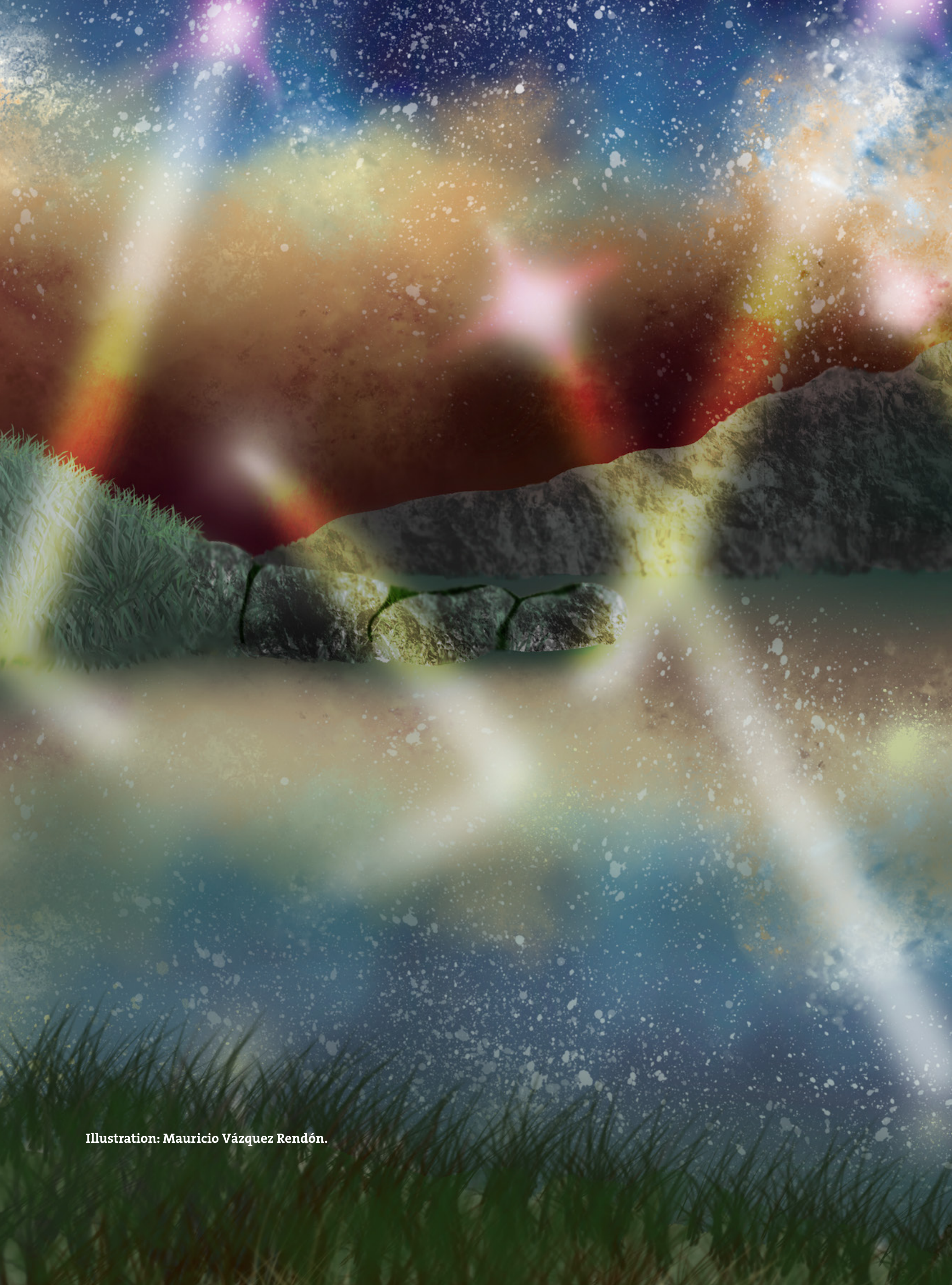

Illustration: Mauricio Vázquez Rendón.

Behind Natural Negative Refraction

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Mathematical models allow us to describe what happens on very small scales. In this research, they were used to explore how light would behave when interacting with a gas in which electrons are free and to answer whether this interaction could naturally cause negative refraction.

It's a hot day. The bright sunshine makes the weather perfect for a dip in the pool. Suddenly, we notice a coin at the bottom of the pool. We try to locate it and dive in to pick it up. The moment we dive in, we realize that it is not exactly where we thought it was.

The explanation for this phenomenon is that the light that reaches our eyes does not follow a straight path but is deflected when the medium in which it propagates changes, for example, when it passes from water to air. This phenomenon is known as **refraction.**

The deflection of light in a different medium is, in a way, something close to our senses because we can witness it every day in various ways, such as when we put a pencil in a glass of water and see it "break". Light does not follow the trajectory that minimizes the distance, but the one that makes the travel time minimum. And although physicists have managed to understand the mechanism of refraction, we are still not entirely clear about many aspects related to another case: when light is deflected in the opposite direction. That is, the phenomenon of positive refraction occurs when light is refracted in the same direction in which it arrives, while negative refraction is when light is deflected in the opposite direction.

The idea of negative refraction was formulated by the Russian physicist Viktor Veselago, who in 1968 put forward the possibility of substances that could deflect light in the opposite direction to the original one. This opened the door to research into metamaterials both theoretically and experimentally because negative refraction leads to many other interesting optical phenomena and can be used to design devices such as antennas and lenses.

On the left is an example of positive refraction. On the right is a representation of what the refraction of light would look like if water were a metamaterial, i.e., an example of negative refraction. Image: Phys.org

In the 1990s, the American physicist John Pendry proposed the construction of the first metamaterial: a structure made of metallic rings that, under certain conditions, could recreate the phenomenon of negative refraction. In subsequent years, many modifications have been made to Pendry's model to develop antennas with better reception and transmission quality for signals such as radio or visible light. In addition, the possibility of implementing panels with metamaterials has been investigated to increase, for example, the processing capacity of technological devices such as computer processors and military applications to improve camouflage techniques.

Although it has been possible to design artificial metamaterials, we do not know of any natural one. For this reason, Universidad de Antioquia's Theoretical Group of Materials Sciences studied whether light could manifest negative refraction in a gas of electrons, called relativistic Fermi gas, considering that in recent years it has been postulated as a good candidate.

A relativistic Fermi gas is composed of electrons, which are considered non-interacting. This type of gas is found at high densities and temperatures, and is present, for example, in the plasma present in stars. When this gas interacts with light, electrons begin to vibrate and scatter the light in different directions. Under certain conditions, it may manifest negative refraction.

To understand how light is scattered by the presence of the gas, the equations that govern electromagnetic fields and special relativity are used. In addition, the behavior of the refractive index is studied. The refractive index is a quantity that determines the propagation of light

within a medium depending on several factors, such as temperature, particle density and incident radiation frequency. In the case of the materials we know, we find that the refractive index is a positive number, but in the case of metamaterials, it is expected to be negative so that negative refraction can occur.

In the case of electron gas, we find that the refractive index is a complex number, that is, it is neither a positive nor a negative number, and therefore, it cannot be concluded that negative refraction occurs. Despite the above, the fact that it is a complex number accounts for the amount of energy that light delivers to the particles and that is used in the creation of antiparticles in the gas together with the energy they acquire because of the temperature.

On the other hand, one of the most important results of the group's research is that a certain portion of the light that interacts with the electron gas does not deviate from its original direction, i.e., it propagates as if no particles were present.

In addition, it was found that, if the gas is under certain temperature conditions and the light incident on it has certain frequencies, the light wave may propagate in the opposite direction to the energy in the wave, which is one of the implications of Veselago's ideas. However, to have more precise conclusions, it is necessary to carry out experimental research to verify the theoretical results we obtained.

The results, although preliminary because of the lack of experimental corroboration, can also give us ideas about what happens in the interstellar medium and the stars. Moreover, since it is a relatively simple model with several considerations, the underlying physics is found to be valuable for the understanding of many phenomena and could be useful for industrial development. X

Experimentally verifying these results is very difficult because it would require recreating a system that is under the same conditions as the material of the stars and having the ability to measure how light behaves in the presence of the gas under very specific conditions.

Glossary

Antenna: part of a radio or television set from which waves are transmitted into the atmosphere or space.

Metamaterial: a type of material with properties that do not usually occur naturally, such as a negative refractive index.

Complex number: a number that has a real and an imaginary part.

Refraction: change of direction undergone by a wave when passing from one medium to another.