# FIRST OBSERVATION OF GLORY FROM SPACE

BY P. L. ISRAELEVICH, J. H. JOSEPH,* Z. LEVIN, AND Y. YAIR

The glory is an atmospheric optical phenomenon that is observed as concentric colored circles around the antisolar point. For centuries, it was considered a rare atmospheric optical phenomenon accessible only for mountaineers; however, with the widespread occurrence of air flights it became rather common, and almost every air traveler has seen it around the aircraft shadow on the top of the clouds. The glory is produced by light backscattering by small (approximately tens of wavelengths of the visible light) water droplets. This backscattering is described by Mie theory. However, there is still no simple explanation for the formation of glories, and the behavior of the ray paths inside droplets is not clear. The pattern of the glory—that is, the angular size of the rings for given wavelengths—depends primarily on 1) the average diameter of the droplets, and 2) the width of their size distribution. These patterns can be successfully simulated and thus be used as a remote sensing tool for determining cloud droplets' size distributions. Here we report the first observation of the glory from space made during the tragic last flight of the space shuttle *Columbia*.

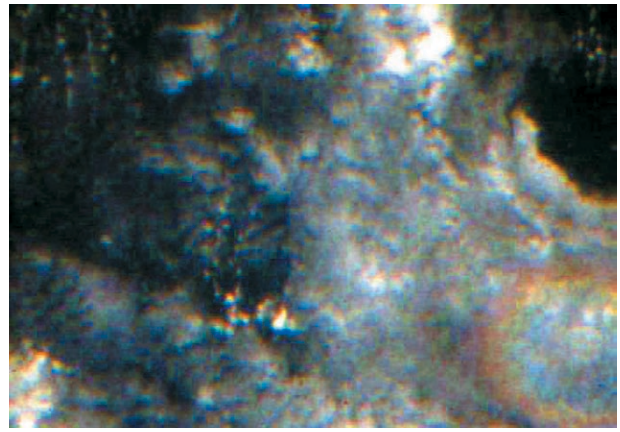

**FIG. 1. True-color image of glory from STS-107.**

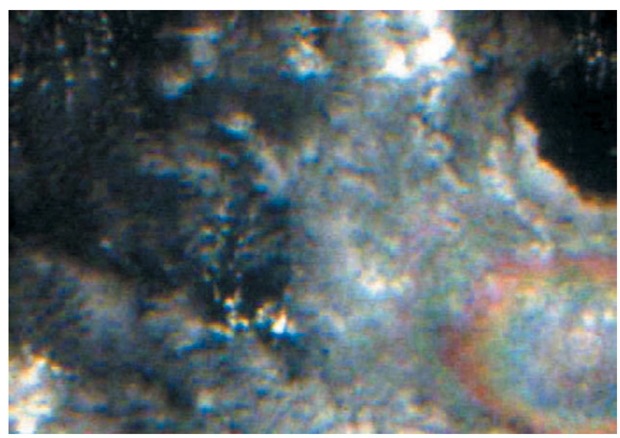

**FIG. 2. False-color image of glory from STS-107.**

**INSTRUMENT.** The observation was performed by a Xybion radiometric camera model IMC-201, which was the main science instrument in the Mediterranean Israeli Dust Experiment (MEIDEX) on board the space shuttle *Columbia* STS-107 flight in January 2003. The shuttle orbit was in 39° inclination at 278-km altitude. The camera was equipped with a rotating filter wheel with six narrow-band filters. The central wavelengths were 340, 380, 470, 555, 665, and 860 nm, and the full widths at half maximum of these six filters were 4, 4, 30, 30, 50, and 40 nm, respectively. The camera was equipped with a 50-mm Hamamatsu UV lens, adjusted with a special baffle to mitigate stray light from entering the optics. The field of view of the camera was rectangular, 10.76° vertical and 14.04° horizontal (diagonal 17.86°). The change-coupled device (CCD) had 486 × 704 pixels. The video format of the IMC-201 camera was National Television System Committee (NTSC), which means that it produced its video output at 30 frames per second (33.3 ms frame$^{-1}$). During the observation, the

**AFFILIATIONS:** ISRAELEVICH, JOSEPH [*DECEASED], AND LEVIN—Department of Geophysics and Planetary Sciences, Tel-Aviv University, Tel Aviv, Israel; YAIR—Department of Life and Natural Sciences, Open University of Israel, Raanana, Israel
**CORRESPONDING AUTHOR:** P. Israelevich, Geophysics and Planetary Sciences, Tel Aviv University, Tel-Aviv 69978, Israel
E-mail: peteri@post.tau.ac.il

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filters were sequentially changed at the frame rate, so that the complete 6-filter sequence took 200 ms. The exposure time with each filter was automatically increased from 50 to 4 ms (in 50-ms increments) until the maximal light level in each frame reached a predetermined level.

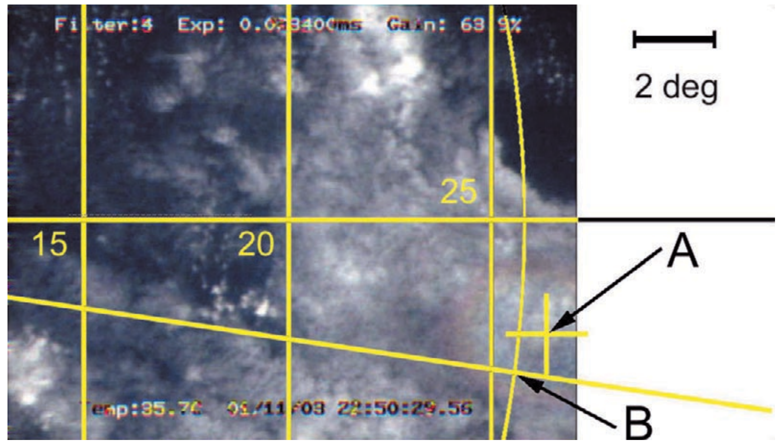


**Fig. 3. Positions of the glory center (A) and antisolar point (B).**

**OBSERVATION.** A glory was observed at 1400:39 UTC 28 January 2003 above the South Atlantic. It appeared in a raw data 6-filter sequence of black-and-white images as a light ring in the lower-right corner of the frame. The radius of the ring increased with the wavelength of the filter. No rings were observed for two UV filters, and it was barely seen in the blue filter. Obviously, the glory is masked in the shortwave lengths by strong wavelength-selective noncoherent scattering by air molecules. Figure 1 shows the color composite of 470- (blue), 555- (green), and 665-nm (red) filters. The 860-nm filter allowed us to observe the glory in near-infrared light. Such observations are rather rare. False color composite (i.e., a green filter image is depicted as blue, a red filter image as green, and an infrared filter image as red) is shown in Fig. 2.

**DISCUSSION.** To prove that the observed light pattern is indeed an atmospheric glory, one should show that 1) it is located at the right place—that is, around the antisolar point; 2) the angular size of the rings correspond to a reasonable size of the water droplets at the top of the clouds; and 3) it is not a result of a backscattering by the particles released from the space shuttle—for example, during wastewater dumps regularly performed in orbit.

The sun–shuttle line is the intersection between the plane containing the local vertical and the sun and the surface of the cone with the apex at the shuttle position and the angle equal to the solar zenith angle. Figure 3 shows a geometric visualization of this configuration. The antisolar point on the top of the clouds corresponds to the intersection of the circle with an angular radius of 26° (solar zenith angle) around the subshuttle point and the projection of the sun–shuttle line onto the Earth's surface (point B). The angular distance between the calculated antisolar point B and the center of the glory (point A) is ~1°, which is within the total accuracy of the space shuttle plus the Xybion camera point accuracy. Therefore, the glory was observed at the right place.

To estimate the size of the droplets producing the glory, we used Philip Laven's program MiePlot (www.philiplaven.com/mieplot.htm) to fit the observation. The result is shown in Fig. 4, where the left panel compares the observation with a simulation of the glory produced by monosized water droplets with a diameter of 12 $\mu$m and the right panel gives the result of a glory simulation for 12-$\mu$m droplets with 15% dispersion in sizes.

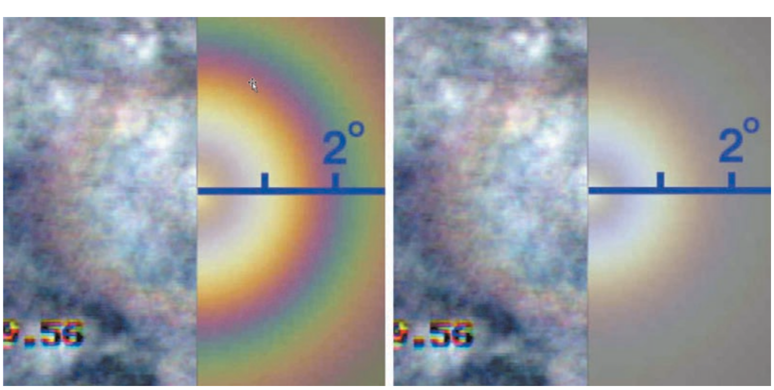


**Fig. 4. Comparisons of the observed glory and simulations for 12-$\mu$m monosized water droplets (left) and 12-$\mu$m droplets with a 15% size dispersion.**

The observed phenomenon cannot be produced by the near-shuttle contamination because a complete termination of water

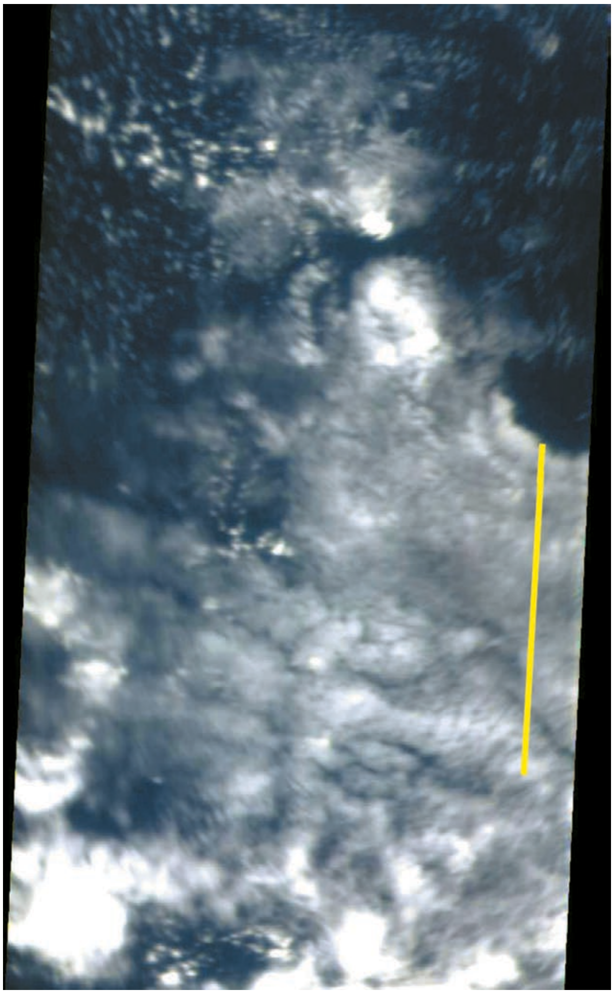

**Fig. 5. Mosaic image of the clouds above the South Atlantic on 28 Jan 2003. The line shows the trace of the glory center.**

dumps from the space shuttle was one of the operational requirements for switching on the Xybion camera. Moreover, the trace of the glory center coincides with the crossing of the stratocumulus clouds, as shown in Fig. 5. The glory appeared when the antisolar point entered the region of the clouds and ceased to be visible when the brightness of the clouds became too strong.

**CONCLUSIONS.** The glory was observed by the MEIDEX Xybion camera on board the space shuttle Columbia during the flight STS-107 on 28 January 2003. It was produced above stratocumulus clouds in the South Atlantic by backscattering from 12-$\mu$m water droplet with a 15% size dispersion. This is the first-ever recorded observation of an optical glory from space.

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