Behind the Cover

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Swarnendu,
Chief Editor,
InScight

Outline

Secret of the Wings: Nanostructures on a Dragonfly

Debanuj Chatterjee

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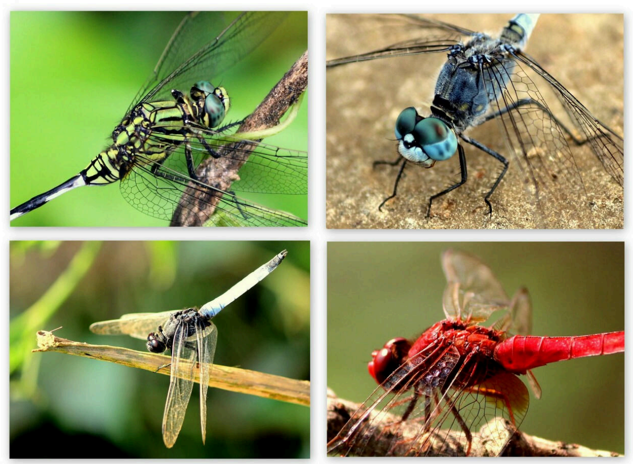

Fig 1: Shots of colorful dragonflies.

It was the summer of 2017 when we visited Puri, a coastal city, in eastern India. On the fall of evening, the beach side road was bustling with tourists as my parents hopped from one shop to another, testing their price negotiation skills with the local shopkeepers. While my parents were busy in their shopping spree, I was having a fun time clicking pictures of some beautiful handcrafts in a souvenir shop, with my camera. While clicking one of those pictures, something interesting caught my attention. I found out that some of the items hanging near a bright light bulb outside the shop had become a playground for stray dragonflies. This species of dragonfly is also known as the globe skimmer (Pantala flavescens) due to its long migratory flights [1]. Around a hundred of them swirled in a chaotic yet mesmerizing dance, basking in the warmth of the incandescent bulb. It was quite serendipitous to discover such a gathering of one of my favorite insects, the dragonfly, while I had a camera in my hand. Before continuing with the story, I cannot resist a brief digression to explain why dragonflies are my favorites as an insect species.

First of all, dragonflies are beautiful, with their large colorful compound eyes and their aerodynamic bodies, perfectly designed for flight (see some of my shots in Fig. 1). Additionally, dragonflies can control the flapping of their four wings independently, allowing them to take off vertically, fly in any direction—including forward, backward, right, left—and hover with unmatched precision. Moreover, while hunting, they can predict their prey's trajectory and make fine adjustments to their own, in real-time all while airborne. The secrets of their flight dynamics, mate selection, predation, and visual information processing are all awe inspiring, making me feel the true ingenuity of Mother Nature.

That evening, instantly I found myself capturing hundreds of close-up shots of these incredible insects. While taking these shots, I observed something very striking. In one of the shots, when I looked closely on the wings on the display screen of my camera, I noticed the insect's wings had a faint opaque blueish pattern (see Fig. 2 (a)). It was quite surprising for me, because I always thought dragonflies had transparent wings. Then I had a look with my bare eyes at those insects. Yes, their wings were transparent to my naked eye. What, then, was that bluish pattern that my camera was displaying on the wings? Trying to answer this question I came across one of those feelings where I realized scientific research is no short of being in the shoes of a detective, trying to solve a case where the answer is apparently omnipresent, yet invisible to the common eye (pun intended). After thinking for a while on this, I had a closer look at some of the other images of dragonflies I captured the same day. I found out that in some of those images, the blue pattern was visible, while it was not present in the rest. For example, in the shot shown in Fig. 2 (b), we do not see the characteristic pattern clearly as seen in Fig 2 (a). In fact, the lower right wing in Fig. 2 (b) seems completely transparent. So, what was going on?

That evening, instantly I found myself capturing hundreds of close-up shots of these incredible insects. While taking these shots, I observed something very striking. In one of the shots, when I looked closely on the wings on the display screen of my camera, I noticed the insect's wings had a faint opaque blueish pattern (see Fig. 2 (a)). It was quite surprising for me, because I always thought dragonflies had transparent wings. Then I had a look with my bare eyes at those insects. Yes, their wings were transparent to my naked eye. What, then, was that bluish pattern that my camera was displaying on the wings? Trying to answer this question I came across one of those feelings where I realized scientific research is no short of

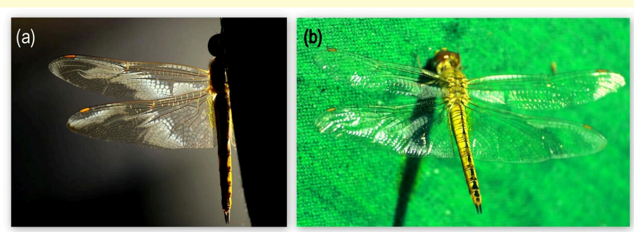

Fig 2: Two different shots of a dragonfly (Pantala flavescens) from two different illumination angles.

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The first clue came when I noticed that the blueish pattern appeared when the line joining the light source and dragonfly's wing was at certain angles to the line joining the wing and the camera lens (see Fig. 3). Does it ring a bell? The first thing that came to my mind was Mie scattering. Mie scattering describes how a small particle (typically dielectric) scatters incident light in different directions. The amount of scattering depends on the angle by which it is being scattered. In other words,when a small dielectric particle is illuminated by a beam of light, it scatters varying amounts of light at different angles. Also, an important aspect of Mie scattering is that it is efficient when the wavelength of the light is of the same order of magnitude as the size of the illuminated particle. Thus, if this blueish pattern on the dragonfly's wing was due to some small structures present on the wings of the dragonfly, those structures must have been similar in size to the wavelength of the incoming light (visible spectrum : 400 nm to 700 nm). In this case, the incoming light was in the visible spectrum, with wavelength ranging from 400 nm to 700 nm. I immediately remembered, a professor at IISER Kolkata once told us in our classes about nanostructures found in the feathers of a peacock. He said that a peacock's

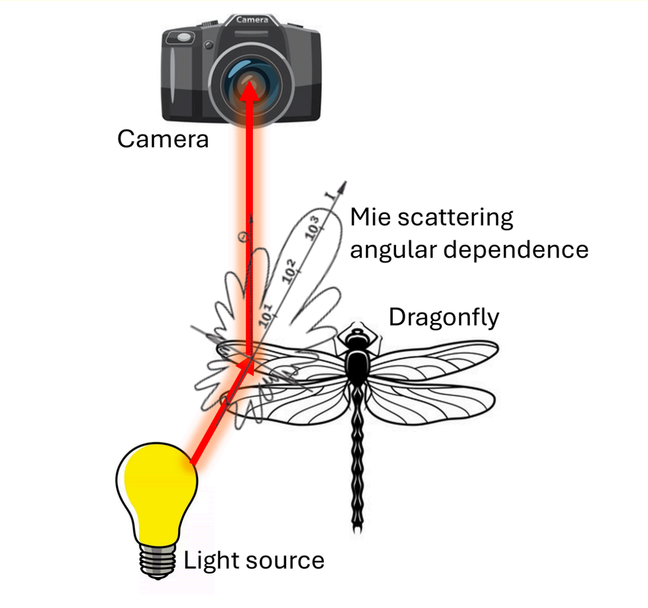

Fig 3: Illustration of angular illumination of the dragonfly's wing and the angular strength of Mie scattering.

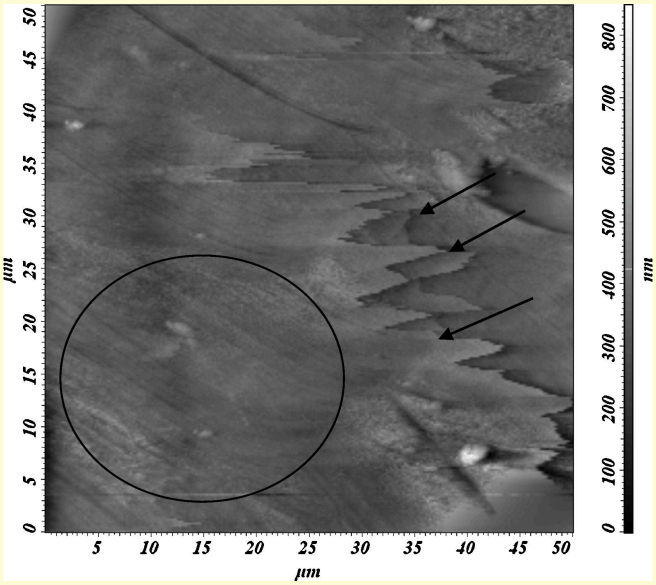

Fig 4: Atomic force microscopy image of a dragonfly's (Sympetrum vulgatum) hind wing, depicting a multilayer arrangement. Reproduced from [3].

blue color does not come from pigment but instead results from light scattering by nanostructures. The same principle applies to some species of blue butterflies. Could the dragonfly's wings be exhibiting a similar phenomenon? It was time to find out!

To investigate further, I turned to Google Scholar. I found a few papers that studied the structure of dragonfly wings and to my surprise I found ample evidence of the presence of nanostructures on their wings [2,3]! In fact, dragonfly wings contain nanoscale pillars, ridges, and pores composed of chitin, often combined with a thin wax coating. An example is shown in Fig. 4, where an atomic force microscopy image from [3] is shown, indicating multiple nanoscale layers (see arrows) and a "ripple wave morphology" (see circular region).

But then shouldn't the dragonfly wings look blue all the time, like peacocks, rather than only from a particular angle? Maybe not. Here I remembered that those faint blue colors on the dragonfly's wings were not conspicuously visible to my bare eyes. I could only see them through the camera. This might suggests that these colors were outside the visible range of my eyes but detectable by my camera.The Canon EOS 1200D camera I used has a CMOS sensor which is capable of detecting wavelengths from approximately 350 nm to 1000 nm, though infrared wavelengths are often filtered out optically. As a result, the camera can detect wavelengths slightly beyond the blue end of the visible spectrum. This suggests that the scattered light had a spectral signature just outside the visible range but still within the CMOS sensor's detection band. Interestingly, a paper suggested that non-iridescent, angle-dependent color formation can occur at wavelengths between 350 nm and 500 nm due to electromagnetic resonances caused by the random aggregation of silica nanostructures. However, whether this is the same mechanism for the dragonfly wings, needs to be verified through a detailed scientific investigation. Another interesting question that came to my mind was about the visibility of these patterns to other dragonflies. It is true that humans cannot see shorter than 400 nm wavelength on the blue side, but what about the visible range of dragonflies? It turns out that dragonflies have a particularly sensitive vision in the wavelength range of 300 nm to 500 nm [4,5], and body and wing colours carry important visual cues influencing their behaviour [5]. Which means one dragonfly should be able to see the patterns on another one. Perhaps this is why they were hovering around the bright light source, where they can see those structures in its aesthetic eminence. Or maybe those nanostructures play a role in their mate selection? In fact, research on the structural properties of the wings of a dragonfly witnessed a boom in the past decade. The wings' nanostructures revealed anti-bacterial properties [6,7], opening potential application avenues in biofilm design for medical implants [8] or even in the food processing industry [9]. In a world of emerging technologies, I strongly believe in the potential of the dragonflies to inspire the next generation of biomimetic innovations.

Debanuj Chatterjee is a Marie Curie postdoctoral researcher at the PhLAM lab in the University of Lille, France, working in the domain of light matter interaction, nonlinear fiber optics for development of advanced spectroscopic techniques. He obtained a PhD in Physics from Université Paris-Saclay, France in 2021. Curious as a scientist, he often finds himself treading down the alleys of history in search of philosophical, scientific and artistic aesthetics.

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Insight Digest

Summarising The Frontiers In Research

Earth has its own electric field weaker than a pencil battery

Collinson, G.A., Glocer, A., Pfaff, R. et al., Nature 632, 1021–1025 (2024)

Contributed by **Chitradeep Saha (CESSI, IISER Kolkata)**

Our planet Earth also has a global electric field – as fundamental as its gravity and magnetic fields. Researchers have successfully measured this electric field for the first time. The quest started over half a century ago when a steady stream of outgoing plasma particles was detected near the Earth's poles. Theories have been proposed and refined over time to understand this peculiar phenomenon. Peculiar. Because the temperature of the outflowing plasma is too cold to evaporate due to solar radiation. Therefore, existing knowledge of global energy fields failed to explain it. Alternatively, the existence of an independent, electric field was hypothesized. However, more mature technology was required to make precise measurements and test the hypothesis. The research team flew a suborbital rocket through the arctic skies that touched the exosphere while sampling various ionospheric properties. The photoelectron spectrometer onboard detected a minute change in electric potential of 0.55 volts – less than that of a standard AA battery – across an altitude range of ~500 km, confirming the existence of such a global electric field. Due to an asymmetric gravitational pull on the lighter electrons and heavier ion cores, charge separation occurs in the atmosphere. The Coulombic force partially counteracts this charge separation; the associated electric field is ambipolar, as it works in both directions. The net effect of this global ambipolar field is to puff up the atmosphere, lifting some ions high enough to escape through the polar caps and giving rise to polar winds.

Mapping Strain in Laser-Written Diamond Waveguides Using Optically Detected Magnetic Resonance

Phys. Rev. Applied 22, 024055 (2024)

Contributed by **M. Sahnawaz Alam (RWTH Aachen University, Germany)**

Color centers in diamond, such as the nitrogen-vacancy (NV) center—which consists of a nitrogen atom adjacent to a vacancy in the carbon lattice—are renowned for their exceptional quantum properties, making them ideal candidates for applications in nanoscale sensing and quantum information processing at room temperature. However, NV centers often suffer from low contrast in experiments, which hampers their performance and limits practical applications. Integrating NV centers with laser-written optical waveguides enhances the coupling of light to these quantum systems, facilitating more efficient manipulation and readout of their states. This integration addresses the low-contrast issue by improving the interaction between NV centers and light. However, the process of laser writing photonic structures inherently introduces strain into the diamond lattice. This strain can alter the electronic and spin properties of the NV centers, affecting their performance and the fidelity of quantum operations. Until now, the full impact of this strain on defect centers has not been thoroughly understood. In our combined experimental and theoretical study, we demonstrate that optically detected magnetic resonance (ODMR) spectroscopy—a technique commonly used to probe the spin states of NV centers—provides sufficient information to fully characterize the spatial distribution of strain within laser-written diamond waveguides. Remarkably, this characterization is possible even without the application of an external constant magnetic field. Our findings present an accessible and non-invasive tool for mapping strain in diamond-based photonic devices. By utilizing ODMR spectroscopy, researchers can gain detailed insights into strain distributions, enabling the optimization of device fabrication processes and the improvement of quantum device performance. This advancement is a significant step forward in the development of diamond- based quantum technologies, potentially impacting a wide range of applications from high-precision sensing to quantum communication and computation.

GWTC-3: Compact Binary Coalescences Observed by LIGO and Virgo during the Second Part of the Third Observing Run

R. Abbott et al., Phys. Rev. X 13, 041039 (2023)

Contributed by **Swarnendu Saha (CESSI, IISER Kolkata)**

This paper, “GWTC-3: Compact Binary Coalescences Observed by LIGO and Virgo during the Second Part of the Third Observing Run”, is an excerpt from the third Gravitational Wave Transient Catalog. The report was published in December 2023 in the journal Physical Review X that reports on observation of gravitational waves by the LIGO, Virgo, and KAGRA for the second half of the period of the third observing run. The interval covered is from November 1, 2019, through March 27, 2020. Our very own Professor Rajesh Kumble Nayak has been a part of this team from IISER Kolkata.

 The paper also lists 35 new gravitational-wave events detected during that period, all the result of a "compact binary coalescence" in which pairs of black holes or neutron stars orbit ever tighter until they eventually merge. This brings the number of gravitational-wave detections across three observation runs to 90. Most of the events in the catalog arise from the merger of black holes, which can be pretty large, but this observing run also marks the first definite identification of neutron star–black hole (NSBH) mergers. Curiously, however, no BNS mergers were confirmed during this period.

 The researchers selected these signals with advanced algorithms and data calibration, estimating probabilities for each event to be of astrophysical rather than noise artifacts. As there is always some inevitable noise, the probability for these signals to be due to a non-astrophysical origin is estimated to be around 10-15%. All the data are made available in the public domain for use by the community through the Gravitational Wave Open Science Center. The expanding dataset from GWTC-3 gives unparalleled insight into the properties and behaviors of black holes and neutron stars, offering unique insights into the population in the universe and providing informative input into the theory governing their formation, structure, and evolution.

Strange Metal and Quantum Spin Liquid in Heavy-Fermion Material: An Array of Exotic Phases

Hengdi Zhao et al., Phys. Rev. Lett. 132, 226503 (2024)

Contributed by **Abhirup Mukherjee (IISER Kolkata)**

Strange metals and spin liquids constitute deviations from the "standard model" of condensed matter physics. For most of the twentieth century, metals were believed to be smoothly connected to non-interacting electrons at low- energies (the so-called Landau's Fermi liquid theory), and insulators and superconductors were believed to arise from spontaneous symmetry breaking (the ground state does not have all symmetries of the Hamiltonian). Violations of these ideas were observed in the 1980s, a notable example being the discovery of high-temperature superconductivity in copper oxide materials. The strange metal phase of the copper oxides, while being a metal, displayed a linear-in- temperature resistivity, in contrast to the quadratic-in- temperature resistivty of Landau Fermi liquids. Due to the large transition temperature of the material and the proximity to an electronic-correlation driven Mott insulator, Phillip Anderson hyppthesised that the ground state of the Mott insulator was close to a "spin liquid", where the system does not settle into any particular configuration (in contrast to the symmetry-broken insulators) but keeps shifting (in the sense of a quantum superposition) between various configurations.

 While these exotic phases typically emerge in different materials, the authors of the present work have experimentally realised these exotic phases in crystals of the material Ba4 Nb1-xRu3+xO12, where x is the hole- doping concentration. By tuning the doping concentration, the material undergoes transition from a heavy strange metal phase to a heavy Fermi liquid phase to finally a spin liquid phase. The "heaviness" arises from the fact that these are heavy-fermion materials in which the inter-electron interactions increase the "inertia" of the quasiparticles. Other results suggest that the excitations in all three phases are described by spinons - spin-1/2 charge-neutral objects. These spinons are fractionalised excitations (to see why, recall that flipping a spin from -1/2 to 1/2 creates a spin-1 excitation). At the heart of these exotic phenomenon in this material is the underlying triangular lattice that leads to geometric frustration (it is not simple to obtain an energy-minimising configuration of spins on this lattice) and the emergence of novel elementary excitations (the spinons). Such a material provides a wonderful platform to realise and study these highly-correlated phases of matter.

General Science Quiz

The theme for this issue's quiz is Astronomy. Enjoy.

Q1. This Nobel Prize-winning physicist has an element named after him. His wife, upon being shown the results of his experiment for the first time, said, 'I have seen my death!'. Who is the scientist?

1. Wilhelm Roentgen
2. Pierre Curie
3. Henri Becquerel
4. Enrico Fermi

Q2. *Dr Dilip Mahalanabis*, an Indian paediatrician, is famous for pioneering one of the most important medical advances of the 20th century that dramatically saved lives during the cholera outbreak in Bangladesh in 1971. What is this medical advancement?

1. Vaxchora vaccine
2. Oral rehydration solution (ORS)
3. Zinc supplementation
4. Ringer's lactate

Q3. This physician was one of the pioneers of plastic and dental surgery, and was one of the first to attribute malaria to mosquitoes. The *Royal Australasian College* of Surgeons at Melbourne has a statue in his honour. Who is he?
1. Sushruta
2. Hippocrates
3. Herophilus
4. Dioscorides

Q4. As part of the National Quantum Mission, this Indian research institute is leading the efforts to create a 100-qubit quantum computer, and recently completed end-to-end testing of a *6-qubit processor*, in collaboration with DRDO and TCS. Name the research institute

1. Indian Institute of Science Education and Research Pune
2. Indian Institute of Science (IISc), Bengaluru
3. Tata Institute of Fundamental Research (TIFR), Mumbai
4. Raman Research Institute (RRI), Bengaluru

Q5. Diamond is traditionally known to reside at the top of Mohs' scale of mineral hardness since it can scratch all other minerals on the scale. However, scientists in modern years have discovered other materials that are in fact harder than diamond, and would go above diamond in a modern Mohs' scale. Name such a naturally-occuring mineral.

1. Lonsdaleite
2. Boron carbide
3. Moissanite
4. Cubic boron nitride

Q6. *In Nomine Terra Calens* is a music piece composed by Dr Lucy Jones by converting scientific data from the past 138 years regarding a major global issue into various musical notes. The musical piece was performed by Jones and the Los Angeles Baroque at the Los Angeles Natural History Museum in 2019. What global issue was being studied?

1. Global warming
2. Shortage of drinking water
3. Depleting energy sources
4. Increasing air pollution levels

Q7. *Kamala Sohonie* was the first Indian woman to be conferred the degree of PhD, for her ground-breaking work on the electron transport chain. However, she was initially refused admission to one of India's premier research institutes by the institute's director, simply because she was a woman! Who was the director?

1. C V Raman
2. Homi J Bhabha
3. Shanti Swarup Bhatnagar
4. Vikram Sarabha

Q8. String theorists at IISc recently found a series representation of a certain irrational number, while studying quantum scattering of high-energy particles. *Ramanujan* has also worked on representations of this number. Which number are we talking about?

1. π
2. Euler's number e
3. The golden number φ
4. Euler–Mascheroni constant γ

Q9. *Hennig Brand* was a German alchemist who, while searching for the 'philosopher's stone,' discovered a new material that gave off a pale-green glow by concentrating boiled-down urine. What was this new element?

1. Zinc sulphide
2. Strontium aluminate
3. Sulphate
4. Phosphorus

Q10. This 20th century European mathematician, during a US citizenship test, claimed before Judge Phillip Forman that the US constitution had a loophole that could reverse democratic government itself. His theorems in mathematical logic are referred to by his name today. Who is he?

1. André Weil
2. David Hilbert
3. Georg Cantor
4. Kurt Gödel