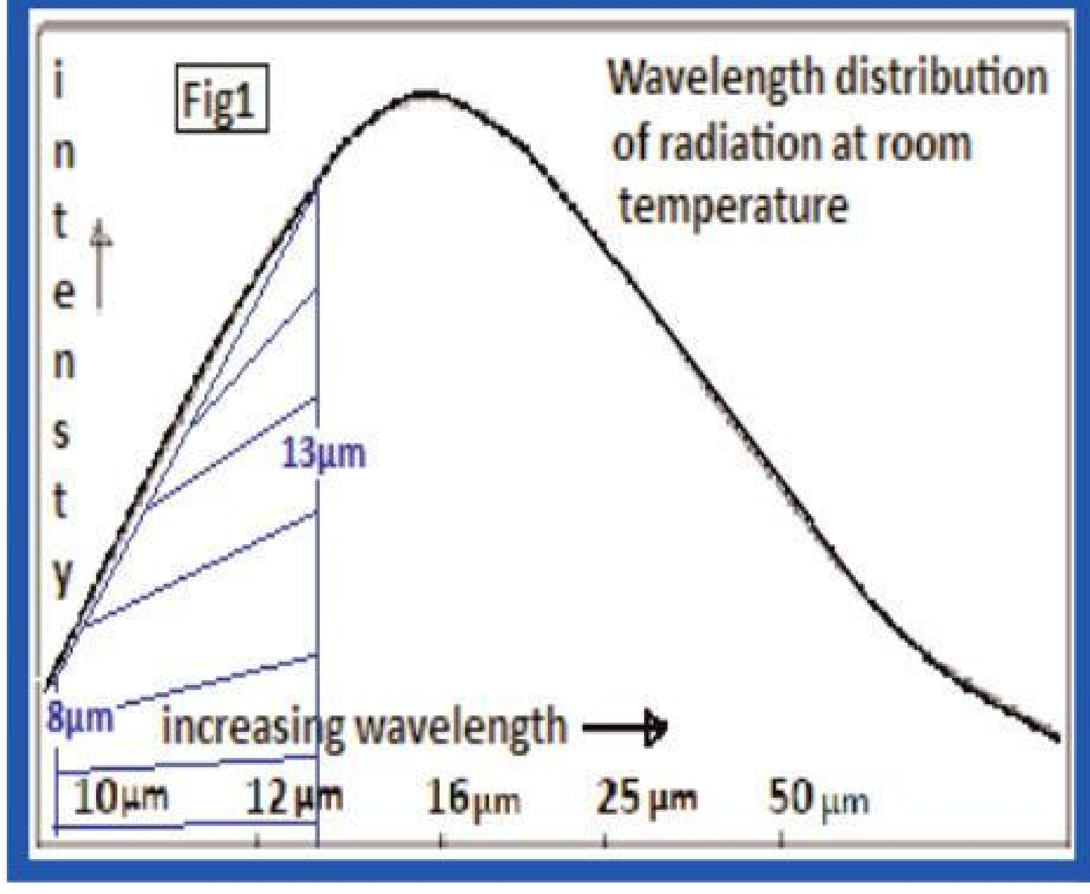
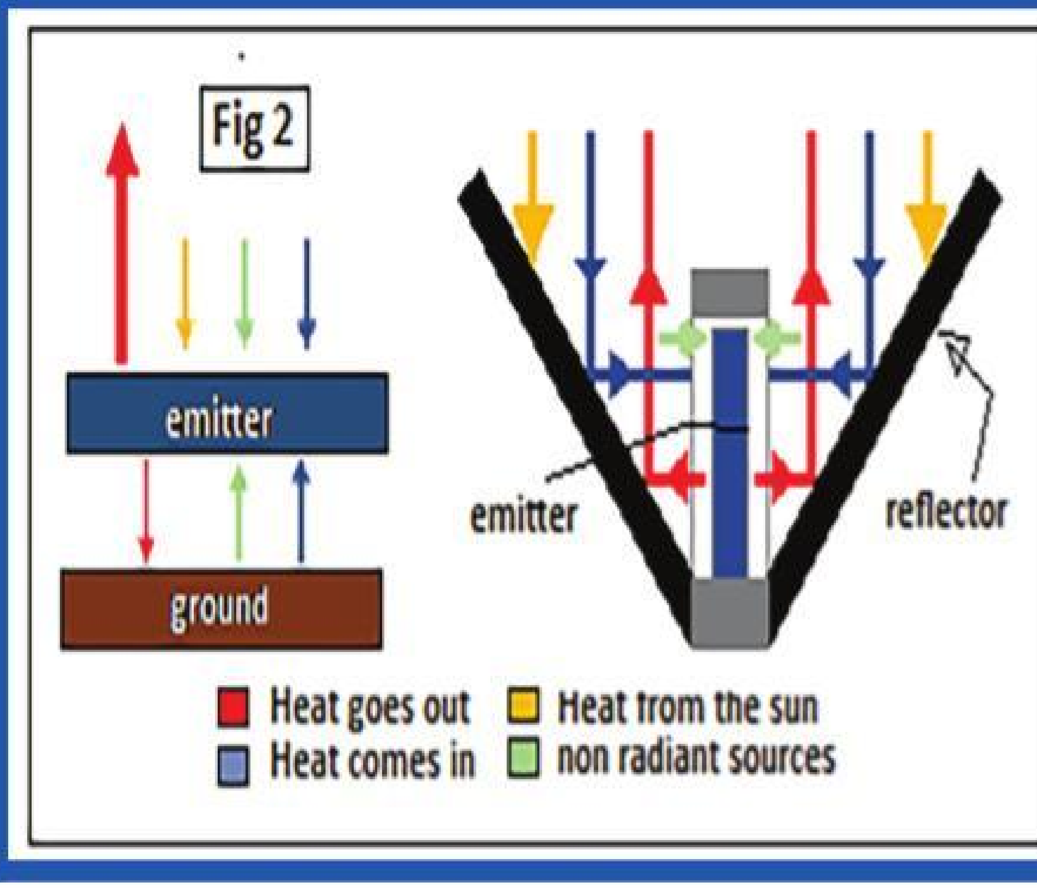
Thermal drainpipe to cool Earth

A newly built device could send heat back into space

S ANANTHANARAYANAN





Goldfinger, the bad guy in Ian Fleming's novel of the same name, had his victims painted in gold paint. But a strip along the backbone was left unpainted. This was because the gold paint did not allow the skin to breathe and a person painted all over would die.

Our atmosphere is like gold paint over the Earth. It traps the sun's heat and acts like a blanket, to keep the Earth from cooling by losing the trapped heat to space. So far, this has been a good thing, to give Earth a degree of uniform warmth, which enabled life to arise and flourish. But carbon dioxide pollution has affected the balance and Earth is collecting more heat than it can handle.

Lyu Zhou, Haomin Song, Nan Zhang, Jacob Rada, Matthew Singer, Huafan Zhang, Boon S Ooi, Zongfu Yu and Qiaoqiang Gan, from The State University of New York at Buffalo, University of Wisconsin and, King Abdullah University of Science and Technology, Saudi Arabia, report in the journal, *Cell Reports Physical Science*, a substantial improvement in technology to throw the heat that the Earth accumulates right back into the chill of outer space.

The way things warm up is really the way things cool down. Nothing will get warm if left to itself. It warms because it receives heat from objects that are cooling, and the heat it receives is more than the heat it is radiating. The Earth's atmosphere is good at receiving heat, and it gets better when it contains more carbon dioxide. As the atmosphere is most dense at sea level, it is nearest to the earth that it is the warmest. And this heat stays there, because the layer immediately above is pretty warm too, and radiates back most of the heat that the lowest, warm layer radiates out.

Except, there is a part of the radiated heat that the upper layers do not absorb, to radiate back, but passes through the upper layer, and all the layers above that, and is lost to the Earth for good. This is because the atmosphere is transparent, or allows free passage, to heat that is radiated in the form of infra-red light with wavelengths in the window of eight to 13 micrometres.

What this implies is that a good way to cool the Earth would be collect the heat we receive, turn as much as we can to IR light in the eight-13 micrometre range, and beam it out to space. We already know that whitewashing the roof can help reflect the heat and keep a building somewhat cooler. But a lot of the reflected heat gets absorbed by the atmosphere and is radiated back. What would work is that we change the heat into that range of wavelengths that can pass through, before we send it out.

Normal objects, at usual temperatures of around 30°C, radiate over a wide range of frequencies, as shown in Fig 1. As stated, most of this radiation would be absorbed by the atmosphere itself, with no reduction of the net heat content, except for emission in the eight-13 micrometre band.

A first method to get emission to stay in this band was developed a few years ago, with a seven-layer stack of the materials, hafnium dioxide and silicon dioxide, mounted on a thin silver base. Hafnium oxide has large emission in the eight-13 micrometre range, while silicon dioxide emits strongly at nine micrometre. The thickness of the layers was regulated, for best efficiency of reflectivity and selective emissivity. The result was a device where sunlight that passed through the stack was reflected skywards with very little radiation absorbed and strong emission at the special wavelength band. And an arrangement that was tried in Stanford University brought about a four to five °C drop in temperature.

Another device by the same team had a wafer of silica, or silicon dioxide, laid over a crystal of silicon, the material of solar cells, with a backing of an aluminum mirror. The result was a solar cell with an arrangement to prevent heating. As the efficiency of solar cells falls steeply when the device warms, the arrangement promised a substantial improvement in the output of solar cells.

While devices in use attain cooling of around 100 W/m^2, the paper says that the best cooling, even in principle, that is possible for a sky facing device is 160W/m^2. In comparison, the energy that comes in from the sun is 1,000 W/m^2. A great part of the energy received is hence not made use of, the paper says.

A first feature that can be improved, the paper points out, is that the emission from one half of the emitter, in the sky facing systems developed, is directed to the ground and wasted. This is shown in the left side part of Fig 2. The authors remedy this by standing the emitter up, vertically, and deploying a pair of mirrors to capture emissions from both faces of the emitter. This, they observe, "breaks the cooling power density limit (which is 160 W/m^2) of the single-sided thermal emitter," and lifts cooling performance to 273.3 W/m^2.

A further feature is that the material of the reflectors is a cermet, or a composite of a ceramic and a metal, which is spectrally selective. This means it reflects light of certain wavelengths and allows light of other wavelengths to be absorbed. The optimised reflector that was used could absorb 90 per cent of the solar radiation and reflect 90 per cent of the radiation in the eight-13 micrometre band, the paper says.

The result was that along with emission of heat, out to space, of more than double what other devices could do, 90 per cent of the remaining solar energy was absorbed. There was tremendous heating of the solar absorption plates, the paper says. The cooling, at the same time, was 14°C in a laboratory trial and 12°C in an outdoor trial, the paper says.

The important thing to note is that radiative cooling, with simultaneous heat capture, is a passive process, that needs no electricity, compressors, etc. Cooling at the rate of 160W/m^2 amounts to cooling like a 0.05 tonne conventional AC unit. A 20 m2 passive emitter, which is a square with sides of 4.5 m, would thus cool like a one tonne AC unit – with no electricity. And it would also produce heat, to warm water, drive a generator, etc., all on solar energy!

An IEA report says air conditioning and electric fans for cooling accounts for 20 per cent of energy used in buildings, and the demand for air conditioning is set to soar in the decades to come. Does it look like the end of the road for conventional cooling systems?

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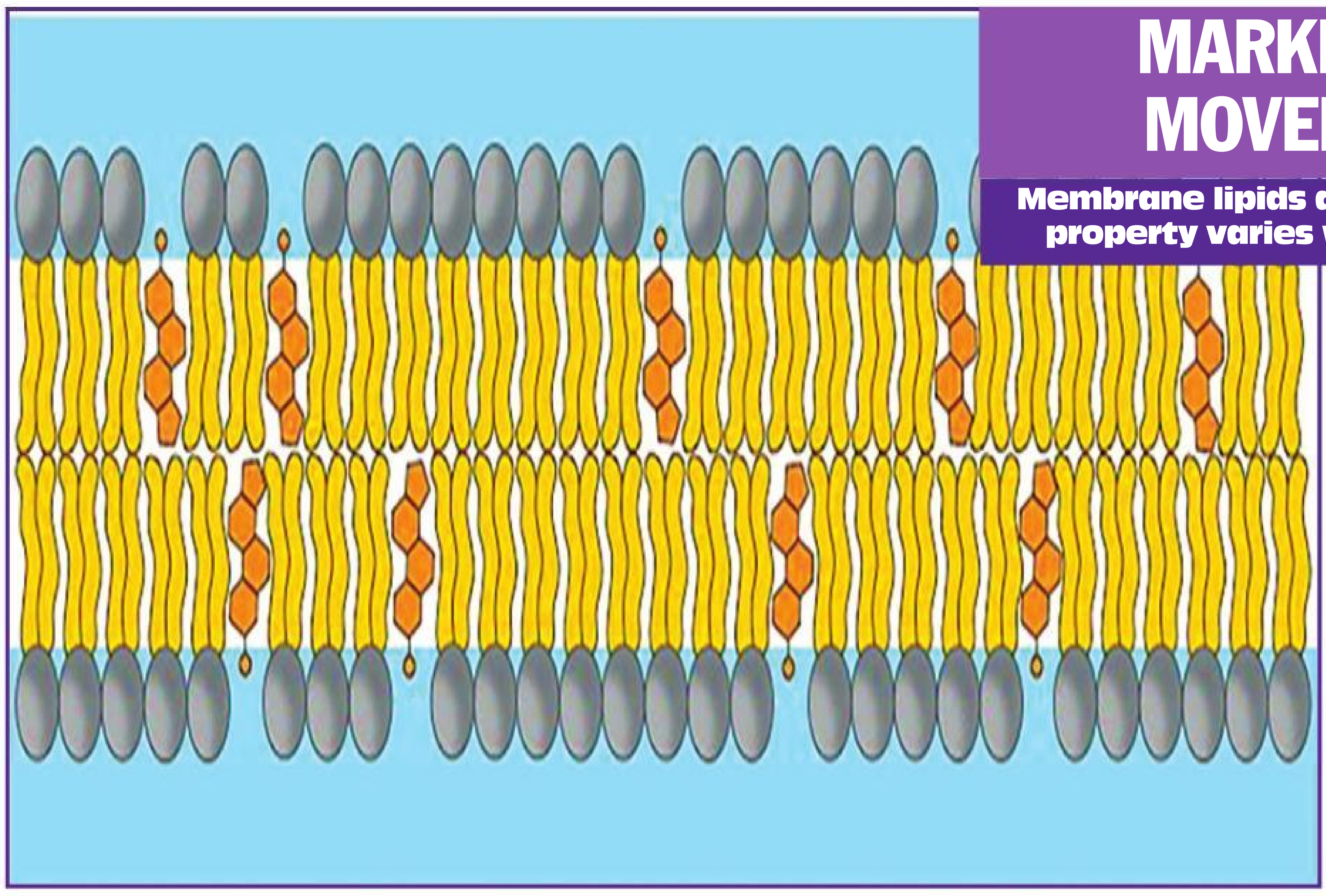
MARKED BY MOVEMENT

Membrane lipids are fluid and that property varies with conditions



TAPAN KUMAR MAITRA

One of the most striking properties of membrane lipids is that rather than being fixed in place within the membrane, they form a fluid bilayer that permits lateral diffusion of membrane lipids as well as proteins. Lipid molecules move especially fast because they are much smaller than proteins. A typical phospholipid molecule, for example, has a molecular weight of about 800 and can travel the length of a bacterial cell (a few micrometres, in most cases) in a second or less! Proteins move much more slowly than lipids, in part because they are much larger molecules, with molecular weights many times greater than those of phospholipids, but mainly due to their interactions with cytoskeletal proteins on the inside of the cell.

The lateral diffusion of membrane lipids can be demonstrated experimentally by a technique called fluorescence recovery after photobleaching. The investigator tags, or labels, bind to lipid molecules in the membrane of a living cell by covalently linking molecules of a fluorescent dye to them. A high-intensity laser beam is then used to bleach the dye in a tiny spot (a few square micrometres) on the cell surface. If the cell surface is examined immediately thereafter with a fluorescence microscope, a dark, nonfluorescent spot is seen on the membrane.

Within seconds, however, the edges of the spot become fluorescent as bleached lipid molecules diffuse out of the laser-treated area and fluorescent lipid molecules from adjoining regions of the membrane diffuse in. Eventually, the spot is indistinguishable from the rest of the cell surface. Not only does this technique demonstrate that membrane lipids are in a fluid rather than a static state, it also provides a direct means of measuring the lateral movement of specific molecules.

Membrane fluidity c hanges with temperature, decreasing as the temperature drops and increasing as it rises. In fact, we know from studies with artificial lipid bilayers that every lipid bilayer has a characteristic transition temperature (T_m) at which it gels ("freezes") when cooled and becomes fluid again ("melts") when warmed. This change in the state of the membrane is called a phase transition and is somewhat like the change that butter or margarine undergoes upon heating or cooling.

To function properly, a membrane must be maintained in the fluid state that is, at a temperature above its T_m value. At a temperature below the T_m value, all functions that depend on the mobility or conformational changes of membrane proteins will be impaired or disrupted, including such vital processes as transport of solutes across the membrane, detection and transmission of signals, and cell-to-cell communication.

The technique of differential scanning calorimetry is one means of determining the transition temperature of a given membrane. This procedure monitors the uptake of heat that occurs during the transition from one physical state to another – the gel-to-fluid transition, in the case of membranes. The membrane of interest is placed in a sealed chamber, the calorimeter, and the uptake of heat is measured as the temperature is slowly increased. The point of maximum heat absorption corresponds to the transition temperature.

The fluidity of a membrane depends primarily on the kinds of lipids it contains. Two properties of a membrane's lipid makeup are especially important in determining fluidity – the length of the fatty acid side chains and their degree of unsaturation (that is, the number of double bonds present). Long-chain fatty acids have higher transition temperatures than shorter-chain fatty acids, which means that membranes enriched in long-chain fatty acids tend to be less fluid.

For example, as the chain length of saturated fatty acids increases from 10 to 20 carbon atoms, the melting point rises from 32°C to 76°C and hence the membrane becomes progressively less fluid.

The presence of unsaturation affects the melting point even more markedly. For fatty acids with 18 carbon atoms, the melting points are 70, 16, 5, and 11°C for zero, one, two, and three double bonds, respectively. As a result, membranes containing many unsaturated fatty acids tend to have lower transition temperatures and thus are more fluid than membranes with many saturated fatty acids.

The effect of unsaturation on membrane fluidity is so dramatic because the kinks that double bonds introduce into fatty acids prevent the hydrocarbon chains from fitting together snugly. Membrane lipids with saturated fatty acids pack together tightly whereas lipids with unsaturated fatty acids do not. The lipids of most plasma membranes contain fatty acids that vary in both chain length and degree of unsaturation. In fact, the variability is often intramolecular because membrane lipids commonly contain one saturated and one unsaturated fatty acid. This property helps to ensure that membranes are in the fluid state at physiological temperatures.

For eukaryotic cells, membrane fluidity is also affected by the presence of sterols – mainly cholesterol in animal cell membranes and phytosterols in plant cell membranes. Sterols are prominent components in the membranes of many cell types. A typical animal cell, for example, contains large amounts of cholesterol – up to 50 per cent of the total membrane lipid on a molar basis. Cholesterol molecules are usually found in both layers of the plasma membrane, but a given molecule is localised to one of the two layers.

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PLUS POINTS

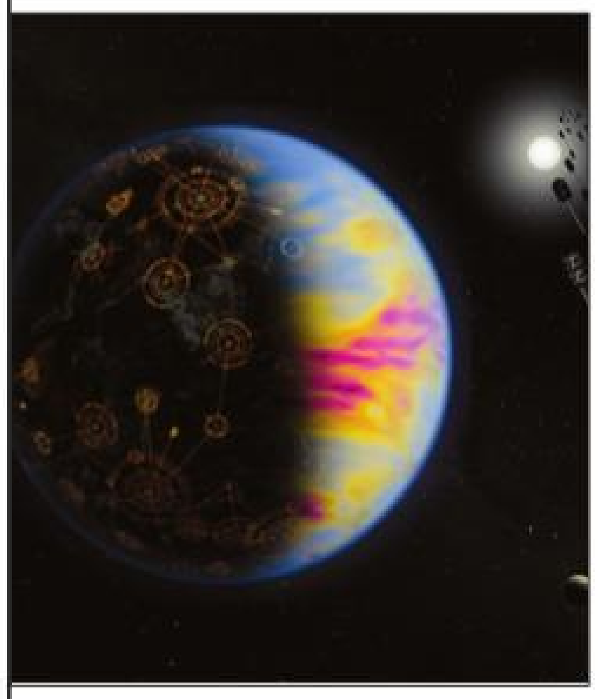
Looking for pollution

Aliens could be detected by measuring atmospheric pollution on other planets, according to new research.

A study by a space agency examined the presence of nitrogen dioxide gas, which is produced on Earth by burning fossil fuels. While the evolution of a civilisation that has developed to oil- or coal-based industries seems slim, the gas is also sourced from other materials including lightning and biological processes.

"On Earth, most of the nitrogen dioxide is emitted from human activity - combustion processes such as vehicle emissions and fossil-fuelled power plants," said Ravi Kopparapu of Nasa's Goddard Space Flight Center in Greenbelt, Maryland, "In the lower atmosphere (about 10 to 15 kilometres or around 6.2 to 9.3 miles), nitrogen dioxide from human activities dominate compared to non-human sources. Therefore, observing nitrogen dioxide on a habitable planet could potentially indicate the presence of an industrialised civilisation."

Nitrogen dioxide gas could be what scientists call a "technosignature", which is when there is presence of a gas that is released as a by-product of an industrial process. This is similar to a biosignature, which are gases such as oxygen and methane produced by organic activity. Due to the huge number of planets in the universe, as well as their distance, scientists need to use these indications – which can be measured at great distances – to determine which worlds are worth investigating.



"Other studies have examined chlorofluorocarbons as possible technosignatures, which are industrial products that were widely used as refrigerants until they were phased out because of their role in ozone depletion," said Jacob Haqq-Misra, a co-author of the paper at the Blue Marble Institute of Science, Seattle, Washington, "CFCs are also a powerful greenhouse gas that could be used to terraform a planet like Mars by providing additional warming from the atmosphere. As far as we know, CFCs are not produced by biology at all, so they are a more obvious technosignature than nitrogen dioxide. However, CFCs are very specific manufactured chemicals that might not be prevalent elsewhere; nitrogen dioxide, by comparison, is a general byproduct of any combustion process."

Scientists used computer modelling to predict whether nitrogen dioxide could produce a signal that is able to detect with current and future telescopes. The gas absorbs some colours of visible light, meaning that it can be measured by observing light reflected from the planet.

A planet similar to Earth could be detected up to 30 light years away over 400 hours using a large Nasa telescope; while this is a huge amount of time to study a single planet, it is not unprecedented. Nasa's Hubble Telescope took a similar amount of time for the Hubble Deep Field Observations which has helped scientists study dark matter.

"On Earth, about 76 per cent of nitrogen dioxide emissions are due to industrial activity," said Giada Arney of Nasa Goddard, a co-author of the paper. "If we observe nitrogen dioxide on another planet, we will have to run models to estimate the maximum possible emissions one could have just from non-industrial sources. If we observe more nitrogen dioxide than our models suggest is plausible from non-industrial sources, then the rest might be attributed to industrial activity.

"Yet there is always a possibility of a false positive in the search for life beyond Earth, and future work will be needed to ensure confidence in distinguishing true positives from false positives."

There are benefits and complications to using nitrogen dioxide to look for alien worlds. Happily, stars that are cooler and more common than our Sun produce less ultraviolet light (which breaks down the gas) and therefore increases the chance that extra-terrestrial life can be found.

Conversely, however, clouds or aerosols in the atmosphere could mimic the signature of the gas making it more challenging to detect – although researchers are developing 3D models in order to more accurately map results and deal with these potential imperfections. The research was published online recently in *arXiv*.

–THE INDEPENDENT