5. Other Examples of Caustics and Multiple Imaging

5.1 Gravitational lensing and the wine glass experiment

The formation of multiple images of a distant quasar by the gravitational lensing effects of a foreground galaxy may be very simply, and faithfully, accounted for by the wine glass experiment described below.

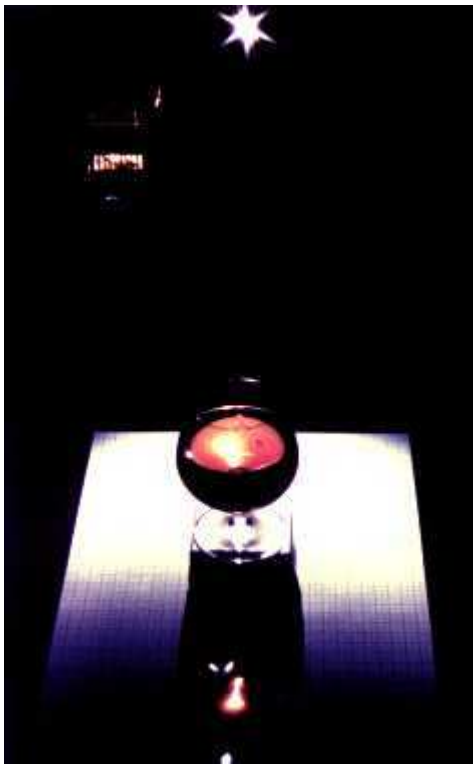

Figure 1: The wine glass experiment. A bright compact light source is used as a distant quasar. The wine glass set on the table (cf Figure 2) distorts the light rays from the quasar and produces a caustics having a triangular shape (see the enlargment in Figure 3). In order to see the multiple images from the distant "quasar", put the glass at the very edge of the table and one of your eyes around the caustics (see text)

In order to successfully make this experiment, please use as the quasar light source a candle, or a bright compact light source as shown in Figure 1. This light source is set at a typical distance of several meters, and somewhat higher, from a table on which a glass full of wine is placed. Like a gravitational lens, the wine glass distorts the background field. This space distortion is very well seen through the glass in Figure 2. Because of the presence of the wine glass, the distribution of light on the table is no longer uniform (see Figure 1). Just behind the glass, higher concentrations of light may be seen at some locations in the form of a caustics (i.e. the intersection of a three-dimensional caustics with the plane of the table). The latter is, in the present case, approximately triangular. The three sides and summits of this triangular caustics are named folds and cusps, respectively.

Figure 2: When looking through the wine glass, the distortion of the background field (millimetric paper) by the lens is very conspicuous

A blow up of this caustics is shown in Figure 3. The folds result from the envelope of pairs of tangent light rays from the candle. As a result, an observer setting his eye on a fold will see a pair of merging images from the distant quasar. Three merging images will be seen at the location of a cusp. In order to be able to put your eye at various locations with respect to the caustics, it is recommended to put the glass at the very edge of the table. You may then also observe that the total number of images increases by two when your eye

crosses a fold from outside to inside the caustics. Figure 4 shows a photograph made with a camera set up at the center of the caustics. Up to 9 different images of the compact light source are visible. As an exercise, draw the various diagrams showing the multiple image configurations of the background light source for different positions of your eye with respect to the caustics (folds and cusps) and compare them with the multiple image configurations observed for the known cases of multiply imaged quasars (a gallery of pictures illustrating various cases of multiply imaged quasars is available via the URL: http://www.aeos.ulg.ac.be/GL/candidates.php.
Note that the formation of caustics of light is a very generic feature in nature. It arises whenever a foreground object (cf. the wine glass in the above experiment, a galaxy acting as a gravitational lens, the wavy interface between air and water in a swimming pool, on a lake, etc.) distorts the propagation of light rays from a distant light source. For instance, for each pair -among the billions- of quasars and galaxies that exist in the Universe, a more or less complex three dimensional caustics is formed behind each galaxy. Whenever an observer lies close to such a caustics, the former sees multiple images of the distant quasar. Due to the relative motion between the quasar, the lensing galaxy and the observer, this phenomenon does not last for ever. It can be shown that the typical lifetime of a cosmic mirage involving a quasar and a lensing galaxy is of the order of 20 million years.

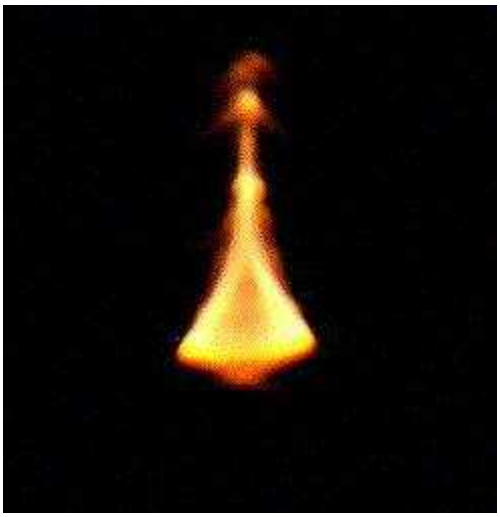

Figure 3: Enlargment of the triangular caustics visible in Figure 1. The caustics results from the redistribution of light rays emitted from the "quasar" by the wine glass

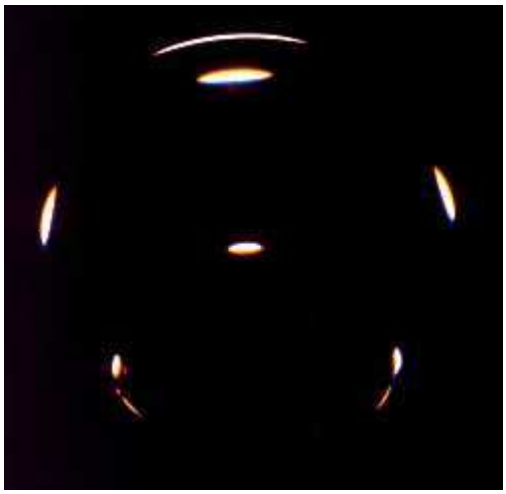

Figure 4: Multiple images of the compact light source seen by the objective of a photographic camera placed near the center of the caustics

5.2 Multiple imaging as seen by whales and sharks

As already stated in the previous section, because of the wind, the interface between the air and the water in a swimming pool, on a lake, on a sea, etc., is wavy and as a result, the propagation of light rays from a distant source (cf. the sun, the moon, etc.) gets distorted after entering water. Here also, complex caustics are formed and Figure 5a reproduces a view of such caustics projected on the body of a swimmer in a pool. Figure 5b illustrates also very well the caustics projected on the body of a whale, as drawn by the famous american painter Miller. There is consequently no doubt that, whenever one of the eyes of a whale crosses the folds (resp. the cups) of the complex caustics, the sun, the moon ... appear to them in the form

of, continuously moving and changing, multiple images. Such multiple images, seen by real sharks inside the large pool at Sea World (Orlando), have been photographed and are reproduced in Figures 6a and 6b.

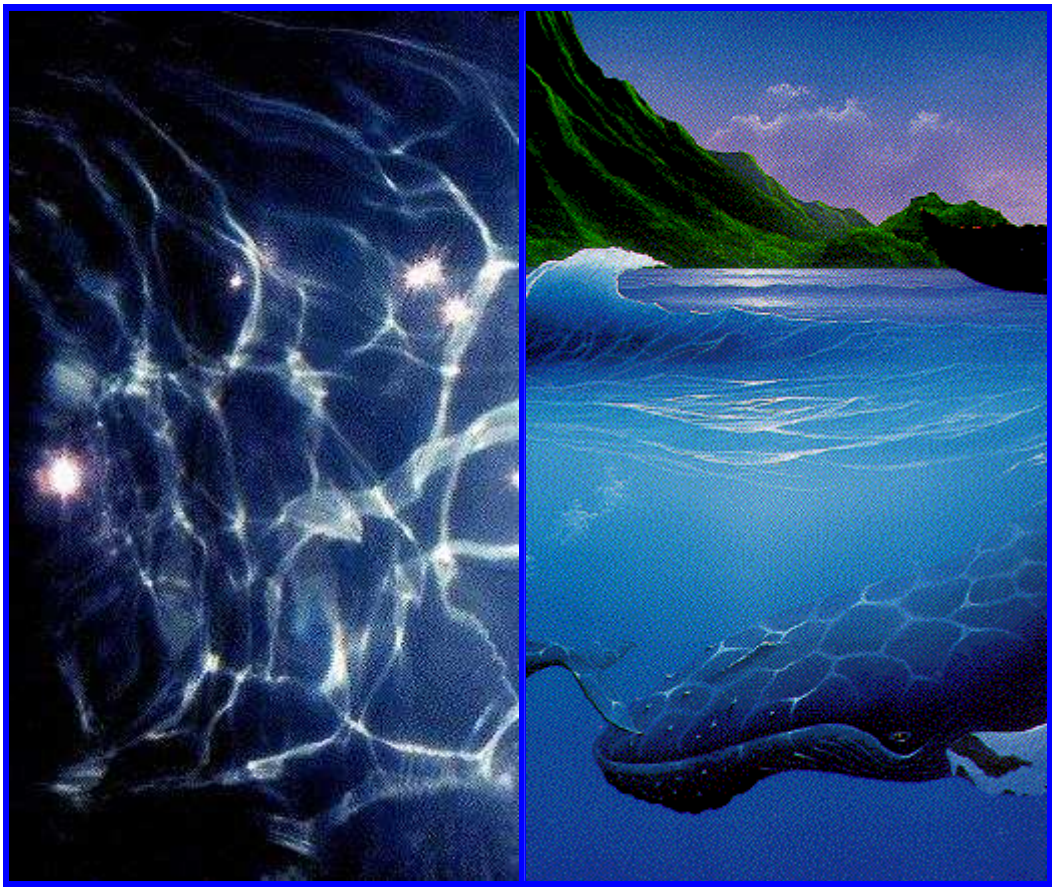

Figure 5: Caustics of light projected on the bottom of the swimming pool (left), and on the body of a whale, as painted by Miller (right). The sun (left) and moon (right) light acts in these case as the distant light source.

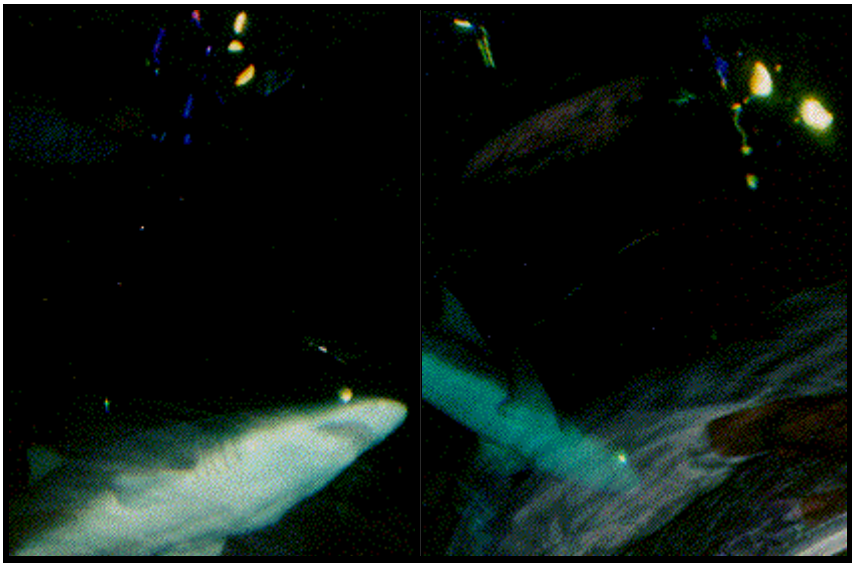

Figure 6: Multiple images seen by sharks in the large pool at Sea World (Orlanda, Florida).

5.3 Multiple imaging at the House of Mirrors

Finally, it is fun to observe multiple images of human beings at the House of Mirrors, available during most of the big city fairs. Such mirages are produced by curved mirrors which distort light rays emitted from the surroundings. Several photographs taken during the Liège october fair in 1989 are reproduced in Figures 6a and 6b.

Figure 7: Multipe images of an astronomer's daugthers photographed at the House of Mirrors during the Liège october fair in 1989

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