

These Stars Have Eyes

The ability to detect and react to light can be critically important for an animal's self preservation, and many varieties of eyes have been developed in the animal kingdom. Recently, a team of researchers from Bell Laboratories, Lucent Technologies, the Weizmann Institute, and the Natural History Museum of Los Angeles have found evidence for a novel photoreceptor system in some species of brittle stars.¹

Spiny brittle stars (top figure) are a class of echinoderms, relatives of starfish and sea urchins. With their wiggly arms, brittle stars are capable of very fast motion. These marine invertebrates lack anything immediately recognizable as eyes, yet some species, such as *Ophiocoma wendtii*, show a remarkable light sensitivity: As shown in the top figure, they change color from day (upper) to night (lower), and they can detect and dart into shadows or crevices when predators approach.

This photosensitivity has been attributed to diffuse dermal receptors. Now, Joanna Aizenberg (Bell Labs) and colleagues have found that the skeletal elements (middle figure) that protect the upper (dorsal) part of the brittle star arms may form what's essentially an extended compound eye in the light-sensitive species. As in all echinoderms, each of these skeletal elements is composed entirely of single-crystal calcite (calcium carbonate). Whereas the dorsal arm plates of light-insensitive brittle stars have an irregular porous structure, those of *O. wendtii* and other light-sensitive species have on their outer surface a regular array of nearly uniform nodules 20–50 μm in diameter (bottom figure).

These protuberances have many properties of an engineered microlens array. Calcite is birefringent, but in these structures the optical axis is normal to the plates and parallel to the lens axis; this optimal orientation prevents the formation of double images. In addition, the researchers found that each protuberance has a nearly ideal double-lens shape that closely resembles the shapes proposed in the 17th century by Descartes and Huygens to minimize spherical aberrations. Such shapes maximize a lens's light-gath-

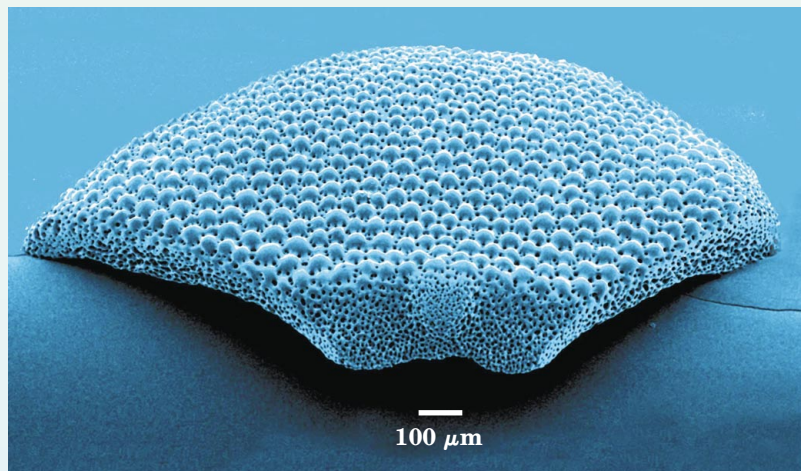


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ering ability and sensitivity. The only other known calcitic lens structures like this in the animal kingdom are from the extinct trilobites, which thrived about 200–550 million years ago.²

Aizenberg and company studied the optical properties of the microlens arrays from *O. wendtii* using photolithography. Similar to someone moving a magnifying glass up and down until focused sunlight ignites a piece of paper, the researchers exposed photoresist at various distances below the lens layer. From the sizes of the exposed spots in the resist, the researchers not only confirmed the focusing ability of the calcitic structures but also determined the focal length and the spot size in the focal plane.

The possible role of these microlenses in the brittle star's photo-



J. AIZENBERG

response system is supported by the presence of bundles of nerve fibers located just beneath the lens layer at the calculated focal points of the lenses. The sizes of the bundles also agree well with the experimentally determined focus spot size (about 3 μm). Furthermore, the color change in *O. wendtii* is due to mobile pigment-containing cells that act somewhat as irises,

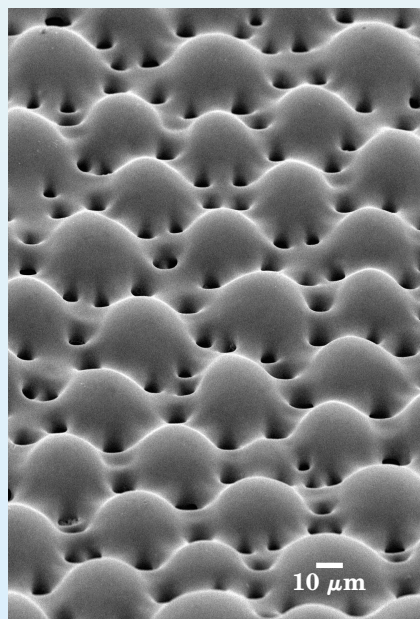
regulating the amount of light that reaches the lenses. Such a response explains why *O. wendtii* is sensitive to lower levels of illumination at night than it is during the day. Some questions remain, though, such as whether it is the nerve bundles themselves or associated tissue that is photoreceptive, and how the brittle star's nervous system processes the signals received from the microlenses.

With their regularity and precise curved shape and orientation, the brittle star microlens arrays should inspire new ideas of what may be possible in the emerging field of biomimetics, or "biologically inspired materials synthesis."

RICHARD FITZGERALD

References

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J. AIZENBERG