by self-assembly into large supramolecular structures dictated by pigment–pigment interactions, as opposed to protein–pigment interactions that govern the structure in all other light-harvesting systems[4]. In both cases, for the chlorosomes and the nanoparticles, it is difficult to reveal the accurate molecular arrangement, but the self-assembly creates a robust and effective structure that maintains the functionality of efficient long-distance energy transfer by simple structural design rules.

From a practical perspective, light-harvesting nanoparticles could be exploited, for example, for energy conversion, for biosensing or in single-molecule biophysics. To this end, the authors showed that much of the light-harvesting efficiency could be maintained when the acceptor was adsorbed to the nanoparticles after the nanoparticle synthesis. Similarly, nanoparticles might be used to enhance dye solar cells. Here, the nanoparticles offer the advantage of improved chemical robustness compared with their natural chlorosome counterparts. Because a minor modification, such as the adsorption of a single acceptor, could change the fluorescent properties of the nanoparticle drastically, this principle could be exploited for biosensing methods similar to sensors based on conjugated polymers[5]. If the interaction of a quencher or an acceptor is modulated by target binding, this could be detected on the level of single molecules even on low-tech devices used for point-of-need biosensing. Finally, such light-harvesting nanoparticles could be used as pseudo- or metafluorophores in single-molecule biophysics and in labelling applications facilitating simpler single-molecule experiments. For these applications especially, the nanoparticles would have to be further developed with respect to homogeneity, surface chemistry for (bio-)conjugation and spectroscopic properties. Interesting questions in this regard are: to what extent do the dyes in the nanoparticle act cooperatively as a single chromophore, and what is the mechanism of the dye–dye interaction? Do the emitters exhibit antibunching[6]? Another important parameter is the maximum count rate that can be obtained before saturation occurs and annihilation processes come into play. Nevertheless, this work is a prime example of how a simple concept of self-assembly can have dramatic photophysical consequences that enable a light-harvesting effect as yet unreached by targeted chemical synthesis, which holds promise for single-molecule detection at low-light and low-tech levels. ❐

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References
1. De Schryver, F. C. et al. *Acc. Chem. Res.* **38**, 514–522 (2005).
2. Trofymchuk, K. et al. *Nat. Photon.* https://doi.org/10.1038/s41566-017-0001-7 (2017).
3. Puchkova, A. et al. *Nano Lett.* **15**, 8354–8359 (2015).
4. Orf, G. S. & Blankenship, R. E. *Photosynth. Res.* **116**, 315–331 (2013).
5. Thomas, S. W. III, Joly, G. D. & Swager, T. M. *Chem. Rev.* **107**, 1339–1386 (2007).
6. Wientjes, E., Renger, J., Curto, A. G., Cogdell, R. & van Hulst, N. F. *Nat. Commun.* **5**, 4236 (2014).

BIOPHOTONICS

Graded-index squid eyes

In contrast to human eyes, the eyes of fish and squid tend to have fixed spherical lenses with a radial refractive index profile that is parabolic. This design is considered optimal for maximizing sensitivity and visual acuity in the light-limited ocean and, as predicted by the famous nineteenth century Scottish physicist James Clerk Maxwell, allows an aberration-free image to be formed. However, until now, it has been unclear how the graded-index lenses found in such creatures are formed from homogeneous materials such as protein solutions. Now, Jing Cai and co-workers from the University of Pennsylvania, USA have investigated the spherical lens of a decapod squid (*Doryteuthis pealeii*) (pictured) and have found the answer (*Science* **357**, 564–569; 2017).

The refractive-index material of the squid's lens is made up of proteins called S-crystallins that are composed of a glutathione S-transferase enzyme and a variable-length peptide loop.

The research team used gel electrophoresis to characterize the protein molecular weight distribution as a function of lens radius. The experimental results showed that proteins with very short loops were highly abundant in the core of the lens, whereas those with medium-sized loops were more abundant at the periphery. S-crystallins with long loops were found throughout the lens.

Credit: AAAS

The spatial structure of S-crystallins was investigated by small-angle X-ray scattering. A structural fitting analysis confirmed that the protein solutions contained pairwise-linked chains of S-crystallin and complex, multiparticle nodes within the protein network.

When tissue taken from different radial positions of the lens was diluted to a volume fraction of 0.01 and then centrifuged, a protein fluid and a pellet were observed. Both the relative amount of protein and the density of the pellet were found to increase towards the centre of the lens, thus explaining its graded refractive-index profile. In samples taken from the periphery, the pellet was a soft, volume-spanning translucent gel, whereas samples taken from the core of the lens formed a white powder.

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