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Optics

Reflections on closed loops

from David K. Lynch

Reflection and refraction at the surface of gently rippled water produces images containing a variety of closed curves, the shapes of which depend on the spatial, or angular, distribution of the incident light field. The loops usually represent the distorted boundaries of high contrast features in the scene. In these columns[1] recently Thomas Gold discussed the formation of closed loops in reflections of linear objects such as the mast of a sailing boat, but point sources and objects extended in two dimensions also form closed-loop images. Here, I compare the loops resulting from reflection and diffraction of all three types of source.

All real sources are extended to some degree but sources that approximate to a point, such as the Sun and Moon, create a myriad of rapidly formed loops (Fig. 1), usually in the shape of distorted ovals[2,3]. Because the water contains many surfaces inclined at precisely the correct angle to reflect light to the observer, the casual observer sees the loops — which form almost too rapidly to follow — coalesce to create the familiar glitter patch[4,5]. These are readily seen in any body of water illuminated by a point source high overhead, such as bath tubs, swimming pools and coffee cups. The statistics of such reflections have been discussed by Longuet-Higgins[2], but the details of loop formation have not been well studied.

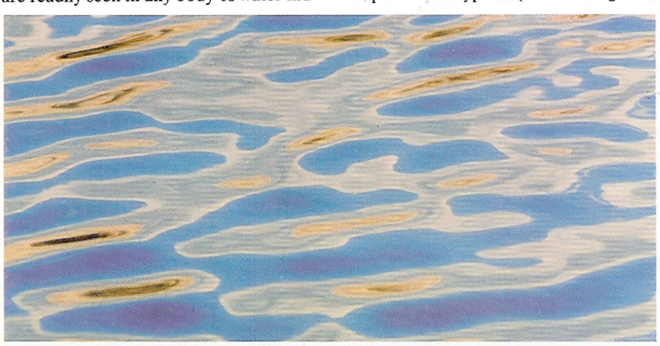
Theoretical studies of point sources show that there is not a one-to-one correspondence between the source and its image: that is, the solutions are not unique. For example, when the local radius of curvature of the water is twice the distance between the observer and the surface, the image of a point source is spread into a two-dimensional patch of light.

For linear sources of light such as masts, the reflected structure depends on the angle of the line of sight and the orientation of the source[1,3]. Since a vertical mast separates two extended, nearly identical featureless regions, the blue sky seen inside a loop comes from one side of the mast and the blue region surrounding the loop comes from the other, a distinction that cannot be made for point sources.

With extended sources, such as mountains and clouds, the closed curves form landpools and skypools (W.C. Livingston, personal communication), regions of reflected blue sky light surrounded by darker regions from the landscape and vice-versa (Fig.2). Except for the distortion, landscape re-imaging is often extremely accurate on water in terms of surface detail. The reflected blue sky seems almost white at the boundary of the skypool. This is simply the reflection of the true brightness and colour distribution of the sky made readily visible because many tens of degrees of vertical sky are compressed into a small angle. However, skypools are not distorted images of the entire sky because only a small part of the sky is actually re-imaged; the upper and lower parts of the skypool originate from the same part of the horizon and approximate to mirror images.

Refraction can also render objects of all three categories into closed curves. The most common examples can be seen on the bottom of a swimming pool. High contrast point-like sources (most commonly the Sun) appear as loops, analogous to those formed by reflected points. Such linear sources, distorted by refraction, become the familiar bright webs on the bottom when light is focused by the wavy surface of the water[6] (Fig.3). Because of dispersion, these loops also show brilliant colours. Extended sources, such as a bright rocky or sandy bottom, also display closed contours when viewed at low incidence. In these images the phenomenon is developed to its most fascinating complexity (Fig.4).

Much of the structure in both reflected and refracted distortions depends on the



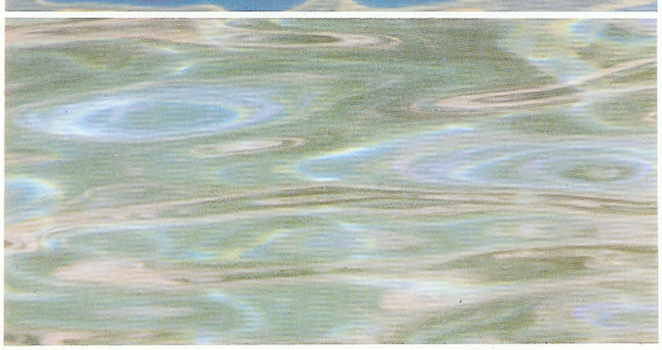
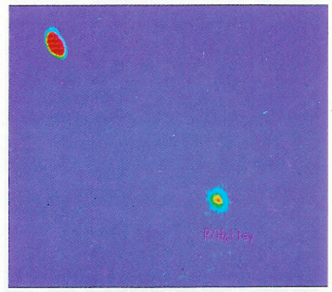


Fig.2 (top) Skypools and landpools in a reflection of an extended source.
Fig.4 (bottom) Refracted images of the sandy bottom of a lake.



First sight of Halley

CCD image of comet P/Halley (1982i) obtained on the 18 April 1985 with the 4.5-m Multiple Mirror Telescope of the Fred L. Whipple Observatory (MMTO). The integration time was 10 minutes and the seeing FWHM was 0.8 arc seconds. The comet image extends 5 arc seconds in the sunward direction with a brightness *V* of 18.7. The object at the top left is a binary star whose images have been smeared in following the comet's motion. The contoured bands of the cometary image indicate that the coma has been resolved. The image was digitally processed by K. Hege of MMTO. The first spectra from the coma are discussed on page 241.

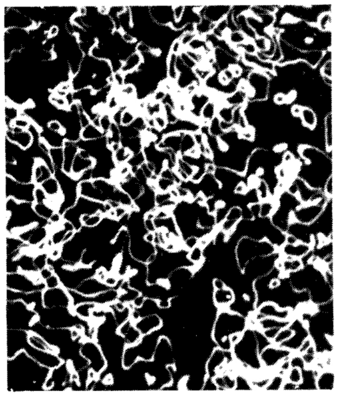


Fig.1 Reflection of a point source: the moon.

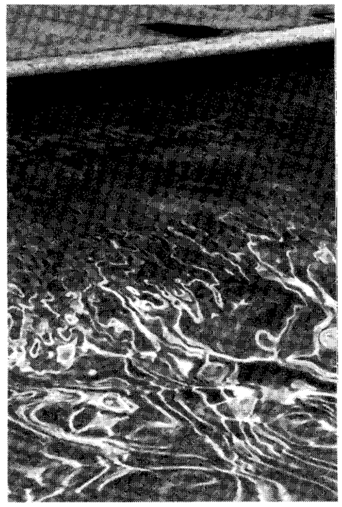


Fig.3 Refracted image of a linear source on the bottom of a swimming pool.

duration of the observation and the spatial distribution of the source. If photographs of point sources reimaged by the water are taken with shutter speeds far shorter than the period of the waves, the image usually shows many sharp loops, together with partial loops caught as the shutter opens or closes in the middle of a trajectory. Exposures much longer than the wave period result in overlapping images. For a point source against a dark background, overlaps are simple but photographs of an extended source create patterns of colours and shapes that rival the finest impressionist art. □

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