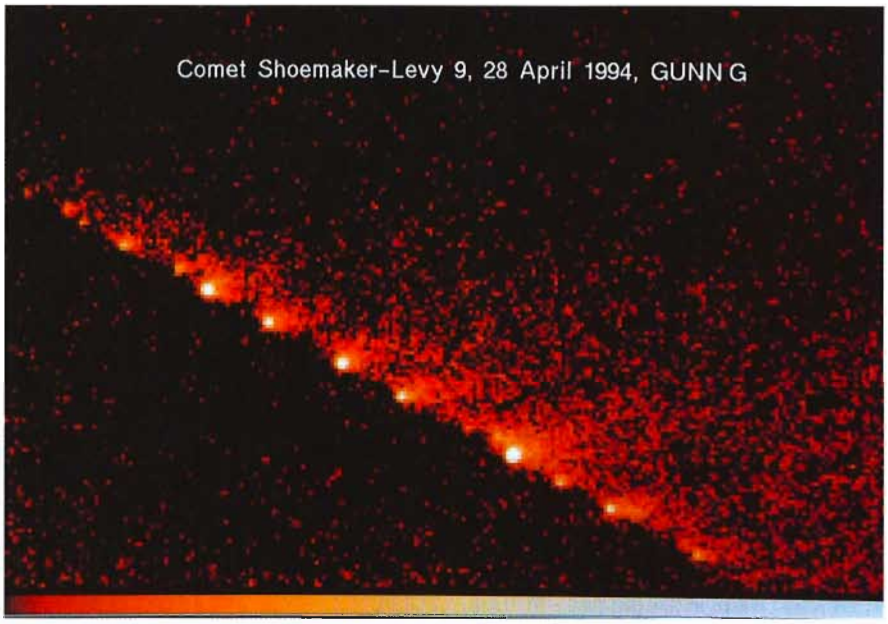

Figure 1.

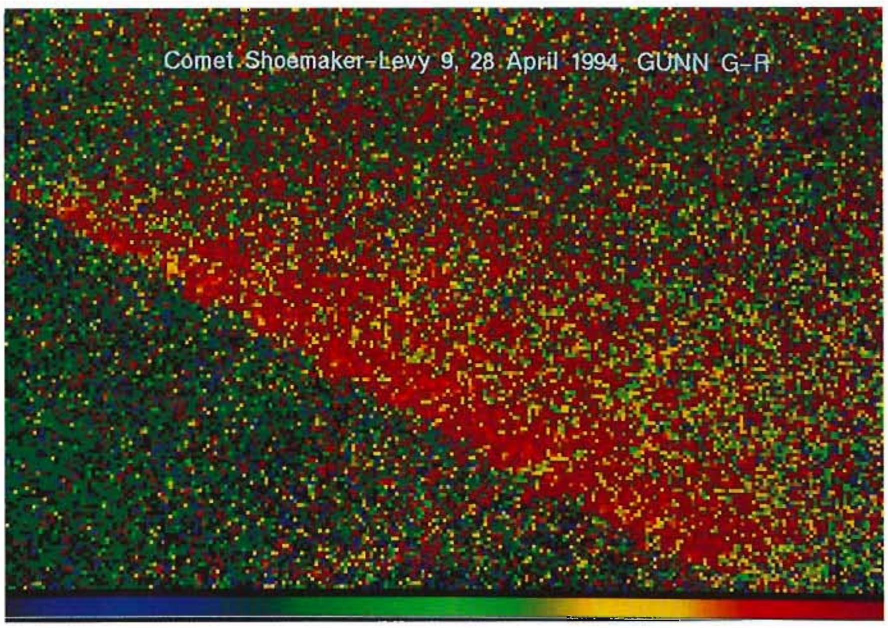

Figure 2.

ent colours. Whether the observed trend is indeed real, depends on the accuracy of sky background subtraction, which still needs to be assessed.

To determine the opposition effect and obtain information on the dust size, our images must be compared with images of other observers, obtained at other times and phase angles. It is interesting to note that no significant change in the appearance and direction of the tails occurred when the comets passed opposition. This indicates that the dust particles do not move under a combined central force of solar gravitation and light pressure repulsion, but are significantly influenced by Jupiter's gravity field.

Predicting the Impacts

R.M. WEST and O. HAINAUT, ESO-Garching

Astrometry of SL-9

For several reasons, it was of importance to predict the locations and times of the impacts of the SL-9 fragments with the greatest possible precision. The first, approximate calculations were performed towards the end of 1993 by Brian Marsden at the Minor Planet Center. They were based on long observation series, in particular by Jim Scotti at Kitt Peak, and correctly showed that the impacts would all happen in the southern Jovian hemisphere, but the timings were still not very accurate.

More astrometric observations were made during the first months of 1994, and the predictions slowly gained in precision. Don Yeomans and Paul Chodas at JPL used the special orbital software available at that institution (from where the Galileo spacecraft is navigated) to further improve the accuracy and in mid-June, about one month before the event, the 1 σ timing accuracy had been reduced to about 30 min for many of the fragments. This corresponded to 95% intervals of approximately $\pm$ 1 hour, i.e., not yet good enough for most purposes.

The ESO Observations

A few nights were allocated in early May at the Danish 1.5-metre telescope at La Silla to our astrometric programme for comet SL-9. In view of the need for the highest possible accuracy, we were very glad to learn at the same time that it would be possible to make unpublished Hipparcos positions available and we are very thankful to Michael Perryman (ESTEC) and Catherine Turon (Paris) for having provided us with these data.

Indeed, the first SL-9 observations showed that it would be possible to obtain a formal accuracy of about $\pm$0.2 arcsec in both coordinates. There was a problem, however, in that our observations appeared to be systematically offset by 0.5–0.7 arcsec from those by other observers. An analysis of this problem showed that this was most likely due to the lower astrometric accuracy of the Guide Star Catalogue (GSC) which formed the base for the other measurements. Note, however, that this catalogue was compiled to serve a different purpose and was never claimed to be of the highest perfection in astrometric terms. The offset was in the sense that the Hipparcos-based ESO positions would tend to move the times of the impacts later.

During the first 14 days of July, we provided Brian Marsden and Don Yeomans with (almost) daily positions of most of the SL-9 fragments. We wish here to acknowledge the extremely positive attitude by many La Silla observers (see below), who graciously allowed us to use their telescopes for astrometric exposures in the early evening, and some of them even did the observations for us.

The subsequent procedure was the same every day. One of us (O.H.) cleaned the exposures at La Silla and immediately transferred them to Garching over the internal link. Here the other (R.W.) measured the secondary astrometric standards on an ESO Schmidt plate, made the transfer to the CCD frame and obtained the positions of the comet fragments. They were then sent on to the orbital computers in the afternoon and new orbits became available a few hours thereafter. On several occasions, new impact predictions were also made.

It turned out that the ESO observations carried a great weight in the end, when it became more and more difficult for all observers to image the comet as it came very close to Jupiter. The last week we were pretty much alone in the field. The very last, measurable frames were obtained with the NTT on July 15.0 UT, or less than 48 hours before the first impact; the night thereafter, the strong straylight from Jupiter would have been too dangerous for the ultra-sensitive CCD array.

Still, we were not the last to see the comet. Observations of some of the latter fragments were made a few days later by the HST, just a few hours from impact, and David Jewitt at Hawaii obtained some final positions by means of the coronographic technique (covering Jupiter with a mask in the telescope) at the same time.

The Prediction Accuracy

The final predictions were believed to be good to about $\pm$8 minutes (1 $\sigma \sim$ 4 minutes). However, although there is still some uncertainty about the exact impact times for many of the fragments – the definitive values will probably have to wait until the Galileo data have all been reduced – it now appears that the predictions were generally 5 - 7 minutes too early.

It is not yet known what the real cause for this discrepancy is, but at least part of it may probably be explained by the above-mentioned GSC systematic offset. It is the intention, however, to look into this to learn whether other effects could possibly have been present.

In this connection, the hitherto unexplained observed elongation in the direction of Jupiter of most of the fragments as they came very close will also have to be studied; perhaps there is a connection between the two effects? For this, a careful morphological/photometrical study will now be made of the ESO astrometry frames.

Acknowledgements

We are very thankful to Michael Perryman (ESTEC) and Catherine Turon (Paris) for having provided us with Hipparcos pre-publication positions, without which we would not have achieved the accuracy needed for this programme. We are also most thankful to the following observers at La Silla for having supported this programme (in reverse chronological order): Pierre Dubath (Lick Observatory and Geneva Observatory), Richard de Grijs (Kapteyn Laboratory, Groningen), Felix Mirabel, Pierre-Alain Duc and Sylvain Chaty (Saclay, Paris), Andrea Cimatti (ESO), C. Alard (Observatoire de Paris), Marcella Carollo (Leiden) and Rita Schulz (MPIfAe, Lindau).