Why are plants green? Research team's model reproduces photosynthesis

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UC Riverside-led research team's model to explain photosynthesis lays out the next challenging phase of research on how green plants transform light energy into chemical energy. Credit: Gabor lab, UC Riverside.

When sunlight shining on a leaf changes rapidly, plants must protect themselves from the ensuing sudden surges of solar energy. To cope with these changes, photosynthetic organisms—from plants to bacteria—have developed numerous tactics. Scientists have been unable, however, to identify the underlying design principle.

An international team of scientists, led by physicist Nathaniel M. Gabor at the University of California, Riverside, has now constructed a model that reproduces a general feature of photosynthetic light harvesting, observed across many photosynthetic organisms.

Light harvesting is the collection of solar energy by protein-bound chlorophyll molecules. In photosynthesis—the process by which green plants and some other organisms use sunlight to synthesize foods from carbon dioxide and water—light energy harvesting begins with sunlight absorption.

The researchers' model borrows ideas from the science of complex networks, a field of study that explores efficient operation in cellphone networks, brains, and the power grid. The model describes a simple network that is able to input light of two different colors, yet output a steady rate of solar power. This unusual choice of only two inputs has remarkable consequences.

"Our model shows that by absorbing only very specific colors of light, photosynthetic organisms may automatically protect themselves against sudden changes—or 'noise'—in solar energy, resulting in remarkably efficient power conversion," said Gabor, an associate professor of physics and astronomy, who led the study appearing today in the journal *Science*. "Green plants appear green and purple bacteria appear purple because only specific regions of the spectrum from which they absorb are suited for protection against rapidly changing solar energy."

Gabor first began thinking about photosynthesis research more than a decade ago, when he was a doctoral student at Cornell University. He wondered why plants rejected green light, the most intense solar light. Over the years, he worked with physicists and biologists worldwide to learn more about statistical methods and the quantum biology of photosynthesis.

Richard Cogdell, a renowned botanist at the University of Glasgow in the United Kingdom and a coauthor on the research paper, encouraged Gabor to extend the model to include a wider range of photosynthetic organisms that grow in environments where the incident solar spectrum is very different.

"Excitingly, we were then able to show that the model worked in other photosynthetic organisms besides green plants, and that the model identified a general and fundamental property of photosynthetic light harvesting," he said. "Our study shows how, by choosing where you absorb solar energy in relation to the incident solar spectrum, you can minimize the noise on the output—information that can be used to enhance the performance of solar cells."

Coauthor Rienk van Grondelle, an influential experimental physicist at Vrije Universiteit Amsterdam in the Netherlands who works on the primary physical processes of photosynthesis, said the team found the absorption spectra of certain photosynthetic systems select certain spectral excitation regions that cancel the noise and maximize the energy stored.

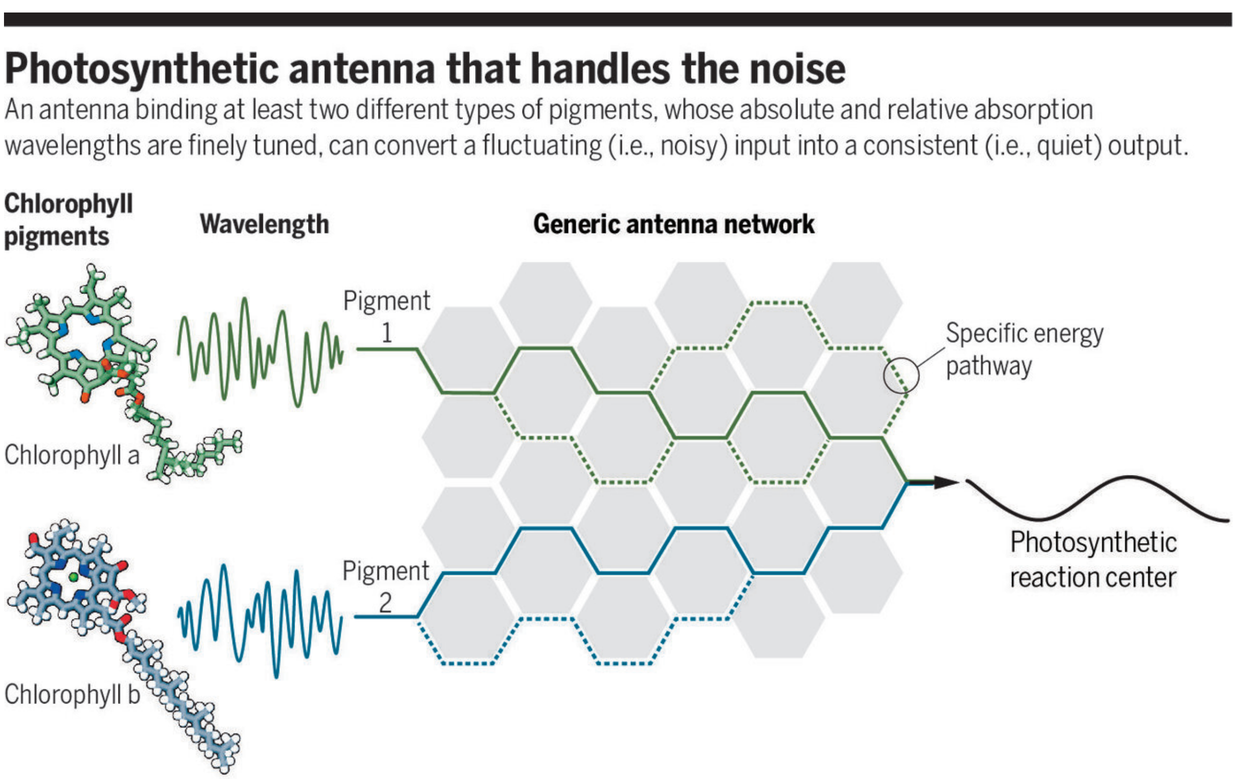
"This very simple design principle could also be applied in the design of human-made solar cells," said van Grondelle, who has vast experience with photosynthetic light harvesting.

Gabor explained that plants and other photosynthetic organisms have a wide variety of tactics to prevent damage due to overexposure to the sun, ranging from molecular mechanisms of energy release to physical movement of the leaf to track the sun. Plants have even developed effective protection against UV light, just as in sunscreen.

"In the complex process of photosynthesis, it is clear that protecting the organism from overexposure is the driving factor in successful energy production, and this is the inspiration we used to develop our model," he said. "Our model incorporates relatively simple physics, yet it is consistent with a vast set of observations in biology. This is remarkably rare. If our model holds up to continued experiments, we may find even more agreement between theory and observations, giving rich insight into the inner workings of nature."

To construct the model, Gabor and his colleagues applied straightforward physics of networks to the complex details of biology, and were able to make clear, quantitative, and generic statements about highly diverse photosynthetic organisms.

"Our model is the first hypothesis-driven explanation for why plants are green, and we give a roadmap to test the model through more detailed experiments," Gabor said.



Photosynthetic antenna that handles the noise. Credit: Nathalie Cary, Science/AAAS

Photosynthesis may be thought of as a kitchen sink, Gabor added, where a faucet flows water in and a drain allows the water to flow out. If the flow into the sink is much bigger than the outward flow, the sink overflows and the water spills all over the floor.

"In photosynthesis, if the flow of solar power into the light harvesting network is significantly larger than the flow out, the photosynthetic network must adapt to reduce the sudden over-flow of energy," he said. "When the network fails to manage these fluctuations, the organism attempts to expel the extra energy. In doing so, the organism undergoes oxidative stress, which damages cells."

The researchers were surprised by how general and simple their model is.

"Nature will always surprise you," Gabor said. "Something that seems so complicated and complex might operate based on a few basic rules. We applied the model to organisms in different photosynthetic niches and continue to reproduce accurate absorption spectra. In biology, there are exceptions to every rule, so much so that finding a rule is usually very difficult. Surprisingly, we seem to have found one of the rules of photosynthetic life."

Gabor noted that over the last several decades, photosynthesis research has focused mainly on the structure and function of the microscopic components of the photosynthetic process.

"Biologists know well that biological systems are not generally finely tuned given the fact that organisms have little control over their external conditions," he said. "This contradiction has so far been unaddressed because no model exists that connects microscopic processes with macroscopic properties. Our work represents the first quantitative physical model that tackles this contradiction."

Next, supported by several recent grants, the researchers will design a novel microscopy technique to test their ideas and advance the technology of photo-biology experiments using quantum optics tools.

"There's a lot out there to understand about nature, and it only looks more beautiful as we unravel its mysteries," Gabor said.

More information: T.B. Arp el al., "Quieting a noisy antenna reproduces photosynthetic light-harvesting spectra," *Science* (2020). science.sciencemag.org/cgi/doi … 1126/science.aba6630

"The simplicity of robust light harvesting," *Science* (2020). science.sciencemag.org/cgi/doi … 1126/science.abc8063

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