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A Pulsing-Mirror Eye in a Deep-Sea Ostracod

Andrew R. Parker

Green Templeton College, University of Oxford,
Woodstock Road, Oxford OX2 6HG, United Kingdom and
Lifescaped, Somerset House, Strand, London WC2R 1LA, United Kingdom

Abstract. In the deep sea, it is unknown how eyes that use concave mirrors to focus can distinguish between the small bioluminescent lights of their prey and those larger lights of more distant predators. Beyond 1000 m depth, where sunlight is no longer perceptable, the deep sea contains a continuous field of (mostly) blue, bioluminescent lights. Here, some predators, such as the ostracods of the genus *Gigantocypris*, famed for their gooseberry-like appearance, are attracted to their prey through the prey's bioluminescence. The enigmatic eyes of *Gigantocypris* spp. focus light using large, parabolic mirrors. Here, I show that the mirrors flex, pulsing continuously, so causing large, distant light sources to pass in and out of focus while small, nearby light sources remain in focus with each pulse cycle. This distinguishes predators from prey and constitutes a new type of eye.

Introduction

Species of the "giant" myodocopid ostracod (Crustacea) genus *Gigantocypris* Müller, 1895, are pelagic crustaceans with shrimp-like bodies enclosed within spherical, bivalved "shells", 10 to 32 mm in diameter, and are emblematic of the deep sea. They live between about 600 and 2,300 m depth world-wide and use a pair of oar-like antennae to swim and hunt small, bioluminescent, pelagic animals such as copepods and small fish (Land, 1984; Land & Nilsson, 2002). Species of *Gigantocypris* are characterized by a pair of large (naupliar) eyes, which, rather than using convex lenses to focus light onto a retina, use concave, parabolic mirrors about 3 mm wide, appearing like car headlights (Land, 1984). These are considered the parabolic reflecting eye type, one of the 10 fundamentally different types of eye (Land & Fernald, 1992).

Each retina of *Gigantocypris* sp. is not a flat sheet, as is usual for an eye, but condensed into a light-bulb shape (Land & Nilsson, 2002). The curvature of each mirror in the horizontal and vertical planes is different, which means that the image of a point source will be astigmatic: a line at right angles to the mirror (Land & Nilsson, 2002). The retina is also elongated in this direction (about 750 microns long), and "so may have some capacity to resolve these linear images" (Land & Nilsson, 2002). At a depth of 1000 m there is no remaining sunlight (Denton, 1990; Herring, 2002), so the function of these eyes has been assumed to assist predation by tracking down the bioluminescent organisms, which are common at such depths (Land & Nilsson, 2002). However, our current understanding (Land & Nilsson, 2002) cannot account for this required function.

In a deep field of bioluminescence produced by very different animals from large fish to tiny planktonic shrimps, a predator such as *Gigantocypris* sp. must distinguish between the light of a large predator at distance and a small prey animal nearby. Although the former light emerges from a larger and brighter source (photophore), if the small prey animal is closer to an observer's eye, both lights may appear equal. Indeed, small prey that are conspicuous may be afforded protection through "mimicry" as a result of this phenomenon. A discovery made from examining *living* specimens of an unidentified species of *Gigantocypris* revealed another, critical character of the *Gigantocypris* eye that enables it to distinguish its prey.

Keywords: eye function, new type of eye, predation, bioluminescent light, concave mirrors, Crustacea, Ostracoda
ORCID iD: Andrew R. Parker https://orcid.org/0000-0002-4564-2838
Corresponding author: Andrew R. Parker Andrew@Lifescaped.com
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Figure 1. *Gigantocypris dracontovalis* Cannon, 1940, whole animal, lateral view; muscles (yellow) behind parabolic mirrors of left eye evident (dorsal left-centre).

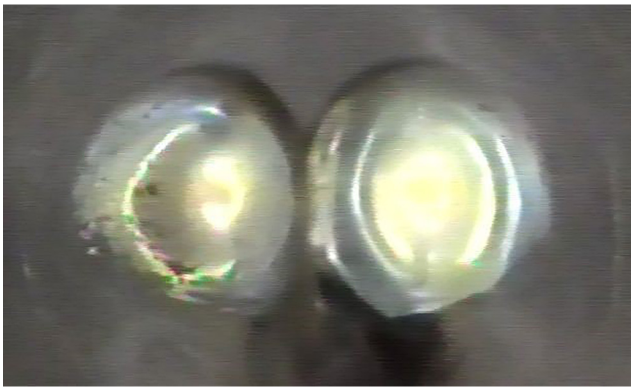

Figure 2. Frame from a magnified video recording of a resting *Gigantocypris* sp. showing paired eyes only, anterior view. The mirrors appear silver; the layer of black, absorbing pigment beneath is not visible. A white-yellow light is back-reflected.

Living *Gigantocypris* observed

Studies of the eye of *Gigantocypris* to date have considered only preserved specimens, and their optical apparatus. However, an examination of a whole, preserved animal led to the discovery of four large muscles behind each eye, attached to the near-lateral edges of the reflector, i.e., behind the parabolic part (Fig. 1). These muscles provided evidence that the mirrors move, prompting an examination of living specimens.

In 1999, living specimens of *Gigantocypris* sp. were collected by a mid-water trawl off the Cape Verde Islands during RRS *Discovery* Cruise 243. Video recordings were made of several specimens free-swimming in a kreisel tank, including close-ups showing detail of their large eyes. In these recordings, from anterior and dorsal views, the parabolic mirrors of the eyes were observed to flex and pulse. In a resting specimen (Fig. 2), the eyes could be magnified and observed in detail: the parabolic parts of the mirrors were measured to flex back to a maximum position as shown in Fig. 3B and pulse regularly at a rate of 0.5 cycles per second (n = 28 cycles). The spherical part of the mirrors, in the dorso-ventral ("vertical") plane, was not observed to move.

Ray tracing calculations revealed that when the luminous object is far, the oscillations of the parabolic reflector cause the object to go in and out of focus at the retina, as the reflector is relaxed then "flattened" (Fig. 3A, B). However, when the luminous object is nearby, the oscillations of the parabolic reflector cause little change to the image focused on the retina (Fig. 3C, D). This principle was confirmed using a model flexible, parabolic mirror and a laser. Therefore, during a pulse cycle of the retina, a light source nearby will remain detected by the ostracod (appearing always "on"), whereas a light source far away will appear to turn on and off twice per second. The latter light will appear to flicker; a flickering light is more conspicuous than a steady light (Haamedi & Djamgoz, 1996) and hence a distant predator will appear particularly perceptible. In conclusion, *Gigantocypris* sp. can distinguish its prey within a field of bioluminescent light sources, while probably requiring less information processing than for rigid lens type eyes.

Such a "pulsing mirror eye" functions in a radically different way to any other eye. Since this eye type is not evident from preserved specimens, other species with parabolic reflecting eyes, such as the deep-sea amphipod *Scypholanceola* (from a similar environment), should be re-assessed while alive. On another note, the transparent window in the carapace of *Macrocypridina castanea* (Parker *et al.*, 2019; 2021), was found to have applications in commerce. In a similar manner, examination of the submicron structure of the *Gigantocypris* mirror, particularly how it withstands continuous flexing to maintain a flawless mirror, may be relevant to the mirror of the Hubble telescope—a comparable imaging system whose mirror does develop flaws over time.

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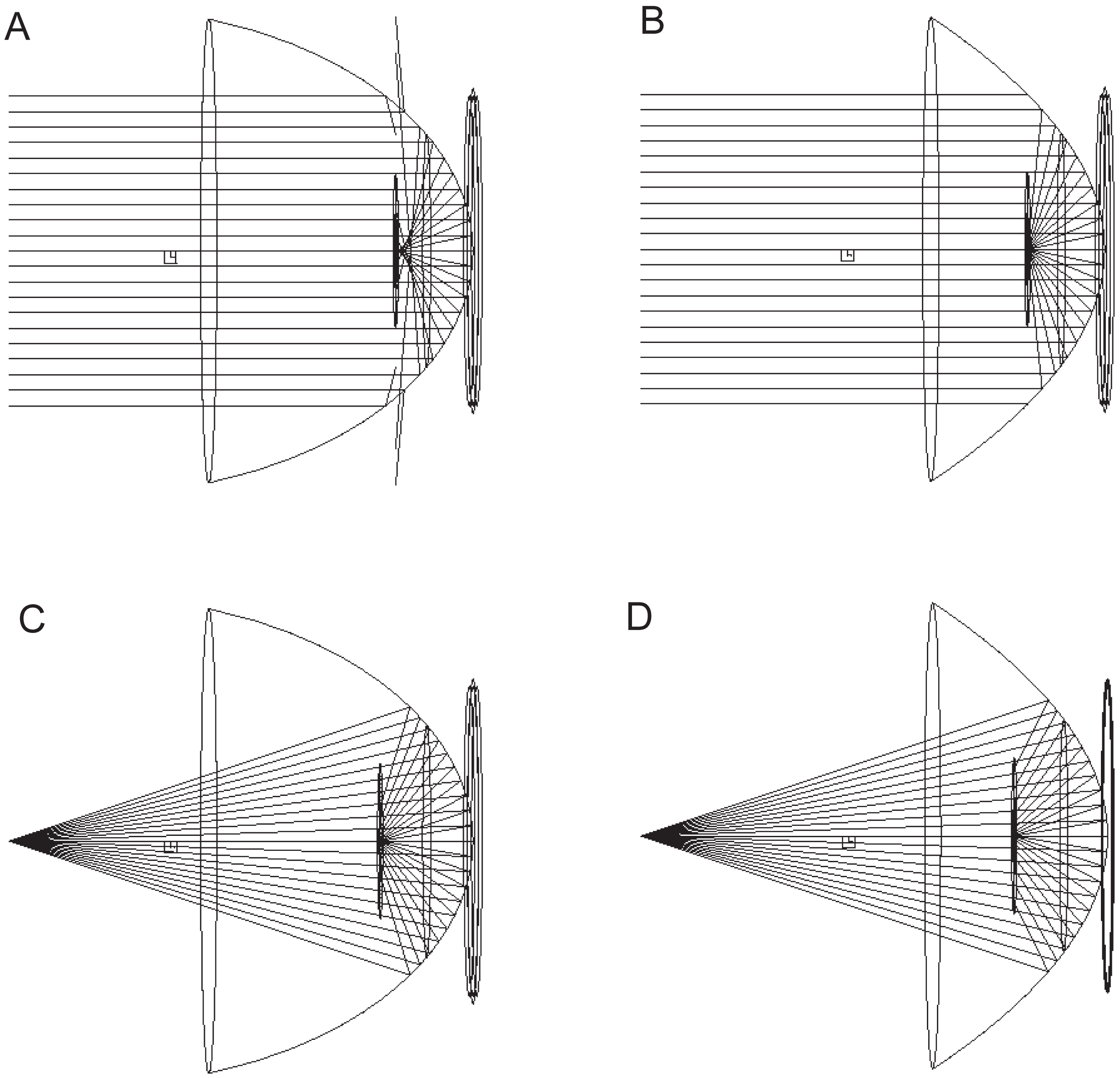

Figure 3. Ray tracing of light imaged on the *Gigantocypris* sp. retina: (*A–B*) when the luminous object is distant, the oscillations of the parabolic reflector cause the object to go in and out of focus at the retina, as the reflector is relaxed and then "flattened"; (*C–D*) when the luminous object is nearby, the oscillations of the parabolic reflector cause little change to the image focused on the retina.

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