Shedding light on the afterglow

Clouds of microscopic particles in the solar system create a dim glow in the wake of the sun, says **S Ananthanarayanan**

ZODIACAL Light, as this glow is called, appears as a dim triangle that rises from the horizon a little after sunset and can also be seen shortly before sunrise. After the slanting rays of the just set sun no longer illumine the upper atmosphere, or before the same thing starts happening just before sunrise, this is a gentle glow that pervades the western or eastern sky, so faint that it is perceptible only on moonless nights and away from the glare of cities.

Why this glow arises is a question that has not been satisfactorily answered for a long time. But Peter Jenniskens, US astronomer and senior researcher at the Carl Sagan Centre, and David Nesvorny report in the *Astrophysical Journal* that they have worked out the source of the dust that scatters sunlight and causes this curiosity.

The name *Zodiacal* comes because the path of the sun, along which the zodiacal light appears, is also the circle that contains the 12 signs of the Zodiac, which are the star formations that seem to move around the earth as the earth goes around the sun once a year. This plane, which contains the path of the earth around the sun, is called the *ecliptic* and the reason is that it is in this plane that an eclipse can take place. It also turns out to be the plane that contains the sun and the planets of the solar system.

The phenomenon has been known since ancient times and even finds mention in Islamic scriptures, for the "false dawn" that the early morning glow suggests, to be distinguished from the real dawn, which is the time for the first prayer of the day. Astronomers in the 17th century in fact had made quite a study and had put it down to occur because of dust particles in the solar system. This was quite correct, but the source and nature of the particles was not known.

Forward scattering

The scattering of sunlight takes place in the dust that is found in a disk along the ecliptic, starting at the sun and extending beyond the solar system. If this scattering medium of dust were considered like the atmosphere, which scatters sunlight, we may expect that there would be scattered light reaching us from all directions, like the blue scattered light that comes in from the sky during daytime.

According to the theory of scattering of light by very small particles, called *Raleigh Scattering*, the shorter wavelengths (the blue end of the spectrum) are scattered through the largest angles, while the longer wavelengths are scattered the least. This is the reason that light from the rising or setting sun is reddish, while the blue light that has been scattered reaches us from the sky overhead.

But this theory does not apply to the scattering by interplanetary dust, which consists of comparatively larger particles. In this case, the scattering, known as *Mei Scattering*, is found to be about the same for all wavelengths and strongly in the forward direction. This is the reason that Zodiacal light is visible only when the sun has barely set or is about to rise, when scattered through a shallow angle. There is very little scattering, towards the earth, from the dust outside this zone and hence the absence of *Zodiacal Blue Sky*.

What makes the dust?

How this dust arises has been studied for a long time. At first, it was though to be an extension of the sun's atmosphere. In *An Universal Dictionary of Arts and Sciences*, published in London in 1728, we find the mention, "The Zodiacal light is nothing but the solar atmosphere, a rare and subtile fluid, either luminous by itself, or made so by the rays of the sun surrounding its globe; but in a greater quantity, and more extensively, about its equator, than any other."

But small particles in orbit in this manner are affected by diverse effects because of collisions and light from the sun. The effect of absorption of light from the sun, which is radially outward, surprisingly results in the particles spiralling *inwards*, an effect that calls on the General Theory of Relativity to be explained. Briefly, it is that when a particle absorbs a photon moving radially out its circular motion around the sun is not affected. But on absorption of the photon, its mass effectively increases. This is like a skateboard that is rushing along, but a weight is suddenly placed on it. The skateboard slows down. In the same way, the orbiting particle moves slightly *inward*.

And again, when the absorbed photon is re-emitted that photon goes out at an angle, without restoring the momentum that the particle lost when it absorbed the photon. The result is that the particle ends up a little closer to the sun, thanks to its absorbing a particle of light that was beaming out from the sun! And in this way, particles in orbit around the sun must slowly spiral inwards.

Another effect is that when the particles get weathered down to less than 10 microns, the radiation pressure effectively kicks them out of the inner solar system.

The dust is thus gradually getting used up and it is of interest to understand where it keeps coming from. It has been generally thought that the dust came from the tails of active comets and from the debris of colliding asteroids in the asteroid belt. But Nesvorny and Jenniskens, authors of the paper in *Astrophysical Journal*, have, for the first time, dynamically modelled the forces that act on dust generated from the different candidate sources. And they find that the only model that works, to explain the thickness of the cloud, is when the dust is released in orbits that approach Jupiter.

Now comets are of different kinds, some which arise from belts of rocky objects, maybe debris of planet formation, in orbit around the sun. One belt is the nearer, *Kuiper* belt, and the other the remote *Oort* belt. These objects, in almost circular orbits around sun, get disturbed by planets, in the case of the nearer belt and by nearby stars, in the case of the Oort belt, and they plunge into a deep, elliptical orbits. And then they get strongly affected by the planets, the far off comets, which have large periods, being affected by Jupiter, the largest of all the planets, more than twice as massive as the others combined. Haley's comet, with a period of 76 years, is a celebrated example.

This group of large period comets is called the Jupiter Family Comets and Nesvorny and Jenniskens found that 85 per cent of the interplanetary dust came from fragmentation of Jupiter Family Comets, asteroids having perhaps a minor role. This confirms what Jenniskens had earlier observed, that meteor showers usually contain no active comet parent bodies, but originate from the fragmentation of (mostly dormant) Jupiter Family Comets.

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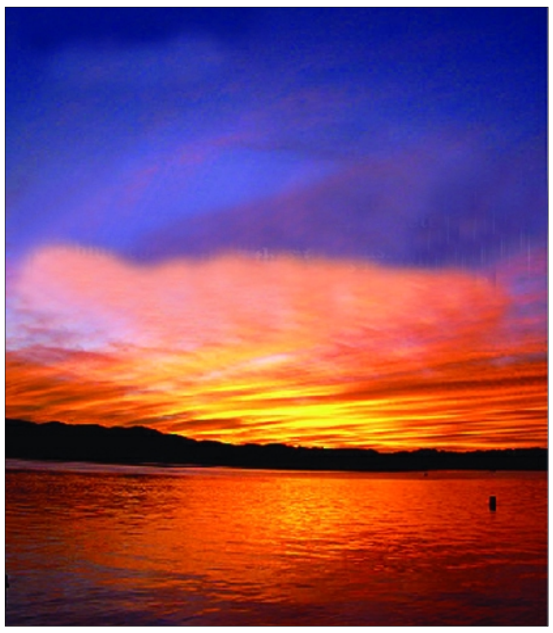


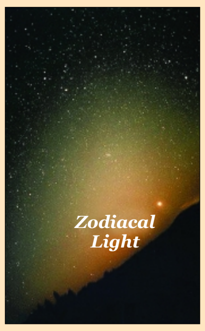
Raleigh Scattering: Light that comes in straight is depleted of the blue component and is reddish, while light scattered from the sky is largely blue.

Rock star in comet science

BRIAN May, celebrated lead guitarist of the rock band *Queen*, started life as an astrophysicist. After graduating from Imperial College, London, in Physics and Mathematics, he started work on his PhD, but abandoned it for a life in music. He did publish two important scientific papers, on the "night sky spectrum" and "Zodiacal particles", and in 2007 he completed his PhD thesis — *A Survey of Radial Velocities in the Zodiacal Dust Cloud*. May also co-authoured the book *Bang! – The Complete History of the Universe* with Patrick Moore and Chris Lintott.

Spectral signature

THERE is also an opposite of the Zodiacal Glow in a similar glow, a spot, in fact, above the opposite horizon. This glow is because of sunlight reflected *right back* by dust particles on the other side of the earth! This light, which is known as *gegenschein*, is strong enough to be seen because the particles would be in full phase, like the full moon, and does have the same spectral signature as sunlight too!



A new superconductor

Japanese scientists have found that picene, a heavier cousin of benzene, becomes superconducting when laced with potassium or rubidium.
Saswato R Das reports

JAPANESE scientists led by Professor Yoshihiro Kubozono of Okayama University are reporting that a simple hydrocarbon, *picene*, exhibits electrical superconductivity below the relatively high temperature of 18 K. The Japanese team details its findings in a recent issue of *Nature*. If confirmed by others, this will be the first time in a decade that a new organic, high-temperature superconductor may have been found, and it could lead to a new class of superconductors.

Jeff Lynn, who investigates superconductivity at the National Institute of Standards and Technology in Gaithersburg, Maryland, says, "The results look quite interesting and I would expect the article to cause a stir in the superconductivity community."

Superconductivity, first discovered by Dutch physicist Heike Kamerlingh Onnes in 1911, is a phenomenon in which the resistance of a material to the flow of electricity vanishes. Originally observed at extremely low temperatures in metals like mercury and aluminum and tin, many superconductive materials have been found over the years, mostly at cryogenic temperatures, at which point quantum effects dominate. Low-temperature superconductivity is fairly well understood today, thanks to physicists John Bardeen, Leon Cooper and John Schrieffer, who won the Nobel Prize for their work. They said that at low temperatures electrons in the superconducting material pair up to form Cooper pairs. These pairs move along with the current, offering no resistance to its flow, unlike in regular conductors where some electrons impede the flow. The temperature below which superconductivity is observed is called the critical or transition temperature.

Superconductors are widely used in magnets for MRI machines today as well as magnetically levitating trains and particle accelerators, and have been proposed for a host of applications such as quantum computing and smart grids.

In 1986, a new class of ceramic materials was discovered to be superconducting at temperatures up to 90 K. These so-called high-temperature superconductors spurred the search for a room temperature superconductor, which has so far remained elusive. (The higher the temperature below which a material exhibits superconductivity, the less is the need to cool it, which translates to greater usability. A room temperature superconductor would need no cooling, whereas a superconductor that operates at a few Kelvin or less would need very expensive refrigerators.)

Kubozono and colleagues have found that *picene*, a heavier cousin of *benzene*, becomes superconducting when laced with potassium or rubidium. *Picene* is an organic compound, a simple hydrocarbon molecule made up of 22 carbon atoms and 14 hydrogen atoms. Hydrocarbons are very common (for example, the gasoline used in cars is a hydrocarbon).

"Most people, however, wouldn't think of hydrocarbons as being electrically interesting," say Matthew Rossiensky of the University of Liverpool and Kosman Prassides of Durham University, who co-wrote a commentary in *Nature* explaining the significance of the work. "This is exciting news for superconductivity researchers, and should stimulate extensive work on the electronic properties of other acenes (the family of aromatic compounds to which *picene* belongs)."

Yoshihiro Kubozono.

To make *picene* superconducting, the Japanese team doped *picene* with potassium or rubidium in a process called *intercalation*. They created a thin film of the intercalated *picene* and built a field effect transistor to test for superconductivity. "We started to investigate metal doping into *picene* crystals because we expected metallic behaviour. Actually we observed superconducting transition at 18 K," says Kubozono.

Superconductivity experts around the world are intrigued. "In the global picture, the discovery probably won't affect how we think about superconductors as the pairing mechanism is likely conventional, but it certainly provides a new research avenue that should produce interesting results," says Lynn at Nist, who adds that they will start looking into *picene* and related compounds.

But not everybody is convinced that what Kubozono and colleagues are seeing is real superconductivity. Announcements of new superconductors are often met with caution by superconductivity researchers, since many so-called superconductors turned out to be not superconducting.

Theorist and superconductivity expert Chandra Varma of the University of California at Riverside asks, "There is definitely a transition but is it superconductivity? I am not sure."

So what is next? Superconductivity researchers around the world will definitely seek to confirm the Japanese group's work and understand *picene* more. As for the team that is reporting the discovery, Kubozono says, "Currently we are investigating other metal-atom intercalation into *picene* crystals to search for new superconductors. Furthermore, we are synthesising new organic molecules which consist of more benzene rings or are expanded two-dimensionally, in order to intercalate metal atoms into their crystals."

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Taming the toxic

Tapan Kumar Maitra explains the intricacies of the metabolism of poison in organisms

THE entry of a poisonous substance into an organism calls forth protective reactions to restrict the toxic action of the poison. These reactions include excretion of the foreign substance from the organism in an unchanged form, deposition of it in the tissues and decomposition of the poison into simpler substances with the following excretion thereof or inclusion into the general processes of metabolism.

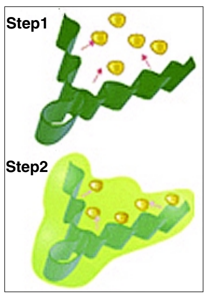
Most pesticides are lipophylic substances, and this is why their excretion from the organism in an unchanged form occurs quite rarely. This is inherent in generally stable chemical compounds such as organochlorine insecticides. Only some hydrophylic compounds can be excreted from insect organisms through the Malpighian tubes and in mammals through the kidneys with the urine. Cases of the excretion of toxic substances in an unchanged form are also known in plants. For instance, in jimsonweed datura, during the first day after applying 2,4-D to a leaf, up to 60 per cent of the entire herbicide applied is excreted through the roots into the nutrient solution. A poison may be discharged from the organism or an insect or mammal together with the excrements, especially with undigested substances, and in the course of vomiting, when the toxic agent greatly irritates the mucous membrane of the alimentary tract.

Finally, an important process inherent only in mammals is the excretion of pesticides from an organism together with milk. Stable organic substances, for instance certain organochlorine compounds, can be excreted in this way.

The deposition of a toxic substance is a property of all living organisms and leads to temporary localisation of the poison in tissues that do not participate actively in vitally important processes.

On penetrating into an insect, an insecticide dissolved in lipids may accumulate in the fat-body and render no toxic action. The deposited substance is then decomposed and is excreted through the Malpighian tubes or is removed in molting together with the chitinous shell. In an animal, the deposition of poisonous substances occurs in the fat cells, while some compounds combine with the serum albumin of the blood. Both these processes precede the decomposition of the toxicants.

The most widespread reaction of any organism to the introduction of a foreign substance is its decomposition. As a result, either less toxic — detoxication — or more poisonous — activation — products may be formed. The most stable are the halogen derivatives of the cyclic hydrocarbons and heterocyclic compounds, while the esters of phosphoric acid are less resistant. In the long run, metabolism results in more simple and hydrophylic substances that are easily excreted from the organism or are utilised in the general processes of metabolism.



Hydrophobic interaction between fats and insoluble fibres (step 1), as primary interactions are stabilised thanks to soluble fibres (step 2.)

Several basic types of reactions occurring in an organism are known. They include hydrolysis, oxidation, reduction dehydrochlorination, isomerisation and conjugation. These reactions are catalysed by enzymes and many of them also require a hydrogen donor.

The hydrolysis of poisons in organisms may occur either chemically or with the aid of enzymes. The main role in this process is played by enzymes such as amidase, nitrilase, phosphatase and carboxyesterase whose activity in living organisms is quite high.

Hydrolytic decomposition is characteristic of pesticides of the amide group (propanil), esters of various acids (esters of 2,4-D and MCPA), alkylcarbamates (carbaryl), arylcarbamates (barban), organophosphorus compounds (parathion-methyl) and halogen derivatives of hydrocarbons (hexachlorobutadiene). The products are acids, on the one hand, and alcohols or amines, on the other. Aryland alkylcarbamates are a special case because the acids formed in their hydrolysis are very unstable and rapidly decompose into CO_2 and the corresponding amines.

In hydrolysis, lipophylie substances transform into hydrophylic ones and the behaviour of poisons sharply changes. The reaction products penetrate only slightly through the membranes to the vitally important centres and are excreted from the organism at a faster rate.

In the majority of cases, hydrolysis results in the formation of substances that are less toxic to organisms. There are poisons, however, whose toxicity increases after hydrolytic decomposition. For example, acetyldipterex hydrolyses under the influence of enzymes to trichlorfon, the latter being more toxic to insects and animals.

Oxidation is one of the widespread types of metabolism of poisons in an organism. The mechanism of these reactions is often quite involved and their proceeding requires enzymes and coenzymes, as well as hydrogen donors. For many substances that resist hydrolysis, oxidation is the main direction of metabolism in organisms. The substances formed may have a higher or a lower toxicity and a low or high resistance to hydrolysis.

Various fatty acids and their derivatives that get into a living organism are decomposed by means of the beta-oxidation mechanism. It consists in the stepwise decomposition of fragments of the hydrocarbon chain with an even number of carbon atoms to acetic acid.

This process is of special significance for phenoxycarboxylic acid derivatives. Phenoxybutyricacids, having a low physiological activity, can be oxidised in plants to the corresponding phenoxyacetic acids characterised by a higher phytotoxicity. Depending on the activity of the beta-oxidation systems, the sensitivity of plants to herbicides varies.

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