An Alternate explanation of the 'spokes' observed in Saturn's Rings

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INTRODUCTION

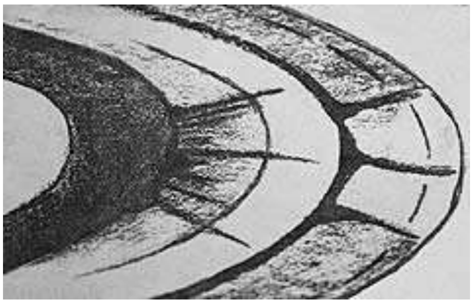

Fig 1: Stephen O'Meara's drawing of the spokes in Saturn's rings (Image PBS.org)

Observed first by amateur astronomer Stephen J. O'Meara in the 1970's (Fig. 1) and then subsequently observed by the Voyager Spacecraft flybys in the early 1980′s (Fig. 2), it was realized that these strange features, which flare out like spokes on a bicycle wheel, were not caused by gravitational interactions with the planet, moons, or ring material. Further observations were made by Cassini in 2005 when it was confirmed the 'spokes' are likely related to the gas giant's global magnetic field. (O'Neil, 2014)

Saturn's spokes rotating https://www.youtube.com/watch?v=7XJj0pjumwE (44 secs)

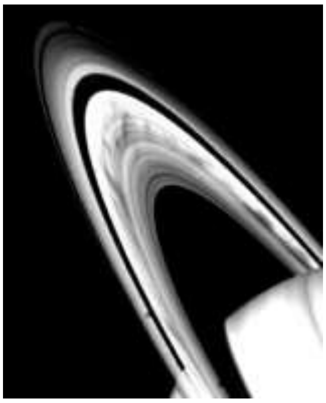

Fig 2: Dark spokes in Saturn's B ring observed by Voyager (Image Courtesy of JPL NASA)

The most popular model says meteorites bombard the rings, producing a transient cloud of dense plasma that charges the grains. Another possible explanation is that high-energy electron beams from aurora on Saturn create the temporary plasma cloud (Groshong, 2006).

Scientists explain the ‘spokes’ in Saturn’s rings due to electrostatically charged dust particles that are suspended in Saturn's magnetic field. As such these particles rotate in sync with the planet rather than its ring particles which display Keplerian motion about Saturn (Beatty, 2006). At times, due to the angle of incoming sunlight, these electrostatically charged dust particles lose their electrostatic charge and fall back into the main ring structure hence the spokes disappear at times. The spokes have been observed by the Cassini spacecraft to be able to form on a time scale of minutes and fade away in a few hours.

HYPOTHESIS

The small percentage of carbon which constitutes Saturn's rings is diamagnetic pyrolytic carbon. During the formation of Saturn’s protoplanetary disk, it is hypothesised, that pyrolytic carbon would have been deposited via Chemical Vapour Deposition (CVD) of hydrocarbon gases such as methane, onto fine grains of silicates which acted as a substrate. These fine grains of silicates coated in pyrolytic carbon can levitate above or below a strong magnetic field due to pyrolytic carbon being highly diamagnetic. It is also suggested that Saturn’s B ring has a sufficiently strong magnetic field emanating orthogonally above and below its plane to levitate these pyrolytic carbon grains.

JUSTIFICATION OF HYPOTHESIS

In the laboratory it has been demonstrated that diamagnetic pyrolytic carbon levitates above a sufficiently strong magnetic field, see Fig 3 below.

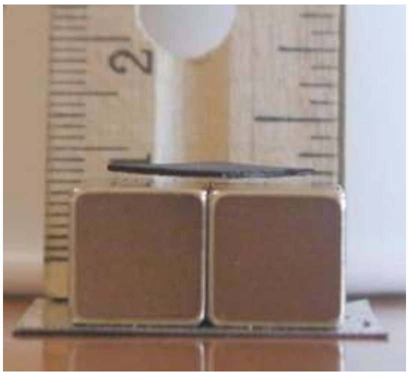

Fig 3: Pyrolytic carbon levitating above a strong magnet (Image credit scitoys.com)

https://www.youtube.com/watch?v=3FwU08frhUg (Pyrolytic carbon levitating- Youtube) 20 secs

Pyrolytic carbon is a man-made substance, but it is predicted that Saturn's rings consist of a small percentage of pyrolytic carbon. This type of carbon is formed in a vacuum at high temperatures of above 1400K, this process is known as flash vacuum pyrolysis. The dark ‘spokes’ which are observed in Saturn’s B ring consist of levitating particles that transition periodically from motion in sync with the rotation of Saturn’s magnetic field to normal Keplerian motion within the main ring. The dark ‘spokes’ are only observed in Saturn’s B ring which corresponds to the 1500K region in the protoplanetary disk formation, see Fig 4 below.

RESEARCH

Research (Henning et al. 2013) suggests that during Saturn's formation the innermost parts of its protoplanetary disk would have reached these temperatures. In the protoplanetary diagram below Fig 4, the 1500K region would correspond to Saturn's B ring. That is why the dark 'spokes' are only observed in the B ring and in no other rings. The temperature beyond the 1500K region would be too cold, so no dark 'spoke' formation would be observed beyond Saturn’s B ring.

Saturn’s ring system is the closest thing we have to the disc of dust and rubble that gave birth to Earth and the other planets 4.55 billion years ago. The protoplanetary disc took shape when a spherical cloud of ultra-cold gas and dust began to collapse under its own gravity. As the spinning cloud shrank, it took the form of a disc, swirling around the newborn sun. “Once the sun had blown away the gas, the disc of orbiting rubble would have resembled the disc of Saturn’s ring system,” says Professor Carl Murray (Chown, 2010).

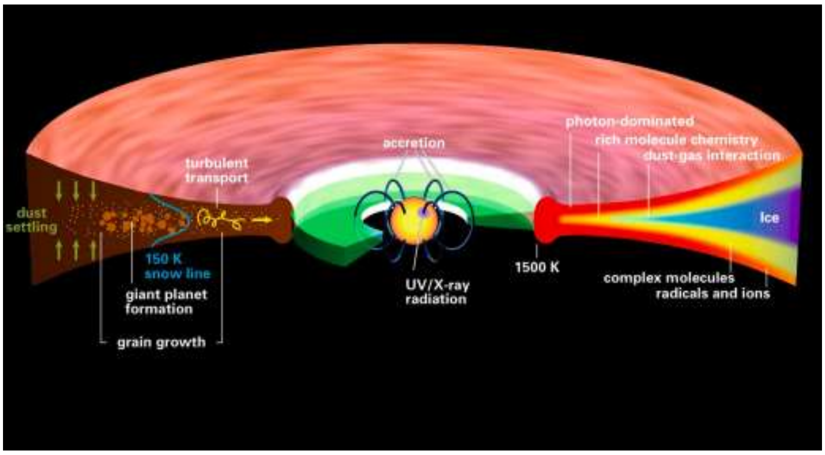

Fig 4: Protoplanetary disk formation (Image credit astrochymist.org)

Observations of suspected planet-forming disks provide estimates of protoplanetary disk masses, surface temperatures, and the rate at which mass is infalling onto the disks. Analyses of primitive meteorites and comets and their components constrain the solar nebula's temperature at the locations and times where those components were formed. Theoretical models of disks undergoing the accretion of mass from an infalling cloud envelope predict disk temperatures in good agreement with these constraints: a moderately warm (500–1500 K) inner disk, surrounded by a cool (50–150 K) outer disk. These models have important implications for the depletion of volatiles in the inner Solar System, for mechanisms of disk evolution, and for the orbital distances at which terrestrial and gas giant planets form. (Boss, 1989)

When thinking of the planet Saturn, one would naturally associate very cold temperatures to the planet, thus having temperatures >1500K to form pyrolytic carbon would be unlikely. However, my recent research suggests that Saturn’s core is actually very hot.

“Finally, at Saturn’s centre is a molten rocky metallic core. Saturn’s interior is hot! At the core, the temperature is at least 15,000 degrees Fahrenheit (8300^{o}C). That’s hotter than the surface of the Sun!” (NASA)

Saturn's 'Ring Rain' chemical composition

Hydrocarbons such as methane can be converted to pyrolytic carbon at temperature above 1400K as indicated in equation 1 below. Research (Spilker, 2019) also indicates that the Cassini mission found an abundance of various hydrocarbons in the 'rain' produced by Saturn's rings see Fig. 5 which represents the composition of 'ring rain' produced by Saturn's rings. It should be noted that silicates were also detected in the 'ring rain' which Fig. 5 neglects to show.

$$\mathbf{CH_{4(g)} + 1400K \rightarrow C_{(s)} + 2H_{2(g)}} \quad \mathbf{(1)}$$

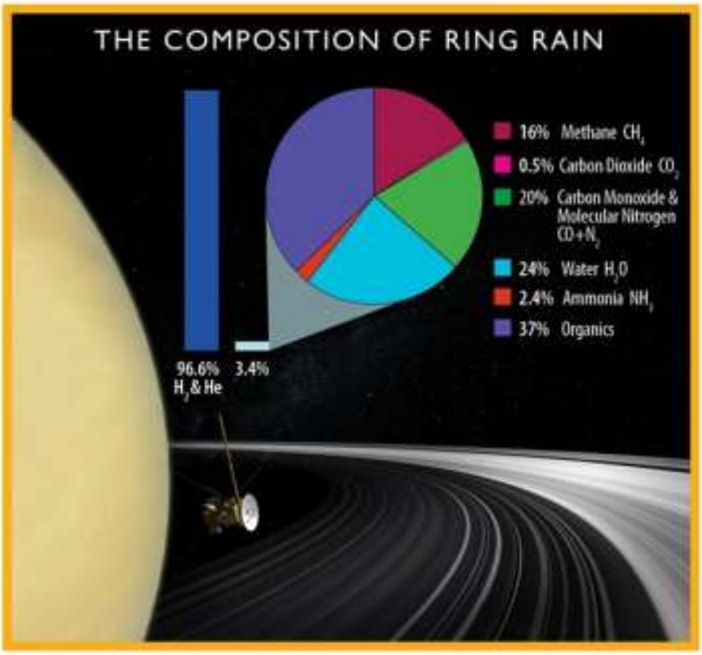

Fig 5: Data showing the Composition of 'Ring Rain' from Cassini Mission (Image Courtesy of NASA/JPL/SwRI)

"Two things surprised me. One is the chemical complexity of what was coming off the rings - we thought it would be almost entirely water based on what we saw in the past." Thomas Cravens (University of Kansas)

"But the downpour coming from the rings included plenty of water as well as molecules like butane and propane" (Miller, 2018). The researchers also found methane, ammonia, carbon monoxide, molecular nitrogen, and carbon dioxide. The methane, Cravens said, was wholly unexpected, as was the carbon dioxide. What the researchers were expecting was a lot more water ice. Molecular hydrogen was the most abundant constituent at all altitudes sampled. Water in fall from the rings was observed, along with substantial amounts of methane, ammonia, molecular nitrogen, carbon monoxide, carbon dioxide, and impact fragments of organic nanoparticles. (Craven et al., 2018)

Pyrolysis and Gasification

Syngas, also called a synthesis gas, is a mix of molecules containing hydrogen, methane, carbon monoxide, carbon dioxide, water vapours, as well as other hydrocarbons and condensable compounds. It is a main product of gasification and majority product of high temperature pyrolysis carried on any biomass, residues, and waste. When produced in pyrolysis, it is created by the vaporisation of volatile compounds from the raw material thanks to the heat, which induces a set of complex reactions. Gases from pyrolysis typically contain significant quantities of methane, hydrogen, carbon monoxide, and carbon dioxide, as well as higher hydrocarbons that build their calorific value and make them important fuel for the chemical and energy industries. (Monnet, 2021)

Gasification is a process that converts biomass or fossil fuel-based carbonaceous materials into gases, including as the largest fractions: nitrogen (N_2), carbon monoxide (CO), hydrogen (H_2), and carbon dioxide (CO_2). This is achieved by reacting the feedstock material at high temperatures (typically >700 °C), without combustion, via controlling the amount of oxygen and/or steam present in the reaction. The resulting gas mixture is called syngas (from synthesis gas) or producer gas and is itself a fuel due to the flammability of the H_2 and CO of which the gas is largely composed. Further reactions occur when the formed carbon monoxide and residual water from the organic material react to form methane and excess carbon dioxide. (Wikipedia, Gasification)

$$4CO_{(g)} + 2H_2O_{(l)} \rightarrow CH_{4(g)} + 3CO_{2(g)} \quad (2)$$

Fig. 6 below shows the D/H gradient with heliocentric distance from the sun. An analogous situation is predicted to occur around Saturn.

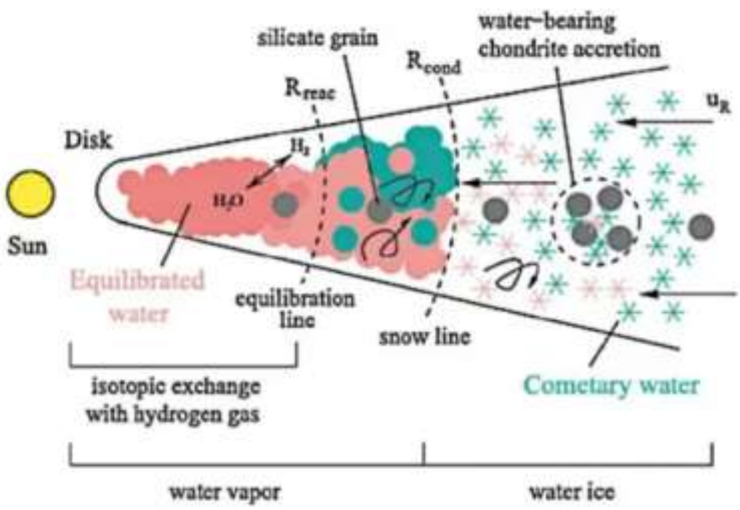

Fig 6: Illustration of the D/H gradient with heliocentric distance. The arrows symbolize motions of gas (Jacquet & Robert)

Steam reforming of hydrocarbons

In gasification, reforming is a means to enhance the proportion of hydrogen by decomposing the hydrocarbons into CO and hydrogen, equation 2. If the feedstock is already made of hydrocarbons, reforming is the first stage towards syngas:

Methane + water → Carbon Monoxide + Hydrogen

$$CH_{4(g)} + H_2O_{(l)} \rightarrow CO_{(g)} + 3H_{2(g)} \quad (2)$$

Pyrolysis is the thermal decomposition of the volatile components of an organic substance, in the temperature range of 400-1,400°F (200-760°C), and in the absence of air or oxygen, forming syngas and/or liquids. An indirect source of heat is used. A mixture of un-reacted carbon char (the non-volatile components) and ash remains as a residual.

Gasification takes this to the next step. It occurs in a higher temperature range of 900-3,000°F (480-1,650°C) with very little air or oxygen. In addition to the thermal decomposition of the volatile components of the substance, the non-volatile carbon char that would remain from pyrolysis is converted to additional syngas. Steam may also be added to the gasifier to convert the carbon to syngas. Gasification uses only a fraction of the oxygen that would be needed to burn the material. Heat is supplied directly by partial oxidation of the carbon in the feedstock. Ash remains as a residual. (Global Syngas Technologies Council, 2021).

The chemical processes of pyrolysis and gasification may explain where the ice and other constituents of Saturn's rings originated from. Thus, Robin Canup's hypothesis that Saturn's rings were formed when a Titan-sized moon with a rocky core and an icy mantle spiralled into Saturn may not be required.

Saturn's 'spokes' composition

Pyrolytic carbon which is also diamagnetic may also explain the dark 'spokes' which are observed in Saturn's rings. Because pyrolytic carbon is so diamagnetic (repelled by a magnetic field) none of it would have been detected in the 'ring rain' detected falling from Saturn's rings to its atmosphere.

It is suggested that the dark 'spokes' are fine grains of silicates that have been covered in pyrolytic carbon due to the process of flash vacuum pyrolysis during the formation of Saturn. Pyrolytic carbon is the best-known material that displays the most similar properties to superconducting materials i.e diamagnetism. See table 1 below which indicates the highly diamagnetic nature of pyrolytic carbon.

Material	χv [× 10−5 (SI units)]
Superconductor	−105
Pyrolytic carbon	−40.9
Bismuth	−16.6
Mercury	−2.9
Silver	−2.6
Carbon (diamond)	−2.1
Lead	−1.8
Carbon (graphite)	−1.6
Copper	−1.0
Water	−0.91

Table 1: Diamagnetic Materials (Table from byjus.com)

Strong variations in density indicate that the electrically charged part of Saturn's atmosphere (the so-called ionosphere) has a strong coupling to the visible rings that consist primarily of ice particles. The ice particles are also electrically charged. (Wahlund et al., 2017). Saturn's rings are therefore electrically charged and thus must produce an electric field. Because of the charging of the ring and the resulting electric field, the electron and ion densities immediately above the ring will not be equal. (Mitchell et al. 2006). Since Saturn's rings are electrically charged with an associated electric field, it is proposed that the rings must emanate a magnetic field orthogonally above and below the ring plane. As such, Saturn's rings can be considered to be an electromagnetic phenomenon.

The ring's magnetic fields enable the fine grains of silicates covered in pyrolytic carbon to levitate above and below the main ice-ring structures due to their highly diamagnetic nature, thus producing the observed dark and bright 'spoke' structures that rotate in sync with the rotation of Saturn's magnetic field. Analysis of the spectral radiation power of the spokes provides a specific periodicity of about 640.6 +/- 3.5 min which almost coincides with the period of rotation of the magnetic field of Saturn (639.4 min).

Moreover, a strong correlation between the maxima and minima of activity of the spokes with the spectral magnetic longitudes is connected to the presence or absence of the radiation of Saturn's Kilometric Radiation (SKR) (Tchernyi et al., 2020).

The dark ‘spokes’ are most visible at the two seasonal equinoxes as the illumination of the rings is greatly reduced making possible unique observations highlighting features that depart from the ring plane i.e. the levitated fine grains of silicates covered in pyrolytic carbon. The dark ‘spokes’ become visible mainly due to two reasons. The first being due to planet shine from Saturn which reflects off the ice particles in the rings but is absorbed by the fine grains of silicates covered in pyrolytic carbon during the seasonal equinoxes. Secondly, due to varying magnetic susceptibility of the pyrolytic carbon grains caused by the change in the intensity of illumination from the sun.

In 2012, a research group in Japan (Kobayashi et al., 2012) demonstrated that pyrolytic carbon can respond to laser light or sufficiently powerful natural sunlight by spinning or moving in the direction of the field gradient. The carbon's magnetic susceptibility weakens upon sufficient illumination, leading to an unbalanced magnetisation of the material and movement when using a specific geometry. (Wikipedia: Pyrolytic Carbon)

This may explain why the dark ‘spokes’ in Saturn’s rings appear seasonally at the equinoxes when the illumination from the sun is at a minimum. Hence the pyrolytic carbon grains levitate above and below the main ring. Illumination from the sun causes a weakening of the pyrolytic carbon's magnetic susceptibility, causing the pyrolytic carbon grains to return back to the main ring.

Mechanism using simple atomic orbital model

The mechanism for carbon’s weakening magnetic susceptibility upon sufficient illumination due sunlight may be explained using the photoelectric effect. For pyrolytic carbon to be highly diamagnetic ie repelled by a magnetic field, its atoms must have an unusual electronic configuration of $Is^2 2s^2 2p_x^2$ (violates Hund’s Rule) so that it has no unpaired electrons.

Upon sufficient illumination due to sunlight the photoelectric effect (Fig 7.) occurs causing the pyrolytic carbon atoms to lose one of their $2p_x$ electrons thus making these atoms paramagnetic ie having an unpaired electron, hence the grains of silicates covered in pyrolytic carbon move back to the main ring ie they are now attracted towards the magnetic field emanating orthogonally from the rings.

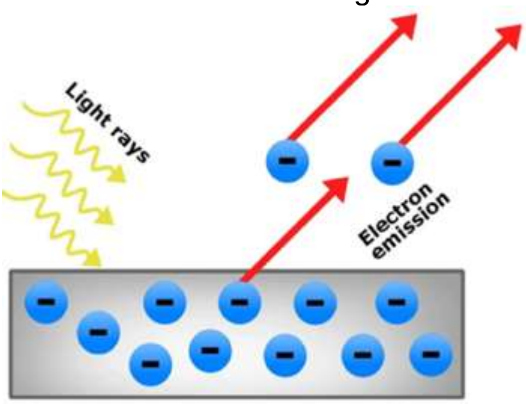

Fig 7: Photoelectric effect: Light hitting a piece of graphite releases electrons (Image credit atomstalk.com)

Mechanism using complex molecular orbital model

During the process of Chemical Vapour Deposition (CVD) of methane gas the carbon atoms would share sp^2 electrons with their three neighbouring carbon atoms. Thus, forming a layer of honeycomb network of planar structure, which is also called monolayer graphene. (Yang, 2018)

In pyrolytic carbon these monolayers would form a turbostratic structure i.e the graphene layers are arranged without order.

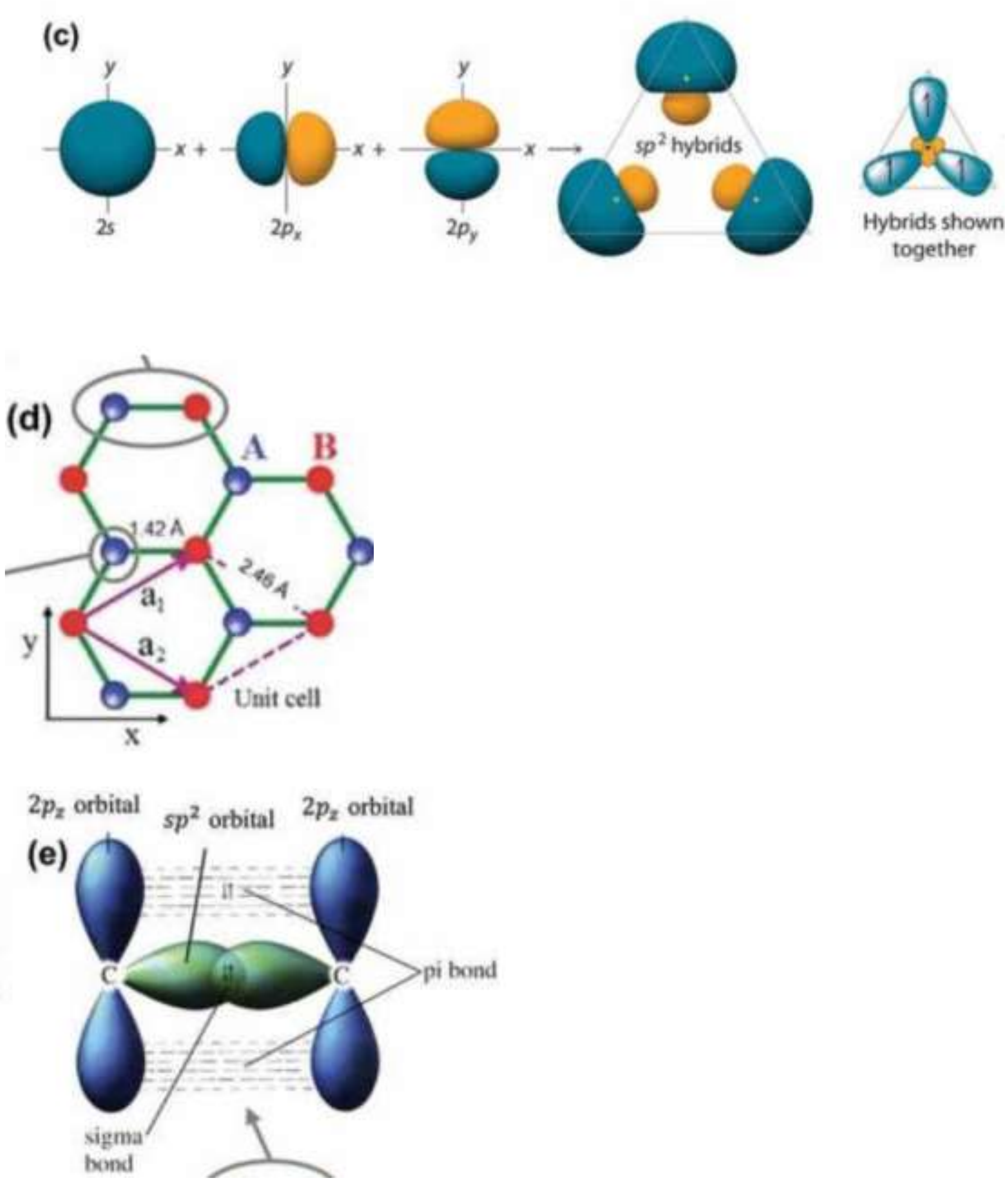

Fig. 8: (c) The formation of sp^2 hybrids. (d) The crystal lattice of graphene, where A and B are carbon atoms belonging to different sub-lattices, a_1 and a_2 are unit-cell vectors. (e) Sigma bond and pi bond formed by sp^2 hybridization. (Yang, 2018)

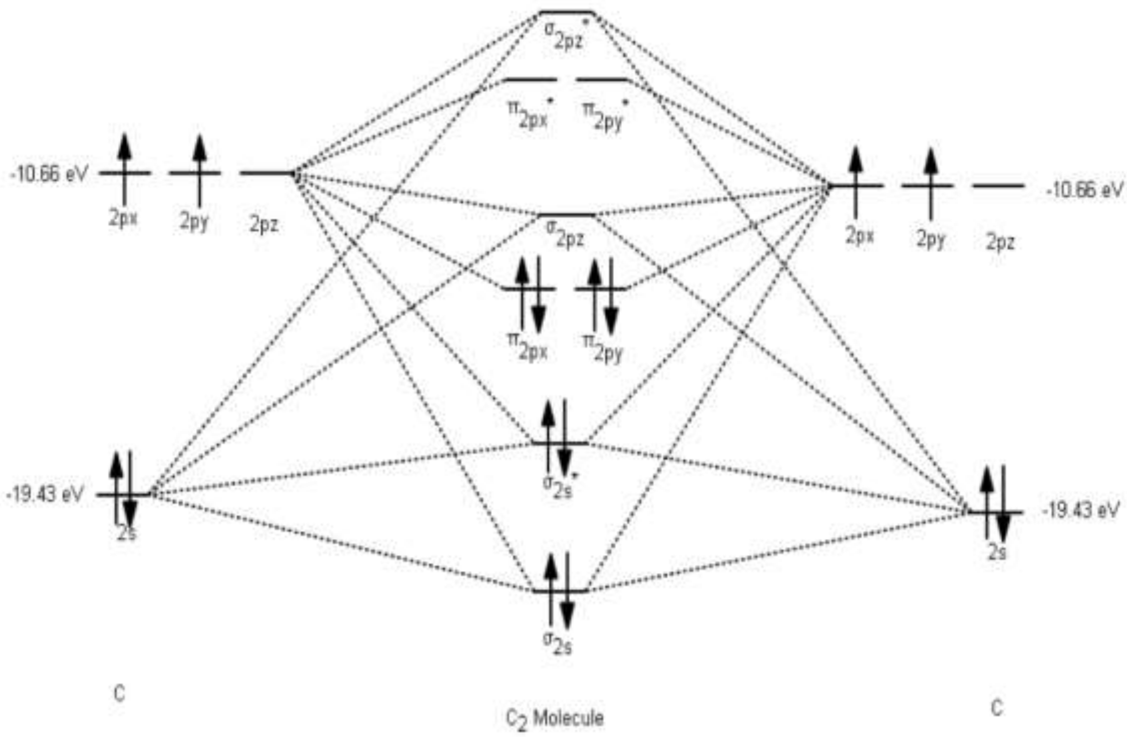

Fig 9: Molecular orbital bonding in C_2. (Socratic.org)

and C_2 has this configuration:

$$(\sigma_{1s})^2(\sigma_{1s}^*)^2\overbrace{(\sigma_{2s})^2(\sigma_{2s}^*)^2(\pi_{2p_x})^2(\pi_{2p_y})^2}^{\text{valence electrons}}$$

Since C_2 has no unpaired electrons, it is diamagnetic. Hence the sp^2 hybridized carbon-carbon bonds formed in pyrolytic carbon would also be all diamagnetic making pyrolytic carbon the most diamagnetic material known at room temperature.

When sunlight of a specific frequency hits the pyrolytic carbon the surface atoms delocalized π electrons are lost due to the photoelectric effect causing the pyrolytic carbon to now become paramagnetic and is thus attracted towards the magnetic field emanating from the rings.

DISCUSSION

Only when the sun is at the equinoxes resulting in illumination of the rings to be at a minimum, does the plasma density above and below the rings reach a maximum. This results in the pyrolytic carbon structure/atoms to each gain an electron thus becoming diamagnetic causing them to levitate above and below the rings making the dark 'spokes' in Saturn's rings visible due to the backscattering of light (Fig 11).

This proposed mechanism suggests that the rings produce a magnetic field which emanates orthogonally above and below Saturn's ring plane.

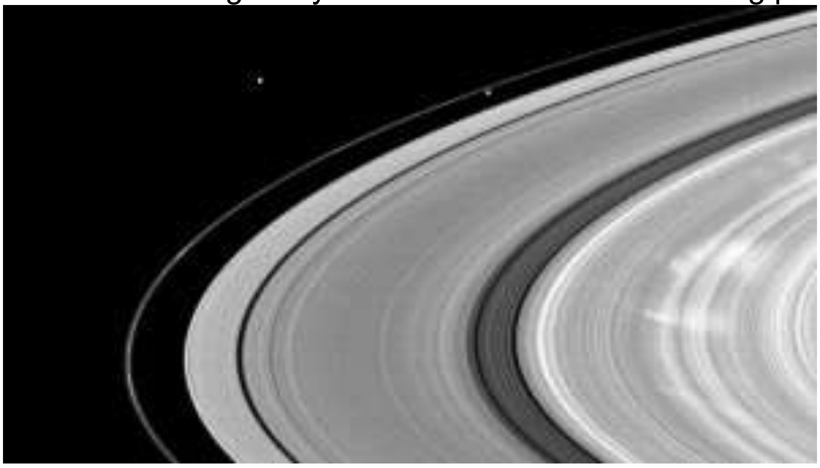

Fig 10: Bright spokes in Saturn's B ring observed by Cassini (Smithsonian National Air and Space Museum

The bright 'spokes' in Fig 10 above, are visible on the unilluminated side of Saturn's rings when the sun's illumination of the rings is at a maximum (directly below or above the ring plane). The bright 'spokes' can be explained due to the forward scattering of light (Fig 11.) caused by the grains of pyrolytic carbon which are levitating above the plane of Saturn's rings.

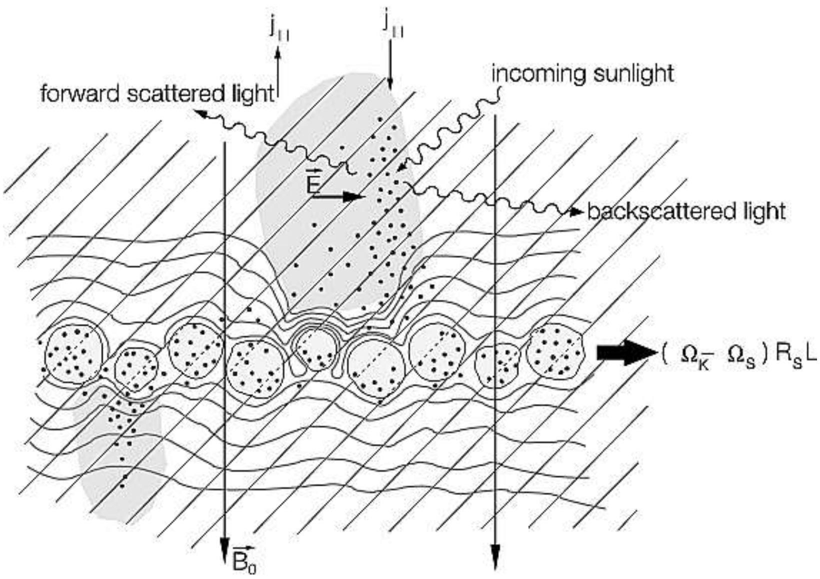

Fig 11: The forward scattering and back scattering of light by the 'spoke' grains (Reviews of Geophysics, AGU).

The bright ‘spokes’ which appear on the illuminated side of Saturn’s rings may be due to the sunlight reflecting off the small, levitated ice particles. These small ice particles are also highly diamagnetic but unlike the silicates covered in pyrolytic carbon, they remain unaffected by natural sunlight i.e they are not magnetically susceptible to natural sunlight ie the photoelectric effect will not occur, so they remain levitated above Saturn’s main rings. Hence, the bright ‘spokes’ should always be observable given sufficient illumination by the sun and the correct angle of observation by the observer. The bright ‘spokes’ may suddenly disappear when the illumination of the sun reaches a critical point, causing the levitated ice particles to sublimate due to the intensity of the sunlight.

Cassini / VIMS Spectrometer

On 2008, July, the Cassini/VIMS spectrometer detected spokes on the Saturn’s B ring for the first time. These are the first measurements of the complete reflectance spectrum of spokes in a wide spectral range (0.35-0.51 µm) Fig 12. Until now, only one spoke, imaged by VIMS on July 9th, has been studied in some details. The spectrum is consistent with a population of spheroidal water ice particles with a quite wide size distribution centered at about 1.90 µm (modal radius), i.e. substantially greater than previously thought. (Adversa et al., 2011).

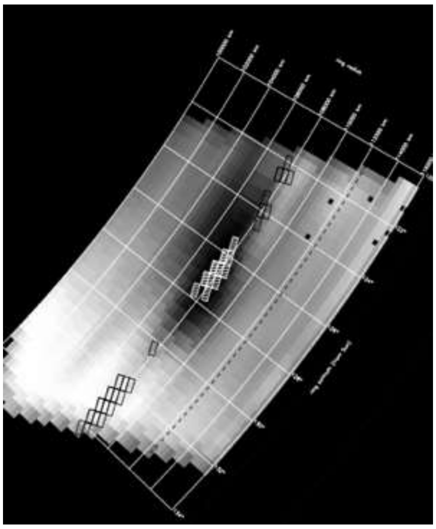

Fig. 12: Cassini/VIMS spectral image of a spoke which is very enhanced after azimuthal reflectance normalization (λ=2.23 µm (Adsersa et al. 2011)

The spectral analysis findings from the Cassini/VIMS image verifies that the bright ‘spokes’ on the illuminated side of Saturn’s rings are ice particles. Although H_2O dominates the near-IR spectra of the rings, their steep decline in reflectance shortward of about 0.6 µm must be due to something else [see, e.g., Esposito et al. (1984) for a review of ground-based observations of the rings’ visible spectrum]. Although early interpretations focused on silicate and/or sulfur-bearing minerals as the most likely colouring agents, recent studies of the rings’ visible and near-IR spectra have identified tholins—reddish, organic-rich, refractory materials suspected to be present in the atmosphere of Titan and on the surfaces of many red outer Solar System bodies, such as Pholus (Wilson et al., 1994; Cruikshank et al., 1998, 2005a)— as the most likely agents responsible for the distinctly reddish colour of the rings at visual wavelengths.

In a study of the colour of Saturn's rings, Cuzzi and Estrada (1998) found that the particles in the A and B rings contain a material which imparts a distinct red colour, while the particles in the C ring and Cassini Division are lower in albedo and less red in colour. They note that "No silicates have the appropriate combination of steep spectral slope and high absorptivity to explain the rings' visual colour while remaining compatible with microwave observations." Titan tholin matches the colors and albedos of the particles when incorporated into the H_2O ice grains. To explain the lower albedo and more neutral colour of the darker rings, Cuzzi and Estrada (1998) suggest that "material with properties like carbon black, as seen in at least some comets and interplanetary dust particles, is needed." Subsequent modeling of the rings by Poulet and Cuzzi (2002) and Poulet et al. (2003) also incorporated tholins and amorphous carbon to achieve fits to the observational data in the 0.3–4.0 μm range. Poulet et al., concluded further that, for the A and B rings, while the carbon grains are intimately mixed in a "salt and pepper" fashion with the ice, the tholins are mixed at the molecular level within the ice grains themselves. (In the C ring, however, their best-fitting model consists of a mixture of crystalline water ice grains of three different sizes, some of which contain molecular inclusions of both tholins and amorphous carbon.) Unfortunately, tholins exhibit relatively few and weak absorption features in the VIMS near-IR region (Cruikshank et al., 2005a), except at wavelengths near 3.0 and~4.5 μm where water ice is also highly absorbing. Thus, we have not so far found specific supporting evidence for tholins in the infrared portion of the VIMS SOI spectra. (Nicholson et al. 2008)

No dark 'spokes' will be observable on the underneath side of the main rings due to the illumination from the sun causing the pyrolytic carbon grains to move back to the main ring due to the photoelectric effect ie the pyrolytic carbon grains (atoms/sp^2 hybridised carbon-carbon bonds)) lose an electron and become paramagnetic and move back to the main ring due to being attracted to the magnetic field emanating from the main ring. The dark 'spokes' become visible only at the equinoxes due to the sun's minimum level of illumination of the rings and back scattering of light. The plasma density above and below the main rings increases to a maximum causing the pyrolytic carbon grains atoms to be 'recharged' i.e gain an electron, thus they become diamagnetic, causing them to levitate above and below the ring plane.

The visibility of the 'spokes' at the equinoxes could also be related to the amount of Saturn-shine as suggested by Hedman et al. 2017. "We will highlight the importance of including illumination sources other than the Sun in the radiative transfer analysis, namely the Saturn-shine and the ring-shine". (Hedman et al. 2017)

CONCLUSION

The chemical process of flash vacuum pyrolysis has converted hydrocarbons such as methane to pyrolytic carbon at temperatures above 1400K during the protoplanetary disk formation of Saturn. The pyrolytic carbon has coated the fine grains of silicates through the process of Chemical Vapour Deposition (CVD). The silicates coated in pyrolytic carbon are now able to levitate above or below a magnetic field due to the highly diamagnetic nature of pyrolytic carbon.

Depending on the angle and frequency of the sunlight hitting the fine grains of silicates coated in pyrolytic carbon the photoelectric effect will cause the ejection of a delocalized π electron from the sp^2 hybridized pyrolytic carbon atoms/bonds. The pyrolytic carbon atoms become paramagnetic; thus, they will now return back to the main ring as they are attracted to the magnetic field emanating from Saturn's rings.

The dark 'spokes' in Saturn's rings are only observable at the equinoxes due to the minimum illumination of its rings by the sun. The bright 'spokes' should be visible when the sun is above or below the plane of Saturn's rings. Therefore, it can be concluded that Saturn always has 'spokes' but their type either dark or bright depends of the position of the sun relative to Saturn and the angle at which the observer is observing the rings.

Saturn's rings are an electromagnetic phenomenon as suggested by Russian Professor Vladimir Tchernyi. Saturn acts like a gigantic electromagnet, as such it creates electromagnetic fields which encompass the equatorial region of the planet. These electromagnetic fields consist of magnetic fields which emanate orthogonally above and below the ring plane. Saturn's rings are analogous to the magnetic field lines produced in a laboratory using a neodymium magnet and iron filings as shown in Fig 13. below.

Fig 13: The Magnetic field lines created by a neodymium magnet looks similar to Saturn's rings

It is also predicted that the recent samples taken from the carbonaceous asteroids Bennu and Ryugu will contain a large quantity of pyrolytic 'diamagnetic' carbon. Further research is suggested concerning the processes of pyrolysis and gasification as possible chemical processes that may help to explain where all Earth's water originated from.

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