Light scattering on dust holds clues to habitability

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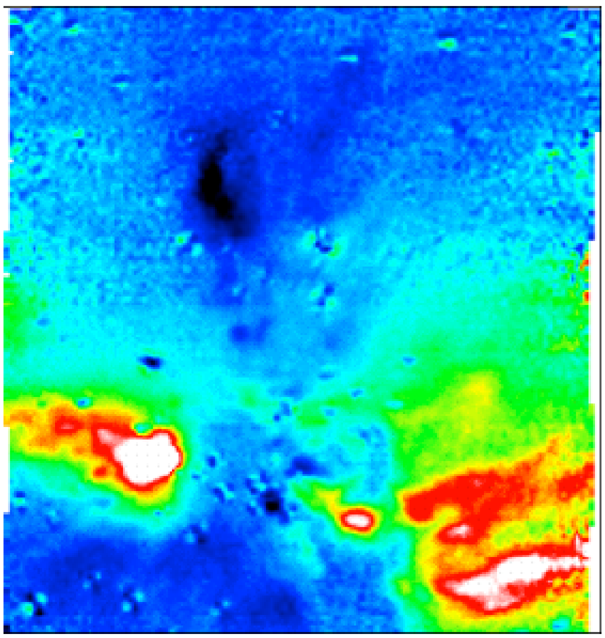


High circular polarization (the red and white regions in the image) observed in the infrared light from reflection nebulae in the star-forming region Orion OMC1 (Bailey et al. 1998). It is caused by alignment of the dust particles in magnetic field, but can be responsible for formation of homochiral organics in these dust particles. Credit: Bailey et al.

We are all made of dust. Dust particles can be found everywhere in space. Disks of dust and debris swirl around and condense to form stars, planets and smaller objects like comets, asteroids and dwarf planets. But what can dust tell us about life's potential in the Universe?

Astrobiologists study dust particles in space for many reasons. The behavior of particles in planet-forming disks yields clues about how planets form and evolve. Studying the composition of dust can help us understand the conditions that lead to habitability on those planets.

But how do you determine if dust contains molecules that may be important for the origin of life, or other materials that could be used to construct habitable environments?

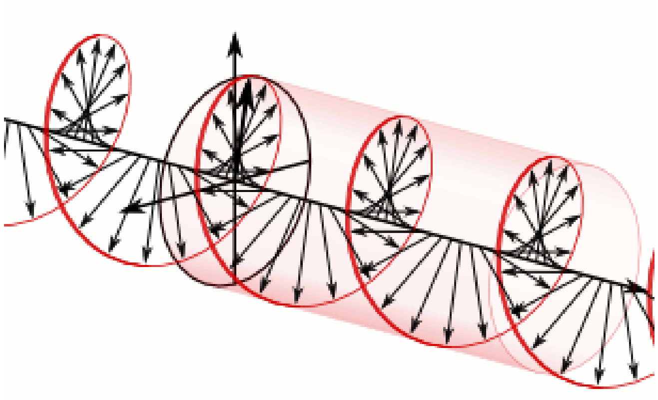
Shining the Light

Astrobiologists study dust in space by watching light coming from dusty regions. As a light wave interacts with the tiny particles, the light is scattered. This scattering causes changes in the light wave. These can include an effect called circular polarization (CP).

A light wave can be roughly imagined as a single line that wiggles up and down. If circular polarization occurs, this line rotates as the wave moves. On paper, the effect looks a bit like a slinky or an old-fashioned spiral telephone chord.

"Discussions on what causes circular polarization (CP) observed in dusty objects can be seen quite often in scientific papers," said Ludmilla Kolokolova, a senior research scientist at the University of Maryland's Department of Astronomy. "Among the most popular explanations of the CP formation are scattering of light on aligned elongated/irregular dust particles, or on the particles that contain homochiral molecules."

It's the potential role of homochiral molecules that makes this process particularly interesting for astrobiology.



The electric field vectors of a traveling circularly polarized electromagnetic wave. Credit: Wikimedia Commons

Chirality refers to molecules that are identical, but can exist in forms that are mirror-images of one another. It's similar to a person's left and right hands. They are both hands and are made up of the same five fingers, but the arrangement of the fingers defines each hand as either left or right. Homochirality means that even though both right- and left-hand forms of an object are possible, only one is found in the environment. This is often the case for some molecules used to build life on Earth.

Many molecules used in life—including sugars and amino acids—can theoretically exist in both left and right-handed forms. However, life on Earth has a preference for only one type. Amino acids, for example, are typically found in the left-handed form. The introduction of right-handed amino acids actually causes cells to die.

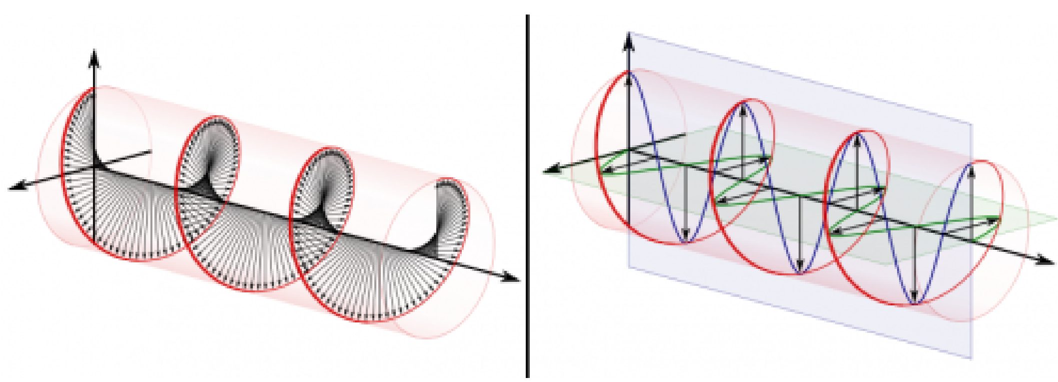
If light has passed through dust in space and experienced CP formation, it could tell astronomers whether or not that dust contains homochiral molecules, which could be an indictor of interest to astrobiologists.

Dust isn't only present in planet and star-forming disks. Comets in the Solar System shed dust as they orbit the Sun, and dust in the atmospheres of extrasolar planets can also affect light by reflecting it. Studying how CP occurs in each of these cases, and whether or not homochiral molecules are involved, could aid in the study of these astrobiologically significant objects.

"If we learn how to separate CP caused by alignment from CP caused by homochirality, we get a good tool in the search for pre-biological and biological materials in space, especially in circumstellar disks and exoplanets," Kolokolova told Astrobiology Magazine.

Raise Your Hand

Kolokolova and Lev Nagdimunov (an undergraduate when the study was made, and now a research assistant in Kolokolova's group at the University of Maryland) used computer models to study the behavior of light waves in order to see if they could spot a difference in CP caused by alignment of the light wave on elongated dust particles, and CP caused by interactions with homochiral molecules.



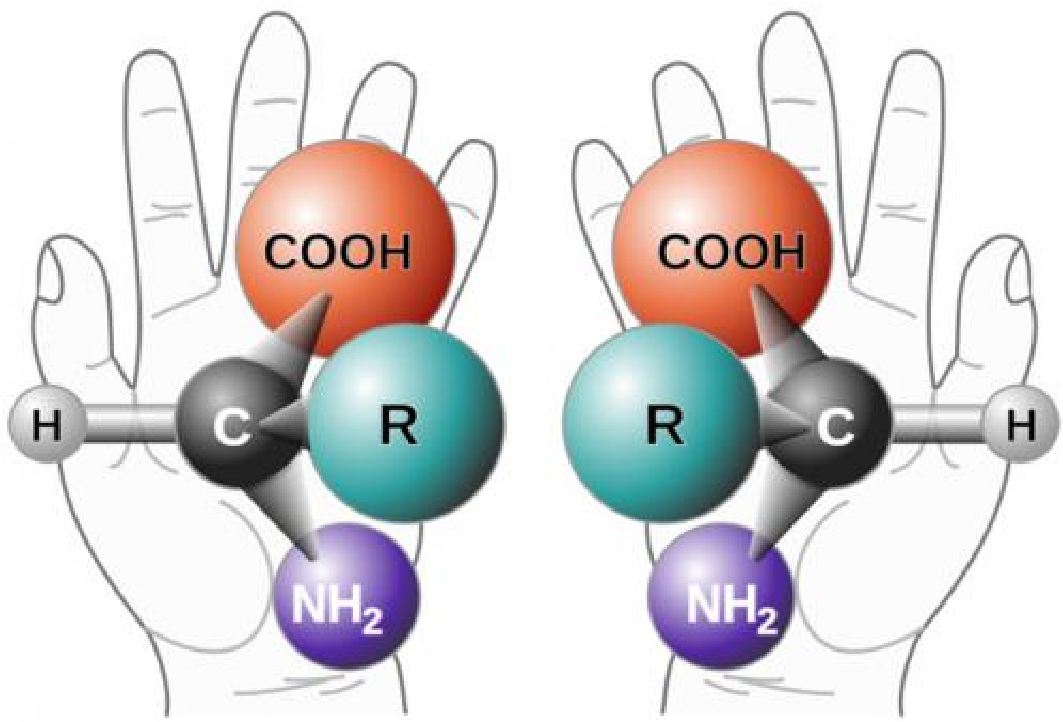
Right-handed/clockwise circularly polarized light displayed with and without the use of components. This would be considered left-handed/counter-clockwise circularly polarized if defined from the point of view of the source rather than the receiver. Credit: Wikimedia Commons

"One way to answer what causes CP in this or that case is to see which mechanism is more realistic for the given environment," said Kolokolova. "For example, in star forming regions, alignment in magnetic fields looks more realistic. However, this is not so obvious for comets, and will be even more difficult to determine in the case of observing CP in exoplanets."

At first glance, the two types of CP look very similar. Looking at the two light beams head on, they appear identical.

"Unfortunately a simple way to distinguish between these two mechanism based on the difference in the phase function of their CP cannot be used. 'Phase function' is dependent on phase angle, and phase angle is the angle between the star (Sun), dust particle, and observer (Earth)," explained Kolokolova. "The phase functions for aligned particles and homochiral molecules are quite similar and, within the errors of observations, almost indistinguishable."

With computer modelling, the team found a slight difference in the exact backscatter and forward scatter directions of light that becomes circularly polarized by alignment versus homochirality. The team hopes that by watching how light is backscattered and forward scattered by dust, they can identify specific signatures for each of the two cases.



Amino acids, sugars and other chiral molecules come in two varieties that are mirror images of each other. Credit: NASA

"Using these results, we can plan observations directed to search for prebiological/biological materials in space, especially in disks and exoplanets," said Kolokolova. "And they can be used in studies of the origin of homochirality; for example, through a survey of homochiral molecules in cosmic dust of different ages."

Kolokolova also points out that identifying homochiral molecules in space can provide important clues about the origins of life. Evidence from meteorites supports the idea that the origin of left-handed himochirality in amino acids used by biology on Earth is related to conditions in the early Solar System. If the dust that formed our solar system only contained left-handed amino acids, it could explain why life on Earth developed a preference for these molecules in the first place. A survey of cosmic dust could reveal that homochirality is Universal, but that doesn't mean that every system would be just like ours.

"It is likely that on other worlds, right-handed amino acids could dominate," said Kolokolova. "It depends on the properties of the original magnetic field that aligned dust particles in star-forming regions."

More information: Ludmilla Kolokolova, Lev Nagdimunov, "Comparative analysis of polarimetric signatures of aligned and optically active ('homochiral') dust particles," *Planetary and Space Science*, Volume 100, 1 October 2014, Pages 57-63, ISSN 0032-0633, dx.doi.org/10.1016/j.pss.2014.01.002.

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