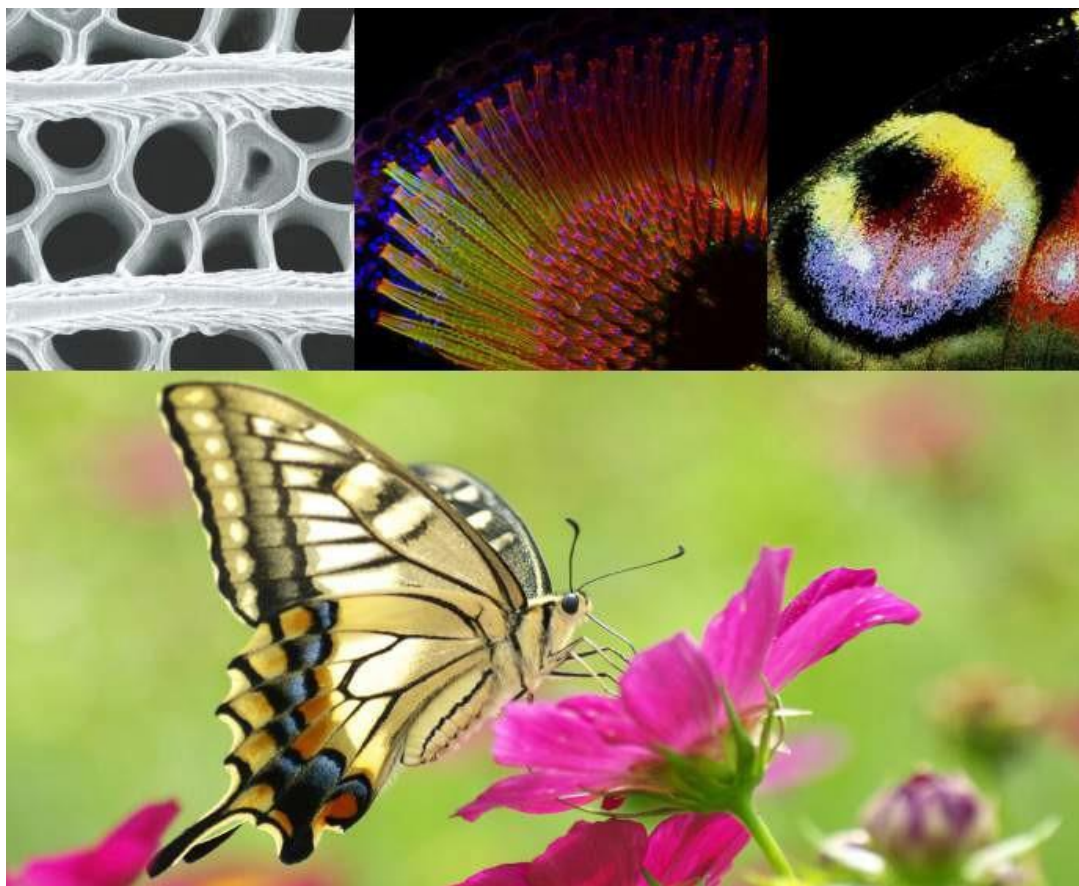


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NANOWORLD

The key to our survival

*A **UHD** 52' documentary*

Directed by Pascal Moret et Julien Guiol

Produced by French Connection & La Belle Société

PROVISIONAL DELIVERY: JUNE 2020

PITCH

Nature is an inexhaustible source of knowledge. After 3 billion years of evolution, it has created amazing mechanisms, even at a microscopic level, that allow plants and animals around us to protect themselves, to grow, to move or to face the attacks of the elements.

This "nanoworld" questions our imagination with its beauty and intelligence. Scientists have finally managed to unravel its mysteries, thanks to photonics. Let's take an unprecedented journey into this other dimension, in which nature-inspired solutions are found to meet the ecological and climatic challenges that threaten us.



Detail of a butterfly's wing

INTRODUCTION

Ever since the emergence of life on earth 3.8 billion years ago, living things have been constantly evolving and adapting to their environment in order to survive as species.

But how have living organisms managed to survive the four vital elements: fire, earth, water and air?

What solutions have they acquired to deal with these potentially life-threatening problems?

For a long time, the ingenuity of nature escaped us because it triumphs at microscopic level using natural nanostructures that allow animals and plants to grow, live and survive every day. It is essential for us, as humans, to understand these nanostructures before they disappear. They are part of the structural foundations of all living things. They remind us of the urgent need to decipher and use nature to help us tackle the climatic, demographic and ecological challenges we are facing.

The aim of this film is to change the way we look at nature on a nanometric scale. In most cases, nature chooses economical and ingenious solutions, based on non-polluting, natural energy and renewable resources. In many ways, nature's solutions are different to the ones we have chosen, but they can show us where to direct our efforts and technology. Faced with the current threat of seeing 54% of all living organisms disappear from our ecosystems, we urgently need to study and unlock nature's mysteries and secrets.



DEFINTION OF NANOSTRUCTURES

According to Serge Berthier, an eminent specialist on nanostructures in living things, *"In nature, we see everything as obvious or 'natural'! The butterfly has wings and it flies, the fish has fins and it swims... Behind this apparent simplicity are extraordinarily complex processes. Flying, swimming, crawling, feeling, gripping, being coloured or transparent, walking on water... none of this would be possible without natural nanostructures."*

Nanometric structures are one level up from the molecule. They are the first surface between the inside and the outside of a living organism. They unveil themselves to the human eye in iridescent colours and reveal astonishing living organisms.

The science that studies nanostructures is called photonics. Thanks to photonics, we can now observe, analyse and understand their natural multifunctionality. By going to discover what they do in nature, we are entering the mechanics of an invisible new world on a microscopic scale.



DIRECTOR'S NOTE

Our film will contain images that will take us to heart of these nanostructures. It will be a journey of discovery into this microscopic universe with three-dimensional reconstitutions to help us understand what nanostructures actually do. The film will take the viewer inside these structures to experience this adventure as a great spectacle. We will play with the scale that we use to qualify living things, by regularly passing through five different points of view: an aerial point of view to put the species back into an environmental context, the human scale with a team scientists going out to collect and study specimens in the field, then, at the scale of living things containing nanostructures.

To reveal the nanostructure, we use an accelerated zoom-in which will take us through different surface layers of the animal or plant down to the nanometre. The permanent collection at the MNHN (Muséum National d'Histoire Naturelle) will allow us to reach this nanometric surface of the species we are observing. Then, using a 3D reconstruction of the structure, we will be able to move around with the camera, like a space ship exploring a new planet. A nanometric microscope will let us observe the nanostructure in three dimensions and better visualise its form. Added to all of this will be explanations of multifunctionality using 2D and 3D animation over real images.

Each living species we look at reveals a different nanostructure that gives it survival functions against the elements. There will also be amusing anecdotes about certain living things. We will bring up examples of existing or potential bio-inspirations. The aim is to present great discoveries made at this scale in nature without going into exhaustive analysis or cataloguing.

The creation of an original sound-design will help bring us closer to these nanoworlds. The music will accentuate the sense of wonder as we discover the nanostructures.

THE MOVIE



FIRE

Belgian scientist Jean-Pol Vigneron studies the behaviour of certain animals in sunlight: *"The sun, our gigantic star, provides us earthlings with light and energy. Without those rays, without that flow of energy, there would be no life. And yet we all know that staying in the sun too long is a sure-fire way to get sunstroke and potentially dangerous sunburn. To ward off ultraviolet rays and protect ourselves we apply sunblock. Most animals can rely on the melanin present in the surface of their skin. But this is not the case for all plants, particularly those from high-mountain environments."*

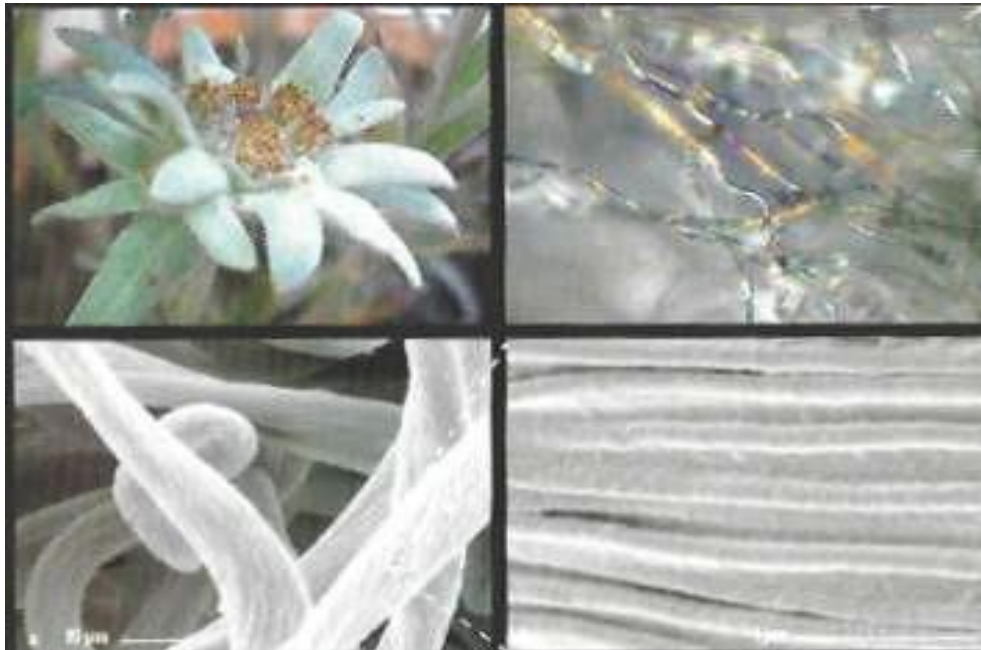
"We know that the intensity of UV rays increases with altitude, about 5 to 10% per kilometre. A flower such as edelweiss manages to absorb the majority of those rays, thus protecting vital cells in its pistil and its stamen which it needs for reproduction. How does this plant achieve this feat? »

Edelweiss or *Leontopodium nivale*

Leontopodium nivale, commonly called **edelweiss**, is a protected species of plant with a white flower found in mountainous regions of the northern hemisphere. Covered by a cotton-like translucent down formed by overlapping, very fine, short ridged hairs. The ridges are composed of clusters of long cylindrical filaments standing parallel to each other to form a relatively regular grid.



The surface of the hairs on the edelweiss plant is graduated with small pointed mounds evenly spaced around the circumference of each hair. Jean-Pol Vigneron explains the importance of this discovery: *"The distance between these structures is the same as the wavelength of UV-A rays. Thanks to this wall, formed by these tubes, part of the UV light is absorbed and the other part is rejected. The sun's UV rays penetrating the hairs are weakened and then gradually absorbed by these filaments. By the time they reach the plant's vital cells, the power of the UV rays is considerably diminished."*



Edelweiss has found an ingenious way of progressively eliminating the harmful effects of ultraviolet radiation. The challenge now is to create a similar natural system to protect our skin. This is particularly important when we know that levels of UV radiation are rising and will continue to do so. A natural system like this would be healthier than current sun screens based on titanium dioxide particles which present certain toxic substances that can be absorbed by the skin.

The edelweiss principle also interests scientists who are working on developing the solar panels of the future. UV rays do not carry enough energy to produce electricity by activating electrons at the heart of the solar panel. In addition, they create unusable heat. By adding a layer which imitates the mechanism in edelweiss hairs, researchers hope to capture the UV rays before they reach the heart of the panel. Protected from the UV rays in this way, those panels would produce a much greater output than the ones we have today.

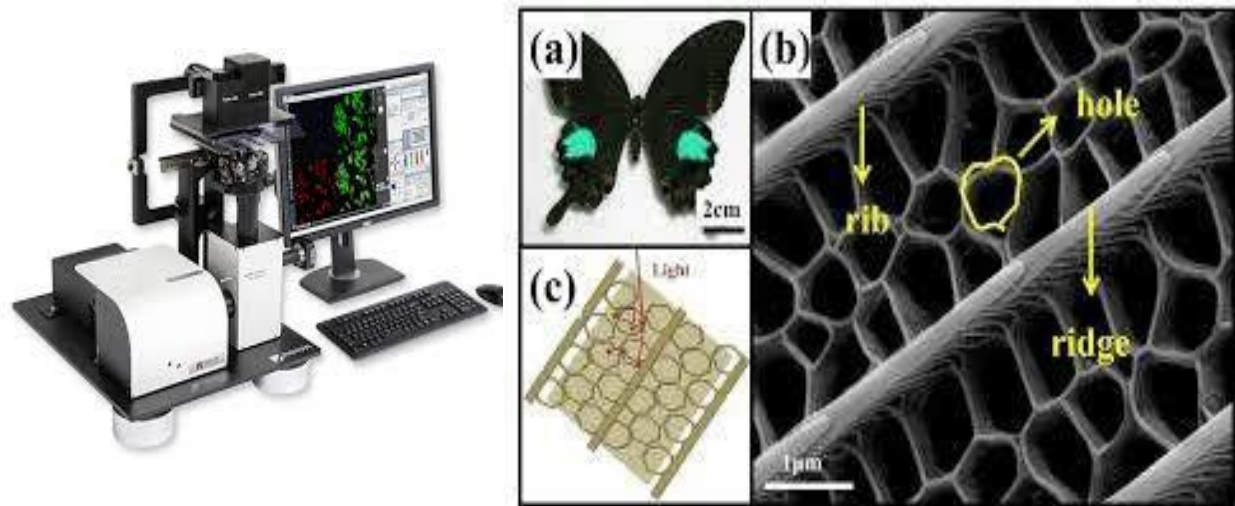
The lizard and the butterfly, photo-thermal collectors

In a valley, the rocks store heat and the head of a lizard appears between two stones. The creature is caught by Serge Berthier, who explains the **lizard's ability** to become a photo-thermal collector.



"When his temperature is too low, he positions himself perpendicular to the sun's rays in order to store the maximum amount of heat, i.e. solar energy. But when the sun is too strong, the lizard moves slightly and positions himself in line with the sun's rays. As these rays always strike at an angle, this minimises the energy received per unit area and increases the reflection coefficient. But how does this process of heat absorption or reflection happen at microscopic level?"

Thanks to a nanoscope and integrated software, the fruit of 50 years of research, a 3D image of the nanostructure now appears on the computer screen.



"Numerous living things have evolved anatomies that optimise solar radiation management. The lizard is a perfect example. No need to reflect sunlight when he gets too hot, he just has to change position. The **cabbage white**, is a butterfly most of us can find in our gardens. Like the lizard, it has found a novel way of protecting itself from overheating. Its nanometric structure is a veritable light trap, guiding rays of light onto its walls until they are completely absorbed without overheating the insect."

EARTH

Two fish are gulping air beside the river. Serge Berthier watches them.

"For animals, leaving the water was not without its dangers. The constraints of aquatic life are not the same as life on land. In the ocean, water envelops the animal from all sides, with Archimedes' buoyant force opposing weight. On land, contact with the ground is tough! Some areas are perfectly smooth and slippery, others are formidably rough. Some even give way when you press down on them. How have crawling animals like lizards and snakes adapted to this?"

Snakes, lizards and frogs, ingenious ways of getting around

Snakes have developed a mode of locomotion that uses either undulation or rectilinear movement depending on ground surface and desired speed. Pushing off from the tip of their tail, they are able to roll out their entire length in a fraction of a second. The secret behind how snakes crawl is in the scales that cover their bodies.



German researcher Konrad Staudt explains how the shape of the scales changes according to their position on the snake's body. To move, the snake anchors part of its body in the ground so it can propel itself forwards: the scales are all aligned in the same direction, towards the rear, so they dig into the ground when the snake pulls backwards and then slide when it pulls forward.

This anchoring effect is created in part thanks to the general shape of the scales and their distribution. They overlap like tiles on a roof, with the tip pointed towards the rear of the animal. The structure of their surface is covered with tight, relatively regular rows of bumps one micrometre long and two hundred nanometres in diameter, all pointing towards the rear of the animal.

But how can they withstand daily scraping against the ground, which is mostly very abrasive and likely to pull particles from the snake's scales through rubbing?

"Sand has an interesting characteristic. It is electrostatic. And it is precisely this characteristic that the snake uses. At the microscopic scale, the extremities of its nanostructure interact with the electrostatic field of the sand, allowing it lift up from the ground. The snake levitates, reducing skin abrasion from the ground."

Konrad talks about the advantage of being able to use electrostatic forces to move objects very quickly without any contact on a surface. This is the principle behind levitating trains, which were tested in Europe and recently put into practice in the USA and Japan.



The shell of the **tortoise** is an excellent means of protection thanks to the strength of its chitin based scales. Like the ordered structure of nacre (mother-of-pearl), a tortoise's shell is composed of 10-20 micrometre-wide platelets of aragonite. In the event of an impact, these platelets can slide sideways. As a result, the mechanical energy of the impact is dissipated, preventing cracks from propagating inwards.

The study of nanostructures in tortoise shells brings us to one of the three great principles of all living things: complexity. The regularity of nanostructures is never perfect, because these processes are subjected to random exterior forces of pressure and temperature. They are in fact poorly ordered structures. And this turns out to be an advantage in the world of living things. In many cases, they prevent one function overriding the others and also guarantee the robustness of the results, i.e. their relative insensitivity to reasonable fluctuations in the environment. The disorder of natural nanostructures is, without a doubt, the hardest property to reproduce.

Inspired by the nanostructures in nacre and tortoise scales, researchers at McGill University in Montréal developed a deformable glass that was 200 times stronger but the same thickness as standard glass. By imitating micro fissures in tortoise and oyster shells, it retains all of its strength and can deform without breaking in the event of an impact.

WATER



"Whether too scarce or too abundant, water, this most vital of elements, constantly presents life-threatening problems to living organisms. Certain structures have emerged to help these organisms move around in it, live in it, capture it or evacuate it, evolving at every scale. Natural nanostructures bring into play numerous principles of physics which are based on the peculiar behaviour of the water molecule, similar to a small electric dipole. One consequence of this is the strong surface tension of water. It is a property which can benefit some creatures and prove deadly for others. It is a property which opens up a huge range of possibilities."

The bug that walks on water



Two members of the expedition have just caught a **Gerris Lacustris pond skater**. Like the Dolomedes spider, this insect is capable of walking on water. Its nanostructure traps air molecules to its body. This little cushion of air allows the Gerris to move across the surface of the water. Its nanometric makeup has given it hydrophobic legs. As a result, the water gives under the weight of the insect and it does not sink.

The diving spider

For living things not blessed with gills, such as the **aquatic Argyroneta spider**, surviving under water is a real challenge. It gets around its air supply problem using nanometric structures that make it highly hydrophobic and by being able to construct a bell of air to take below the surface. This means it can be entirely aquatic and it lives, hunts and breeds underwater.



First of all, its skin is highly hydrophobic. This kind of surface is difficult to get wet. Instead of spreading out, a droplet of water placed on such a surface tends to avoid contact with the solid, holding itself together as much as possible until it is only touching the surface at a single point by forming a perfect sphere.

This spider is also able to trap air on its abdomen, which is covered by a veritable coat of long, overlapping, silky hairs unevenly arranged over its very rough cuticle. This surface traps air and holds the air bubble to the animal. The spider descends at a constant speed so it does not lose the bubble. Well before Edmund Halley, in 1690, this little spider had already invented the diving bell.

In countries that lack water, being able to produce hydrophobic surfaces, materials or metals is a considerable advantage. Stains and impurities find it harder to attach themselves to clothing and coatings. This reduces the need for constant washing and, as a result, reduces water wastage. It applies not only to clothes and textiles but also to metals, tiles and coatings used in healthcare, kitchens, bathrooms, etc.

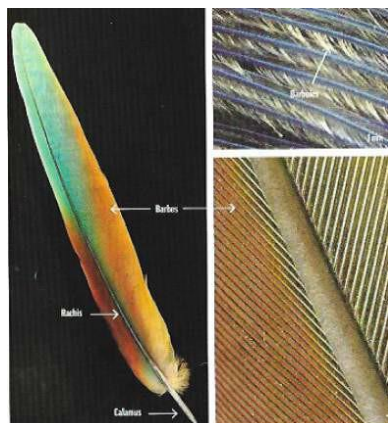
AIR

"Life first appeared in water several billion years ago. Since then, organisms have progressively emerged from it, filling the air with sounds, smells and colours. Light, sound waves, odorous molecules: all of these things are spread and carried in the air, a delicate blend of gases to which living beings had to adapt. Natural nanostructures have also evolved at the frontier that separates living beings from the air, i.e. at skin level. But what direction has this taken?"



The feathers of the red kite are light, robust, hydrophobic and aerodynamic. It is this combination of characteristics that enables the bird to fly and survive.

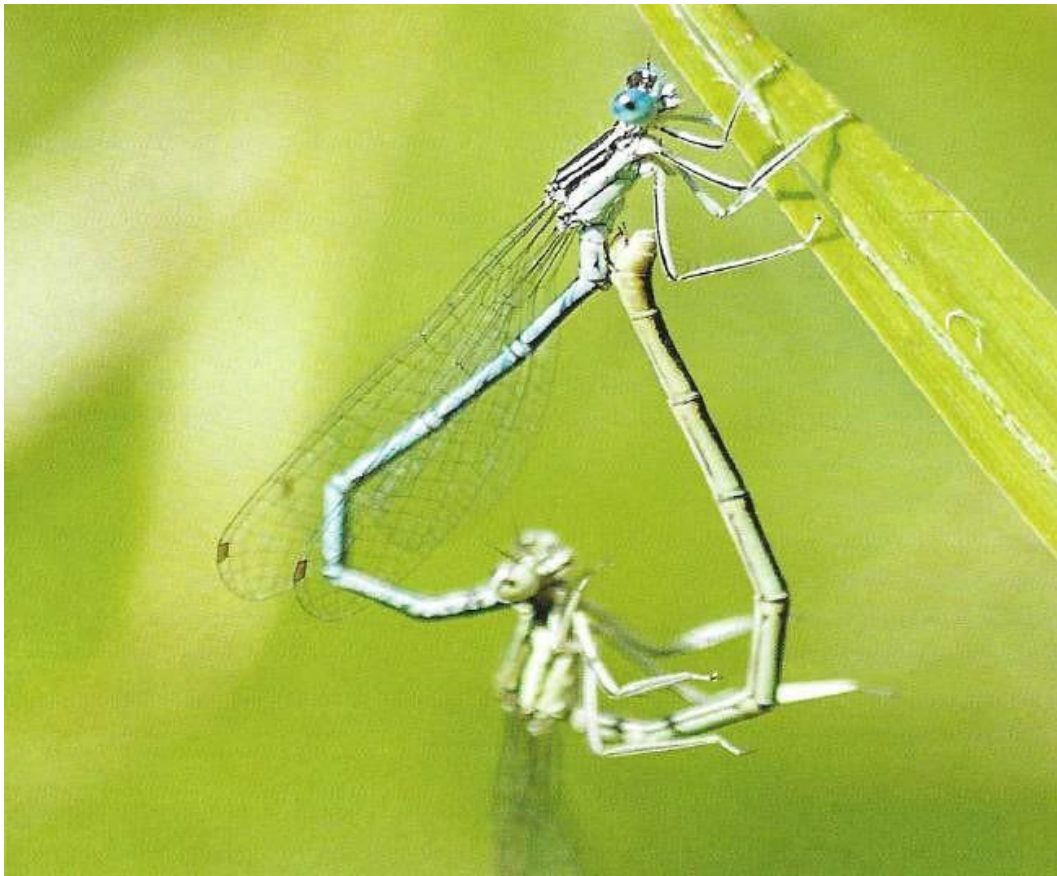
Airplane manufacturers have been studying birds for years. It has helped them to design curved wings to increase aerodynamics and reduce airplanes' carbon emissions by 20%. The wings of the future will be lighter and stronger still. Inspired by nature, humans seek to reproduce it with materials that imitate organic surfaces.



Clinging on to copulate

There are species of dragonflies which join together to form an upside down heart shape when the female and the male reproduce.

Dragonflies reproduce in flight, and their external genital organs must remain in close contact for the duration regardless of the hazards of flying. Scientists are very interested in the nanostructures that help dragonflies to do this, as they offer new perspectives on flexible, temporary and reversible adhesion methods, on a very small scale. 3D animation allows us to see the hooks and hairs on the insects' abdomens which allow them, quite literally, to hook up mid-flight.





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