International Journal of Advanced Research in Chemical Science (IJARCS)
Volume 9, Issue 2, 2022, PP 17-25
ISSN No. (Online) 2349-0403
DOI: http://dx.doi.org/10.20431/2349-0403.0902003
www.arcjournals.org

Synthesis of Organic Molecules in the Interstellar Medium: A Review

A. Magaji[1,2], E.E Etim[1,*], G.O Ogofotha[1]

[1]*Department of Chemical Sciences, Federal University Wukari, Nigeria.*
[2]*Department of Chemistry, Bayero University Kano, Nigeria.*

Corresponding Author:** ***A. Magaji, *Department of Chemical Sciences, Federal University Wukari, Nigeria*

Abstract: *Both simple and complex organic compounds are synthesized during the creation of stars and expelled into the interstellar space and dispersed in the galaxy environment. It is well known that these organic compounds are scattered in the interstellar medium or space via stellar winds. Circumstellar and Astronomical molecular mists envelopes are manufacturing ground for the synthesis of giant organics. Also, it is significant to disclose abiotic pathways to prebiotic organic molecules in the terrestrial environments. Astonishingly great amount of organics that are used in modern biochemistry in the World are detected in the interstellar space, comets, astral surface and atmospheres, meteorites and asteroids and astronomical grain particles. Above eighty gaseous state organic molecules, such as C_2H_2, H_2CO, CH4, CH_3CN (molecules), C_3, C_2H and HCO+ (radicals), C_3H_2 (rings), HC_3N, HC_7N and HC_5N (chains) etc. are manufactured in the interstellar space.*

1. Introduction

The uncovering of an enormous number of gaseous organic molecules in the stellar medium via their vibrational and rotational shifts offered us the principal indication that organic substance can be logically synthesized in intergalactic space. Solid phase molecules generally stated as dust or grains in astrophysical texts have been noticed to occur in the astral medium via the technique of selective annihilation for about a century. Initial proposals of the organic molecular structure of astronomical solids comprised iron, ice and graphite. The discovery of the 10 μm silicate piece in growing stars and in the interplanetary medium in the late 1960s resulted to the recognition that natural resources such as amorphous (formless) silicates are a key constituent of astronomical solids (Woolf and Ney 1969). Even though the presence of organic entities in interstellar has been speculated for quite a number of time, this hint been taken for granted by the astronomical society until in recent times. There is now durable confirmation that complex organic molecule is extensively present in the astral space, in the stellar region of stars, in astronomical clouds, in the diffuse astrophysical medium, and in cold galaxies, (Etim and Arunan, 2015, 2016, 2017;, Hoyle and Wickramasinghe 1977 and Knacke, 1977).

The creation of complex organic molecules has been assumed to take place principally during the astronomical warming from icy cores to scorching cores primarily relating diffusive reactions on dusts resulting to further saturated species, notwithstanding for numerous species only intense at advanced temperatures greater than 10K, Viti et al., (2004). These reactions advance mostly via recombination or connection of radical species on grainy surfaces; the originator radicals are molded from additional standard species by photo disconnection, Garrod (2013); Garrod (2008) and Garrod et al., (2008).

As star creation continues and temperatures increases, thermal desorption progressively come about, until 100 K, complex organic molecule can be identified in the gaseous state. Howbeit for selected time, the progressive warming of star creating cores was alleged to be a pre-requisite designed for complex organic molecular chemistry, it was in the long run understood that the warming state was not the entire process for the reason that certain number of gaseous phase complex organic molecules are principally methyl formate and dimethyl ether that were identified in the gaseous phase of icy cores at temperatures around 10K, which are lesser than assumed to be proficient enough for the formation of complex organic molecules on dust or grains, Bacmann et al., (2012). Propositions were formerly made that gaseous phase routes could result to the synthesis of complex organic molecule, at such low temperatures, Balucani et al., (2015). The most important process proposed is recognized as radioactive association which is further explained below. Many other propositions relating novel surface procedures have been made as well (Jin and Garrod, 2020), and the circumstance remains unsettled till date. For the moment, carbon chained species were as well discovered in warmer stellar region than icy cores, carbon chain study, is believed to have started with the desorption of unstable (volatile) species on cold dust grains (methane) at temperatures as little as 30 kelvin, which starts a second stage of carbon chain creation via gaseous state ion-neutral processes, Sakai and Yamamoto (2013).

2. Origin and Distribution of Complex Organics in the Universe

Kwok (2004) stated that giant organic compounds are now recognized to extensively exist in the Cosmos, from Astrophysical System entities to far galaxies. These organic molecules are manufactured non-biologically, and do not signify breakdown products of existing beings. Similarly, virtually all of the giant organic molecules on Globe are originated biologically, therefore making the Globe exclusion to the extensive existence of non-biological organic compounds in the World. Even though the precise paths of synthesis are unknown, it is generally assumed that these giant organics are manufactured from light organics, moreover, either via chemical or gas-phase reactions on solid state planes. In the astrophysical society, there is a lot of curiosity on the likelihood of organic synthesis occurring in star developing regions, due to weighty concentrations of gaseous state organic molecule in these objects. In the astronomical science society, the genesis of giant organic molecules in Astral System entities is frequently traced to the initial epochs of the Astral System, even if transportation from Astral medium to the prehistoric solar nebula has already been deliberated. The only tangible observable evidence for the synthesis of organic molecules occurs in interstellar envelopes. Throughout the asymptotic complex branch phase of development, the carbon element is formed via triple-α reactions in the astral core and conveyed to the plane through convection. Owing to prolonged atmospheric and low temperatures of these stars surfaces, light molecules for example CN C2 and C3 are synthesized in the interstellar atmosphere and emitted by astrophysical wind. Within the circumstellar envelopes shaped by interstellar wind discharges, above 80 gaseous state organic molecules, such as C_2H_2, H_2CO, CH4, CH_3CN (molecules), C_3, C_2H and HCO+ (radicals), C_3H_2 (rings), HC_3N, HC_7N and HC_5N (chains), are manufactured. All the organic molecules are synthesized within the dynamical periods of the discharge, which is approximately 104 years. After the astral wind finally diminish the astrophysical envelope, and circumstellar atmosphere is open to progressively more active radioactivity as the astral core is slowly exposed. On this platform it gives room for the synthesis of aliphatic and aromatic compounds. We consequently have tremendously solid observational restrictions that giant organic molecules are produced in low-density environs over very limited duration (Etim et al., 2016, 2017a, b, c, 2018, 2020, 2021)

Meanwhile above 90 % of the total stars in the Galaxy undergo this phase of evolution, a very huge sum of giant organic molecules are generated by stars. It is well known that these organic compounds are dispersed in the interstellar medium via stellar winds. However the information about whether the organic compounds synthesized in interstellar medium further transformed into other molecule or destroyed which are not known or documented. It would be irrational to adopt that the initial Astral System inherited a number of these astrophysical material, as the stellar organic molecules of meteorites show notable resemblances to stellar synthesized organic molecules. Meanwhile the organic biomarkers are predominantly strong in ultra-luminous clusters; it is accepted to adopt that the excitation and production of organic molecules in galaxies are associated to the star creation process. Ever since the spectra of clusters denote integrated light yield from the whole cluster, we do not have any statistics on the spatial dispersal or genesis of such organic compounds. We had no information, nevertheless, that organic synthesis occurred in the Cosmos virtually as soon as carbon is manufactured and organic synthesis is common in the Earth. The interstellar space, comprising the premature Earth, was widely bombarded by exterior entities between 4.5 to 3.8 billion years in the past. This has led to assumptions on externally conveyed organic molecules to Earth may have possibly influenced the starting point of life on terrestrial as explained by Chyba and Sagan (1992) and Anders (1989).

As described by Ehrenfreund et al. (2002), it is estimated that the amount of interstellar organics molecule conveyed to Cosmos by asteroids, comets, and Astral Dust particles in the course of the weighty bombardment era surpass those synthesis from earthly sources via Ultra-violate photolysis, electrical discharge from hydro-thermal exhausts by numerous orders of degree. To what degree can these interstellar organic compounds survive and remain intact till the period of delivery is reliant on the mode of energy loss throughout the passage via the atmosphere. Energy emission or loss via radiation has to surpass that of thermal breakdown of organic molecule so as for the organics to survive despite the impact. It is estimated that smaller constituent part such as astral dust particles may be more effectual in the distribution of organic molecules (Pasek 2016). If outer transfer of organic compounds played a key part in the enlargement of life on extra-terrestrial, then comparable situations will also apply to other planetary entities in the Cluster. Meanwhile planetary structures are now commonly recognized in our Cluster or Galaxy (Winn and Fabrycky 2015), related organic enhancement by astral ejecta may have transpired in other planetary structures.

3. Astronomical Clouds

Circumstellar and Interstellar molecular mists envelopes are manufacturing sites for synthesis of complex molecular compounds as described by Kwok (2004); Ehrenfreund and Charnley (2000) and van Dishoeck and Blake (1998). The astral cloud constitutes a minute percentage of the astronomical mass which comprised of majorly hydrogen and helium. They are augmented principally by matter emitted from generating stars and can differ intensely in their ultimate physical factors such as density and temperature. Interstellar material is dominated by gas, also comprises about 1% of slight micron-sized particles. Gas–grain and gas-phase collaborations result to the materialization of giant molecules. Surface catalysis on stellar dust materials enables molecule creation and chemical conduits that cannot progress or proceeds in the gas phase due to reaction obstructions as stated by Cuppen and Herbst (2007) and Ehrenfreund and Fraser (2003). The most plentiful molecule in icy astronomical regions is hydrogen, followed by carbon (ii) oxide which is the moist profuse carbon compound having approximately 10^{-4} CO/H_2. It is categorized by a great binding energy of 11.2 eV and powerfully impacts the chemistry in astronomical clouds. There are two key categories of stellar clouds that motivate molecular synthesis. The temperature is minimal (about 10K), in icy dark clouds and thus the sticking coefficient of major molecules and atoms are close to unity, resulting to a restriction of virtually all species exception of hydrogen and helium. The extraordinary density in dark clouds is about 10^6 cm^{-3} reduces ultraviolet radiation and bids secure vicinities for the synthesis of complex molecules by gas phase interaction and cold chemistry on grains. Several giant organic molecules in gas-phase were recognized via infrared, millimeter, sub-millimetre and radio observations (www.astrochemistry.net lists more than 150 molecules). These compound includes; nitriles, alcohols, aldehydes, acids, ketones, ethers, amides, amines and long chain hydrocarbons. The highest species detected in interstellar icy layers are carbon (iv) oxides, carbon (ii) oxide, methanol and water, with minor addition of ammonia, methanoic acid, methane and H_2CO, Gibb et al., (2004). A modern core to disks Spitzer investigation of ices examined the 6-8 mm section that shows the noticeable bending mode of H_2O ice. The Five self-determining constituents that can be ascribed to eight diverse carriers have been recognized, Boogert et al. (2008). Investigation of carbon (iv) oxide in low-mass proto-stars displayed high profusions (about 32% comparative to water ice), Pontoppidan et al., (2008). Methane ice was perceived in 25/52 targets, with relative abundances fluctuating from 2-8% relative to H_2O ice and extent to 13% in a rare cases, Oberg et al., (2008).

4. Entity in the Astrophysical System

Boss (2004) stated that, the gravitational flop of an interplanetary cloud resulted to the realization of the proto-solar nebula, an instrument by which small bodies and planets emanate from in our Solar System. Carr and Najita 2008 carried out Investigation of proto-planetary disks indicate that solid and gaseous float inward in time. Solids drift inwards quicker than gas, and minor particles propagate up to kilometer-sized structures that grow overtime to form planets. The chemical structure of proto-planetary disks is anticipated to hold hints to the chemical and physical processes that stimulate the creation of planetary systems. In recent times, it was informed that the proto-planetary disks of AA Tauri retain a rich molecular emission band in the mid-infrared, signifying a large quantity of simple organics such as carbon (iv) oxide, hydroxyl group, hydrogen cyanide, ethyne and water vapor.

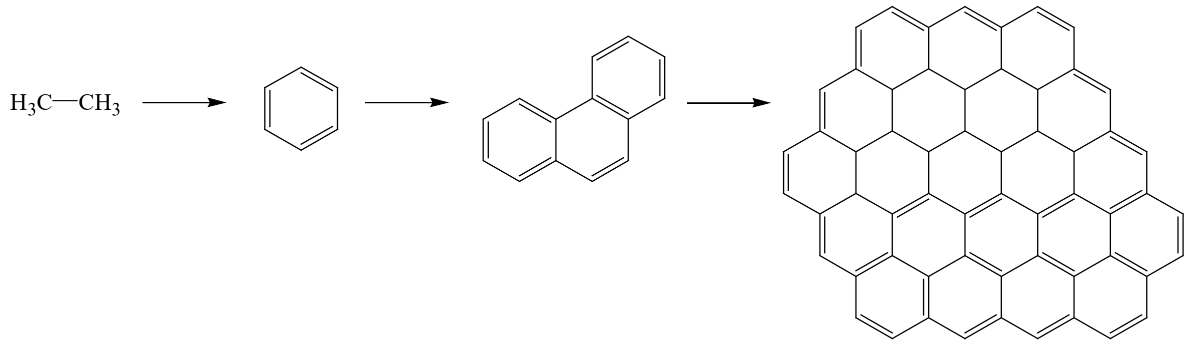

Figure1. *Chemistry of Ethyne resulting in the synthesis of benzene and simple Polyaromatic compound the that successively build up complex molecular structured molecule, it has been anticipated to transpire in circumstellar envelop of carbon-rich shielded environs, Kwok (2004) and Kwok (2009)*

Aromatic constituents, in gaseous and solid state consist the principal portion of organic substances in the Universe Allamandola et al., (1999) and Salama (1999). Statistics from modern space operations (the Spitzer telescope), Deep Impact and Stardust, demonstrate that the dynamic environs of the astral nebula with the concurrent existence of gas, particles and active processes, comprising radiation, shockwaves and lightning can initiate synthesis of organic molecules Gorti et al., (2009). Stormy motion result to centrifugal mixing of the products contained in the disk, which has been established by Stardust information as explained by Dullemond et al., (2008), Visser et al. (2007) and Cruikshank et al., (2005). The carbonaceous catalog of our Stellar System hence comprises a combination of material that was (a) extremely processed by disclosure to intense radiation and temperatures, (b) freshly molded in the astral nebula, and (c) seized as relatively virgin material with substantial astronomical inheritance. Numerous organics are sampled from our interstellar, together with comets, planetary atmospheres and interstellar dust Raulin (2008); Cruikshank et al., (2005) Sephton and Botta (2005) and Ehrenfreund and Charnley (2000). Above fifty organic molecules have been recognized in the interstellar space as reported by Crovisier et al., (2009) and Di Santi and Mumma (2009). The examination of carbon containing compounds in fragments of asteroid 2008 TC3 in recent time exposed fascinating intuitions into the interstellar chemistry as reported by Jenniskens et al. (2009). Micrometeorites and meteorites (carbon-containing chondrites), which signify part of asteroidal and comet bodies, it consist of diverse organic molecules, Sephton and Botta (2005) and Sephton (2002). In the soluble portion of the Murchison meteorite, above seventy other interstellar amino acids have already been recognized aside several other organics, comprising aromatic and aliphatic hydrocarbons, n-heterocyclic, phosphoric and sulfonic acid, carboxylic acids (Martins et al., (2008); Martins et al., (2007); Ehrenfreund et al., (2001) and Cronin and Chang (1993)). Though, the key carbon constituent in meteorite samples is consists of a complex molecular organic fraction Alexander et al., (2007). A current examination by means of ultra-high resolution molecular exploration of the solvent-reachable organic fraction of Murchison exhibit high molecular multiplicity, Schmitt-Kopplin et al., (2010).

5. Association with the Interstellar Space

Laboratory examination of interstellar dust particles and meteorites obtained in the astral space indicates signatures of giant organic molecules. The features (3.4μm) seen in proto-planetary nebulae are discovered in Interstellar dust particle, Keller et al. (2004) and Flynn et al. (2003). The unsolvable organic substance in carbonaceous chondrite meteorites is said to have a molecular structure comparable to kerogen as studied by Derenne and Robert (2010). The nuclei of comets are assumed to comprise substantial aggregates of organic compounds instead of being dull-snowballs, Sandford et al. (2006) and Cody et al. (2011). The colors of asteroids signals the existence of organic compounds, Cruikshank et al. (1998) and these could be established by upcoming sample return operations. Meanwhile, Titan haze displays the 3.4μm features comparable to those observed in proto-planetary nebulae, Kim et al. (2011). Current investigation of interstellar and circumstellar spectra has revealed that there is a durable aliphatic constituent and the conveyor is more stable with blended aliphatic/aromatic compound similar in chemical constituent to the Interstellar organics, Kwok and Zhang (2011).

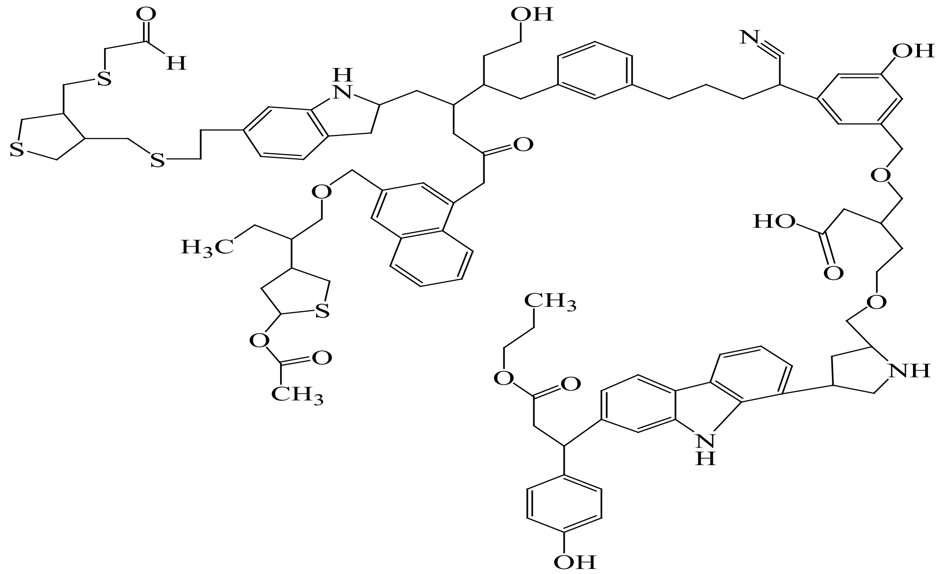

Figure2. *The chemical structure is described by an extremely disordered arrangement of simple units of aromatic rings connected by aliphatic hydrocarbon chains. Sulfur, oxygen and nitrogen are hetero atoms that are commonly in existence and are regarded as impurities. The chemical structure comprises about a hundred Carbon atoms and a typical compound may comprise of numerous structures comparable to this figure obtained from Kwok and Zhang (2011).*

The figure above is a representation of the chemical structure, the resemblance in chemical structure amongst Solar and interstellar System organic molecules which proposed there could connection. It is well recognized that planetary nebulae discharge an enormous amount of gas and dust into the interstellar space, and a portion of the expelled constituents is in form of a complex molecular organic compound. Even though a substantial amount of organic compounds were synthesized by stars, it is indistinct how much quantity of the expelled particles was accreted or fused into the solar nebula, or what quantity of this ancient organics has been transferred to the Earth. It was generally assumed that any astronomical organic compounds in the pre-solar nebula could have been completely ruined and recycled during the creation of the Astrophysical System. Conversely, if the pre-solar organics are in the shapeless solid forms rather than gaseous state molecules; however, complex organic molecules are most likely to survived and be fixed into asteroids, platnetary and comets. The uncover of pre-solar grains centered on isotopic inconsistencies has established that interstellar grains such as diamonds, refractory oxides and silicon carbide can be introduced into meteorites. The premature earth may have acquired organic molecules via accretion process of planet formation or chemically endowed with organic molecules via outer space bombardment by asteroids and comets comprising these astronomical particles as studied by Nittler et al. (1997), Lewis et al. (1987) and Bernatowicz et al. (1987).

6. Conclusion

Currently, carbon chained species were as well detected in warmer astral region than icy cores, carbon chain examination, is thought to have taking place with the desorption of unstable species such methane on icy dust grains at temperatures as minute as 30 K, which starts a second phase of carbon chain conception via gaseous state ion-neutral processes, Sakai and Yamamoto (2013). The wide range of organic molecules recognized by astrophysical interpretations, space exploration and by research laboratory examination of carbonaceous meteorites, proposes that the principal building blocks of life, at least as recognized on the Earth, must be rampant in interstellar systems in our Galaxy and afar, Ehrenfreund et al., (2006). If the early Earth was truly augmented by astral organic molecules, thus existence may have been considerably easier to be initiated owing to the availability of rich required constituent available. Instead of evolving from the scratch, both simple and complex organics such as aliphatic and aromatic constituents of the grains and dust can aid as building material for lipids and nucleic acids.

REFERENCES

Alexander, C., Fogel, M., Yabuta, H. & Cody, G. D. 2007. The origin and evolution of chondrites recorded in the elemental and isotopic compositions of their macromolecular organic matter. Geochimica et Cosmochimica Acta 71, 4380–4403. (doi:10.1016/j.gca.2007.06.052)

Allamandola, L. J., Hudgins, D. M. & Sandford, S. A. 1999 modeling the unidentified infrared emission with combinations of polycyclic aromatic hydrocarbons. Astrophys. J. 511, 115–119. (doi:10.1086/311843).

Anders E (1989) Pre-biotic organic matter from comets and asteroids. Nature 342:255–257

Bacmann, A., Taquet, V., Faure, A., Kahane, C., and Ceccarelli, C. (2012). Detection of Complex Organic Molecules in a Prestellar Core: a New challenge for Astrochemical Models. A&A 541, L12. doi:10.1051/0004-6361/ 201219207

Balucani, N., Ceccarelli, C., and Taquet, V. (2015). Formation of Complex Organic Molecules in Cold Objects: the Role of Gas-phase Reactions. MNRAS 449, L16–L20. doi:10.1093/mnrasl/slv009

Bernatowicz T et al (1987) Evidence for interstellar SiC in the Murray carbonaceous meteorite. Nature 330:728–730

Boogert, A. et al. 2008, The c2d spitzer spectroscopic survey of ices around low-mass young stellar objects. I. H2O and the 5–8 mm bands. Astrophys. J. 678, 985–1004. (doi:10.1086/533425)

Boss, A. P. 2004 From molecular clouds to circumstellar disks. In COMETS II (eds M. Festou, H. U. Keller & H. A. Weaver), pp. 67–80. Tuscon, AZ: University of Arizona Press.

Carr, J. & Najita, J. R. 2008 Organic molecules and water in the planet formation region of young circumstellar disks. Science 319, 1504–1506. (doi:10.1126/science.1153807)

Chyba C, Sagan C (1992) Endogenous production, exogenous delivery and impact-shock synthesis of organic molecules: an inventory for the origins of life. Nature 355:125–132.

Cody GD et al (2011) Establishing a molecular relationship between chondritic and cometary organic solids. Proc Natl Acad Sci. doi:10.1073/pnas.1015913108

Cronin, J. R. & Chang, S. 1993 Organic matter in meteorites: molecular and isotopic analyses of the Murchison meteorite. In The chemistry of life's origin (eds J. M. Greenberg, C. X. Mendoza-Gómez & V. Pirronello), pp. 209–258. Dordrecht, The Netherlands: Kluwer Academic Publishing.

Crovisier, J., Biver, N., Bockelée-Morvan, D., Boissier, J., Colom, P. & Dariusz, C. 2009 The chemical diversity of comets: synergies between space exploration and ground-based radio observations. Earth, Moon, Planets 105, 267–272. (doi:10.1007/s11038-009-9293-z)

Cruikshank DP et al (1998) The composition of centaur 5145 pholus. Icarus 135:389–407

Cruikshank, D., Imanaka, H., Dalle, O. & Cristina, M. 2005 Tholins as coloring agents on outer Solar System bodies. Adv. Space Res. 36, 178–183. (doi:10.1016/j.asr.2005.07.026)

Cuppen, H. M. & Herbst, E. 2007 Simulation of the formation and morphology of ice mantles on interstellar grains. Astrophys. J. 668, 294–309. (doi:10.1086/521014)

Derenne S, Robert F (2010) Model of molecular structure of the insoluble organic matter isolated from Murchison meteorite. Meteoritics Planet Sci 45:1461–1475

Di Santi, M. & Mumma, M. 2009 Reservoirs for comets: compositional differences based on infrared observations, origin and early evolution of comet nuclei. Space Sci. Ser. 28, 127–145. (doi:10.1007/978-0-387-85455-7_8)

Dullemond, C., Pavlyuchenkov, Y., Apai, D. & Pontoppidan, K. 2008 Structure and evolution of protoplanetary disks. Phys. Conf. Ser. 131, 012018. (doi:10.1088/1742-6596/131/1/012018)

Ehrenfreund P, Cami J, Jimnez-Vicente J, Foing BH, Kaper L, van der Meer A, Cox N, D'Hendecourt L, Maier JP, Salama F, Sarre PJ, Snow TP, Sonnentrucker P (2002a) Detection of diffuse interstellar bands in the magellanic clouds. Astrophys J 576:L117–L120.

Ehrenfreund P, Irvine W, Becker L, Blank J, Brucato JR, Colangeli L, Derenne S, Despois D, Dutrey A, Fraaije H, Lazcano A, Owen T, Robert F (2002b) Astrophysical and astrochemical insights into the origin of life. Rep Prog Phys 65(10):1427–1487.

Ehrenfreund, P. & Charnley, S. B. 2000 Organic molecules in the interstellar medium, comets, and meteorites: a voyage from dark clouds to the early earth. Ann. Rev. Astron. Astrophys. 38, 427–483. (doi:10.1146/annurev.astro.38.1.427)

Ehrenfreund, P. & Charnley, S. B. 2000 Organic molecules in the interstellar medium, comets, and meteorites: a voyage from dark clouds to the early earth. Ann. Rev. Astron. Astrophys. 38, 427–483. (doi:10.1146/annurev.astro.38.1.427)

Ehrenfreund, P. & Fraser, H. 2003 Ice chemistry in space. In Solid state astrochemistry, NATO ASI series (eds V. Pirronello, J. Krelowski & G. Manicó), pp. 317–356. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Ehrenfreund, P., Glavin, D., Botta, O., Cooper, G. & Bada, J. 2001 Extraterrestrial amino acids in Orgueil and Ivuna: tracing the parent body of CI type carbonaceous chondrites. Proc. Natl Acad. Sci. USA 98, 2138–2141. (doi:10.1073/pnas.051502898)

Etim, E. E and Arunan, E (2015). Rotational Spectroscopy and Interstellar Molecules. PlanexNews letter, 5 (2): 16-21. Invited mini-review article.

Etim, E. E and Arunan, E (2017). Accurate Rotational Constants for linear Interstellar Carbon Chains: Achieving Experimental Accuracy. Astrophysics and Space Science, 362, 4.DOI 10.1007/s10509-016-2979-6

Etim, E. E and E. Arunan (2016). Interstellar Isomeric Species: Energy, Stability and Abundance Relationship. European Physical Journal Plus, 131:448. DOI 10.1140/epjp/i2016-16448-0

Etim, E. E, Prsanta Gorai, Ankan Das, Sandip Charabati and E. Arunan (2016). Systematic Theoretical Study on the Interstellar Carbon Chain Molecules. The Astrophysical Journal, 832, 144. Doi:10.3847/0004-637X/832/2/144

Etim, E. E., Gorai, P., Das,A., Chakrabarti, S. K and Arunan, E. 2018. Interstellar Hydrogen Bonding. Advances in Space Research, 61(11): 2870-2880, https://doi.org/10.1016/j.asr.2018.03.003.

Etim, E. E., Inyang, E. J., Ushie, O. A., Mbakara, I. E., Andrew, C., Lawal., U. 2017c. Is ESA Relationship the tool for searching for Interstellar Heterocycles? FUW Trends in Science and Technology Journal , 2(2): 665-678.

Etim, E. E., Prsanta Gorai, Ankan Das, and E. Arunan (2017a). Interstellar Protonated Molecular Species. Advances in Space Science, 60: 709-721. DOI: https://doi.org/10.1016/j.asr.2017.04.003

Etim, E. E., Prsanta Gorai, Ankan Das, and E. Arunan (2017b).C_5H_9N Isomers: Pointers to Possible Branched Chain Interstellar Molecules. European Physical Journal D, 71:86. DOI: 10.1140/epjd/e2017-70611-3

Etim, E. E., Prsanta Gorai, Rana Ghosh, Ankan Das. 2020. Detectable Interstellar Anions: Examining the Key Factors. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, Vol: 230, 5, 118011. https://doi.org/10.1016/j.saa.2019.118011

Etim, Emmanuel; Adelagun, ROA; Andrew, Chrysanthus; Oladimeji, Enock. 2021. Optimizing the Searches for Interstellar Heterocycles. Advances in Space Research Journal, https://doi.org/10.1016/j.asr.2021.06.003.

Flynn GJ, Keller LP, Feser M, Wirick S, Jacobsen C (2003) The origin of organic matter in the solar system: evidence from the interplanetary dust particles. Geochim Cosmochim Acta 67:4791–4806.

Garrod, R. T. (2008). A New Modified-Rate Approach for Gas-Grain Chemical Simulations. A&A 491, 239–251. doi:10.1051/0004-6361:200810518.

Garrod, R. T. (2013). A Three-phase Chemical Model of Hot Cores: The Formation of Glycine. ApJ 765, 60. doi:10.1088/0004-637X/765/1/60.

Garrod, R. T., Jin, M., Matis, K. A., Jones, D., Willis, E. R., and Herbst, E. (2021). Formation of Complex Organic Molecules in Hot Molecular Cores through Nondiffusive Grain-Surface and Ice-Mantle Chemistry. arXiv.

Garrod, R. T., Weaver, S. L. W., and Herbst, E. (2008). Complex Chemistry in Starforming Regions: An Expanded Gas-Grain Warm-up Chemical Model. ApJ 682, 283–302. doi:10.1086/588035.

Gibb, E., Whittet, D., Boogert, A. & Tielens, A. G. G. M. 2004 Interstellar ice: the infrared space observatory legacy. Astrophys. J. Suppl. Ser. 151, 35–73. (doi:10.1086/381182)

Gorti, U., Dullemond, K. & Hollenbach, D. 2009 Time-evolution of viscous circumstellar disks due to photoevaporation by FUV, EUV and X-ray radiation from the central star. Astrophys. J. 705, 1237–1251. (doi:10.1088/0004-637X/705/2/1237)

Jenniskens, P. et al. 2009 The impact and recovery of asteroid 2008 TC3. Nature 458, 485–488. (doi:10.1038/nature07920)

Jenniskens, P. et al. 2009 The impact and recovery of asteroid 2008 TC3. Nature 458, 485–488. (doi:10.1038/nature07920)

Keller LP et al (2004) The nature of molecular cloud material in interplanetary dust. Geochim Cosmochim Acta 68:2577–2589

Kim SJ et al (2011) Retrieval and tentative identification of the 3 μm spectral feature in Titan's haze. Planet Space Sci 59:699–704

Knacke RF (1977) Carbonaceous compounds in interstellar dust. Nature 269:132–134

Kwok S (2004) The synthesis of organic and inorganic compounds in evolved stars. Nature 430:985–991

Kwok S, Zhang Y (2011) Mixed aromatic/aliphatic organic nanoparticles as carriers of unidentified infrared emission features, Nature, 479:80–83

Kwok, S. 2004 The synthesis of organic and inorganic compounds in evolved stars. Nature 430, 985–991. (doi:10.1038/nature02862)

Kwok, S. 2009 Delivery of complex organic compounds from planetary nebulae to the Solar System. Int. J. Astrobiol. 8, 161–167. (doi:10.1017/S1473550409004492)

Lewis RS, Ming T, Wacker JF, Anders E, Steel E (1987) Interstellar diamonds in meteorites. Nature 326:160–162

Martins, Z. et al. 2008 Extraterrestrial nucleobases in the Murchison meteorite. Earth Planet. Sci. Lett. 270, 130–136. (doi:10.1016/j.epsl.2008.03.026)

Martins, Z., Alexander, O. D., Orzechowska, G., Fogel, M. & Ehrenfreund, P. 2007 Indigenous amino acids and chiral excess identified in CR primitive meteorites. Meteorit. Planet. Sci. 42/12, 2125–2136. (doi:10.1111/j.1945-5100.2007.tb01013.x)

Nittler LR, Alexander CMO, Gao X, Walker RM, Zinner E (1997) Stellar sapphires: the properties and origins of presolar Al2O3 in meteorites. Astrophys J 483:475–495

Oberg, K., Adwin Boogert, A. C., Pontoppidan, K. M., Blake, G. A., Evans, N. J., Lahuis, F. & van Dishoeck, E. F. 2008 The c2d spitzer spectroscopic survey of ices around low-mass young stellar objects. III. CH4. Astrophys. J. 678, 1032–1041. (doi:10.1086/533432)

Pasek MA (2016) Implications of extraterrestrial material on the origin of life. In: Benvenuti P (ed) Astronomy in focus, vol 1 (in press).

Pontoppidan, K. M., Boogert, A. C. A., Fraser, H. J., van Dishoeck, E. F., Blake, G. A., Lahuis, F., Öberg, K. I., Evans II, N. J. & Salyk, C. 2008 The c2d spitzer spectroscopic survey of ices around low-mass young stellar objects. II. CO2. Astrophys. J. 678, 1005–1031. (doi:10.1086/533431)

Raulin, F. 2008 Astrobiology and habitability of Titan. Space Sci. Rev. 135, 37–48. (doi:10.1007/s11214-006-9133-7)

Sakai, N., and Yamamoto, S. (2013). Warm Carbon-Chain Chemistry. Chem. Rev. 113, 8981–9015. doi:10.1021/cr4001308.

Salama, F. 1999 Polycyclic aromatic hydrocarbons in the interstellar medium: a review, solid interstellar matter. In The ISO revolution (eds L. d'Hendecourt, A. Jones & C. Joblin) p. 65. Les Ulis, France: EDP Sciences, Springer-Verlag.

Sandford SA et al (2006) Organics captured from comet 81P/Wild 2 by the Stardust spacecraft. Science 314:1720–1724

Schmitt-Kopplin, P. Gabelica, Z., Gougeon, R. D., Fekete, A., Kanawati, B., Harir, M., Gebefuegi, I., Eckel, G. & Hertkorn, N. 2010 High molecular diversity of extraterrestrial organic matter in Murchison metoerite revealed 40 years after its fall. Proc. Natl Acad. Sci. USA 107, 2763–2768. (doi:10.1073/pnas. 0912157107).

Sephton, M. A. & Botta, O. 2005 Recognizing life in the Solar System: guidance from meteoritic organic matter. Int. J. Astrobiol. 4, 269–276. (doi:10.1017/S1473550405002806)

Sephton, M. A. 2002 Organic compounds in carbonaceous meteorites. Nat. Prod. Rep. 19, 292–311. (doi:10.1039/b103775g)

van Dishoeck, E. F. & Blake, G. 1998 Chemical evolution of star-forming regions. Ann. Rev. Astron. Astrophys. 36, 317–368. (doi:10.1146/annurev.astro.36.1.317)

Visser, R., Geers, V. C., Dullemond, C. P., Augereau, J., Pontoppidan, K. & van Dishoeck, E. F. 2007 PAH chemistry and IR emission from circumstellar disks. Astron. Astrophys. 466, 229–241. (doi:10.1051/0004-6361:20066829) 59 Brownlee, D. et al. 2006 Comet 81P/Wild 2 under a microscope. Science 314, 1711–1716. (doi:10.1126/science.1135840)

Viti, S., Collings, M. P., Dever, J. W., McCoustra, M. R. S., and Williams, D. A. (2004). Evaporation of Ices Near Massive Stars: Models Based on Laboratory Temperature Programmed Desorption Data. Monthly Notices R. Astronomical Soc. 354, 1141–1145. doi:10.1111/j.1365-2966.2004.08273.x

Winn JN, Fabrycky DC (2015) The occurrence and architecture of exoplanetary systems. Annu Rev Astron Astrophys 53(1):409–447. doi:10.1146/annurev-astro-082214-122246.

Woolf NJ, Ney EP (1969) Circumstellar Infrared emission from cool stars. Astrophys J 155:L18.

www.astrochemistry.net lists more than 150 molecules

Citation: *A. Magaji et al."Synthesis of Organic Molecules in the Interstellar Medium: A Review", International Journal of Advanced Research in Chemical Science (IJARCS), vol. 9, no.2, pp. 17-25, 2022. http://dx.doi.org/ 10. 20431/ 2455-7153.0902003*

Copyright: *© 2022 Authors. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.*