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Nature's Smallest Rainbows, Produced by Peacock Spiders, May Inspire New Optical Technologies

Intense rainbow iridescence found to come from specialized scales on the spiders

Brightly colored Australian peacock spiders (Maratus spp.) captivate even the most arachnophobic viewers with their flamboyant courtship displays featuring diverse and intricate body colorations, patterns, and movements – all packed into miniature bodies measuring less than five millimeters in size for many species. However, these displays are not just pretty to look at. They also inspire new ways for humans to produce color in technology.

Peacock spider, Maratus robinsoni. Photo courtesy coauthor Jurgen Otto.

One species of peacock spider – the rainbow peacock spider (Maratus robinsoni) – is particularly impressive, because it showcases an intense rainbow iridescent signal in males' courtship displays to females. This is the first known instance in nature of males using an entire rainbow of colors to entice females to mate. But how do males make their rainbows? A new study published in Nature Communications looked to answer that question.

Figuring out the answers was inherently interdisciplinary so Bor-Kai Hsiung, a postdoctoral scholar at Scripps Institution of Oceanography at the University of California San Diego, assembled an international team that included biologists, physicists and engineers. Starting while he was a Ph.D. student at The University of Akron under the mentorship of Todd Blackledge and Matthew Shawkey, the team included researchers from UA, Scripps Oceanography, California Institute of Technology, and University of Nebraska-Lincoln, the University of Ghent in Belgium, University of Groningen in Netherlands, and Australia to discover how rainbow peacock spiders produce this unique iridescent signal.

The team investigated the spider's photonic structures using techniques that included light and electron microscopy, hyperspectral imaging, imaging scatterometry and optical modeling to generate hypotheses about how the spider's scale generate such intense rainbows. The team then used cutting-edge nano 3D printing to fabricate different prototypes to test and validate their hypotheses. In the end, they found that the intense rainbow iridescence emerged from specialized abdominal scales on the spiders. These scales combine an airfoil-like microscopic 3D contour with nanoscale diffraction grating structures on the surface. It is the interaction between the surface nano-diffraction grating and the microscopic curvature of the scales that enables separation and isolation of light into its component wavelengths at finer angles and smaller distances than are possible with current engineering technologies.

"Who knew that such a small critter would create such an intense iridescence using extremely sophisticated mechanisms that will inspire optical engineers," said Dimitri Deheyn, Hsuing's advisor at Scripps Oceanography and a coauthor of the study.

For Hsiung, the finding wasn't quite so unexpected.

"One of the main questions that I wanted to address in my Ph.D. dissertation was 'how does nature modulate iridescence?' From a biomimicry perspective, to fully understand and address a question, one has to take extremes from both ends into consideration. I purposefully chose to study these tiny spiders with intense iridescence after having investigated the non-iridescent blue tarantulas," said Hsiung.

The mechanism behind these tiny rainbows may inspire new color technology, but would not have been discovered without research combining basic natural history with physics and engineering, the researchers said.

"Nanoscale 3D printing allowed us to experimentally validate our models, which was really exciting," said Shawkey. "We hope that these techniques will become common in the future."

"As an engineer, what I found fascinating about these spider structural colors is how these long evolved complex structures can still outperform human engineering," said Radwanul Hasan Siddique, a postdoctoral scholar at Caltech and study coauthor. "Even with high-end fabrication techniques, we could not replicate the exact structures. I wonder how the spiders assemble these fancy structural patterns in the first place!"

Inspiration from these super iridescent spider scales can be used to overcome current limitations in spectral manipulation, and to reduce the size of optical spectrometers for applications where fine-scale spectral resolution is required in a very small package, notably instruments on space missions, or wearable chemical detection systems.

In the end, peacock spiders don't just produce nature's smallest rainbows.They could also have implications for a wide array of fields ranging from life sciences and biotechnologies to material sciences and engineering.

Adapted from materials written by the University of Akron. Additional peacock spider photo and video content available from co-author Jurgen Otto on Otto's Flickr, YouTube and Facebook pages.

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