

An Investigatory Chronicle Prepared on the Sun's Heliosphere: An Interstellar Province Encompassed in Cosmology

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Abstract

The Sun, predominantly the elemental source of energy for existence of life on planet Earth is a G-type major sequence star often denoted by G2V which is straightforwardly a yellow dwarf with the light emanating from it is genuinely white. This had been created approximately 4.6 billion years ago from the gravitational collapse of matter surrounded by the prodigiousness, encompassing an outsized molecular cloud. Majority of this matter assembled at the central segment, the remaining portion gets flattened and fixed into an orbiting disk which in due course of time evolved as our most familiar accretion, the solar system. The Sun is positioned at the central core of the solar system. This approximately perfect colossal sphere of hot charged plasma particles encompasses significant heating due to nuclear fusion reactions happening in its innermost core. The starting off the solar wind transpires on account of the outward expansion of the plasma beam of charged particles that takes place from the province of Sun's outermost ambience i.e., the Sun's corona. These charged plasma particles experience an incessant heating mechanism up to a salient point which might be considered as an important point blotch exceeding this bench mark, the gravitational force exerted by the Sun becomes incapable of grasping or sustaining the plasma beam which in turn subsists as solar wind. As a consequence of this phenomenon, the stream of solar wind traverses alongside the Sun's magnetic lines of force extending outward in the radial direction. Projecting outward, the solar wind structures a huge bubble shaped formation in the vicinity of the Sun, the heliosphere. This bulky bubble stretches far apart from the orbits of majority planets of the solar system. The point where the strength of the solar

wind is not so much sufficient to repulse the interstellar medium is named as the heliopause and is frequently deliberated to be the external boundary of the Solar System.

Keywords: Heliosphere, Heliopause, Solar, System, Wind.

Introduction of the Solar Wind as an Ingredient of Interstellar Medium:

In Physical Cosmology and Space Science, the Interstellar Medium for which the scientifically apprehended abbreviation is ISM, can be predefined as the synchronization of cosmologically aggrandized matter and interstellar radiation that subsists in the planetary space stretching between the star arrangements which are standardized as a proper subset of a galaxy. The constituents of the extreme fascinating although mysterious in numerous rationales the 'interstellar substance or cosmological matter' consists of a quantity of gases imminent in the ionic structure, sometimes in atomic manifestation and in addition molecular configuration too together with its supplementary subsidiary general essentials such as dust particles and cosmic rays. It occupies the inter-terrestrial space. As a ramification, it turns out to be fused properly into the contiguous intergalactic cosmological space. This planetary phenomenon generates energy that occupies the identical volume, in the structure of electromagnetic radiation which is the interstellar field radiation.

Even though the density of atoms persists in the Interstellar Medium (ISM) is generally extremely lower as compared to that in the best laboratory vacuums, the mean free path between collisions has been established to be less in comparison to those systematically apprehended characteristic interstellar measurements lengthwise. In next to no time these ascend the ISM to accomplish as a gas or further specifically, as to some extent ionized plasma, actioning in response to pressure forces and not as an assortment of non-interacting particles.

Analysis Performed on the Constituents of Interstellar Medium (ISM)

The ISM is self-possessed scores of stages of matter persists in the ionic, atomic or molecular state together with temperature and density of interstellar matter. The interstellar medium is predominantly made up of hydrogen gas, trailed by helium with extents of carbon, oxygen and nitrogen [1].

The thermal pressures of these numerous scaffolds are maintaining some sort of disturbed equilibrium positions among themselves. Magnetic fields and turbulent motions of the interstellar material i.e., the slightly ionized plasma particles exert pressure too inside the inter-planetary regions and are energetically more significant than the thermal pressures. Persistent plasma waves in interstellar space have been detected by the Voyager 1 space probe.

In the interstellar medium, matter is predominant in molecular form fundamentally and attains number densities of 10^{12} molecules per m^3 which is approximately equal to one trillion molecules per cubic metre measurement scale. In high thermal diffused planetary regions, gas particles are in exceedingly ionized state whose densities are expected to be as low down as 100 ions per cubic metre of the interstellar medium. As per the statistics carried out in terms of mass, 99%

constituents of the ISM are varied gas particles, only 1% of which is dust particles [2]. The hydrogen and helium gases are principally a consequence of primordial nucleosynthesis, while the heavier fundamentals in the ISM are chiefly an upshot of strengthening in the progression of stellar evolution attributable to stellar nucleosynthesis. A numerically aggrandized data reveals that out of the gas constituents of the ISM, numerically 91% of atoms are hydrogen and 8.9% are found to be helium, along with 0.1% being atoms of elements heavier than hydrogen or helium [3], acknowledged as metals in astronomical manner of speaking. While the investigation is performed in terms of mass of the constituent gases, this aggregates to a percentage assessment of 70% hydrogen, 28% helium and 1.5% heavier elements.

1.2 Interstellar Matter:

**Table 1
Constituents of the Interstellar Medium (ISM)**

Sl. No.	Components	Fractional Volumes (in Percentage)	Scale Height (pc)	Temperature (Kelvin Scale)	Density (particles/cm ³)	State of Hydrogen	Primary Observational Techniques
1	Molecular Clouds	< 1%	80	10-20	10 ² – 10 ⁶	Molecular	Radio and Infrared molecular emission and absorption lines
2	Cold Neutral Medium (CNM)	1-5%	100-300	50-100	20-50	Neutral Atomic	H I 21 cm line absorption
3	Warm Neutral Medium (WNM)	10-20%	300-400	6000-10,000	0.2-0.5	Neutral Atomic	H I 21 cm line emission
4	Warm Ionized Medium (WIM)	20-50%	1000	8000	0.2-0.5	Ionized	H α emission and pulsar dispersion
5	H II Regions of Discharged Ions	< 1%	70	8000	10 ² – 10 ⁴	Ionized	H α emission, pulsar dispersion

	Especially of Hydrogen						and radio recombination lines
6	Coronal Gas, Hot Ionized Medium (HIM)	30-70%	1000- 3000	$10^6 - 10^7$	$10^{-4} - 10^{-2}$	Ionized (Metals also Exceedin gly Ionized)	X-Ray emission, absorption lines of highly ionized metals, basically in the ultraviolet

Table Data Courtesy: NASA/ European Space Agency (ESA)

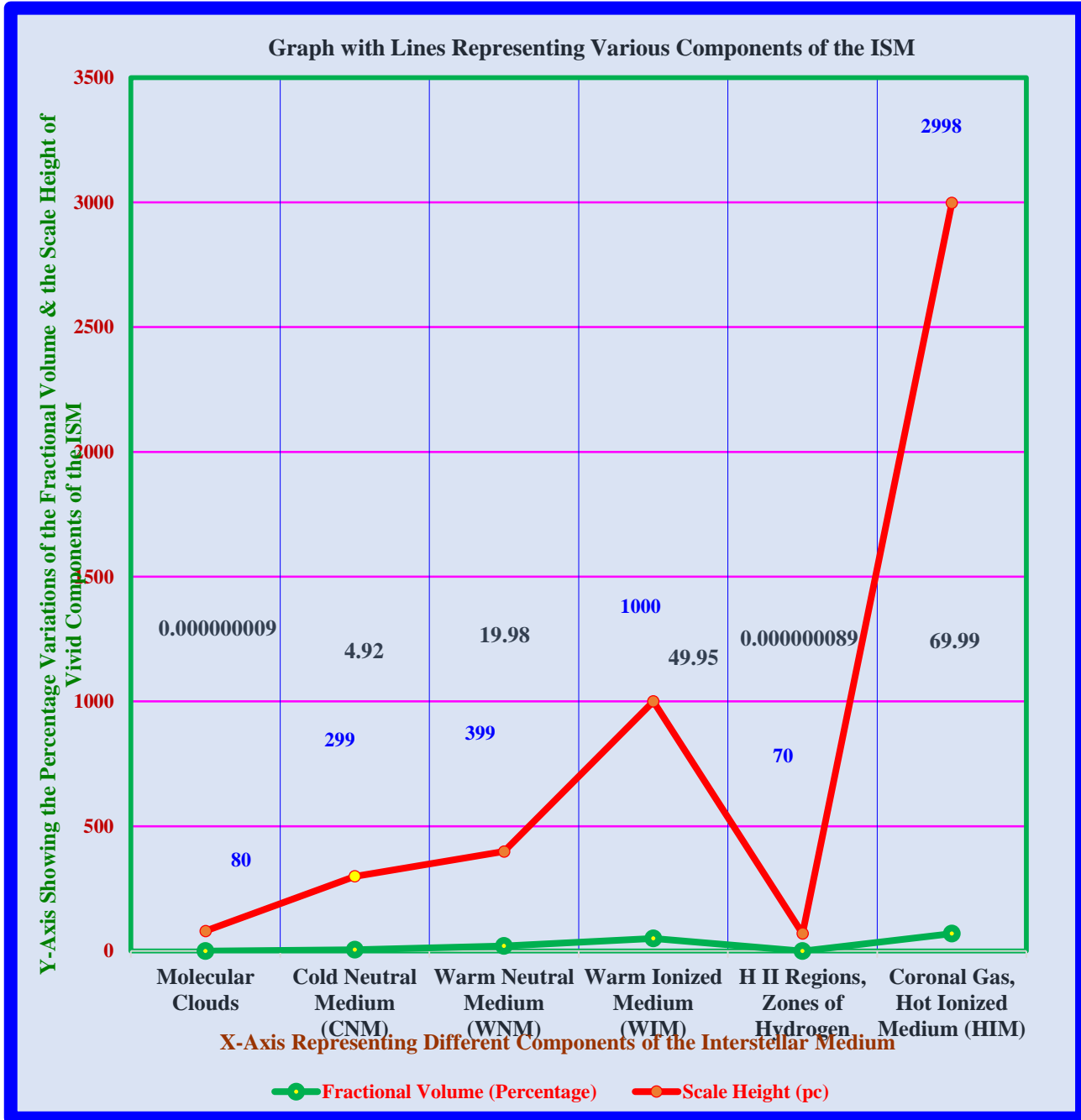


Fig. 1

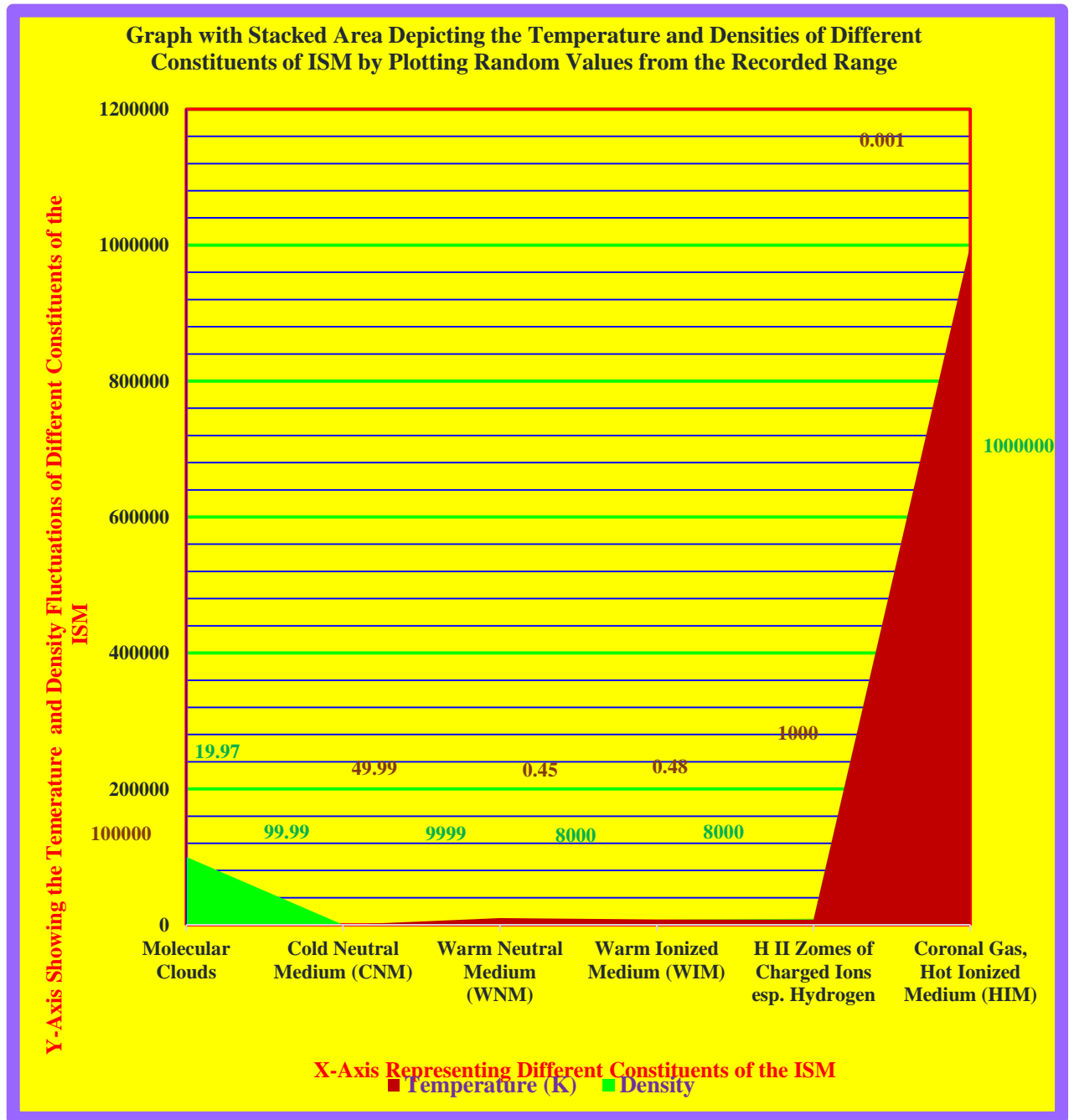


Fig. 2

Province of Standstill Experienced by Solar Wind:

The Interstellar space is encompassed by a dilute gas exhibiting simultaneously neutral and ionized particles. This interstellar region space is wrapping around by a weak magnetic field. Whenever the solar wind does not exist in the planetary medium, the interstellar plasma invades intensely into the solar system. The magnetic fields entrenched in both the plasma intermediates of interstellar and solar wind

prohibits them from interpenetrating one another's arena. As a consequence of this phenomenon, a cavity inside the province of interstellar plasma medium is spontaneously gets stimulated by the present solar winds of the cosmos.

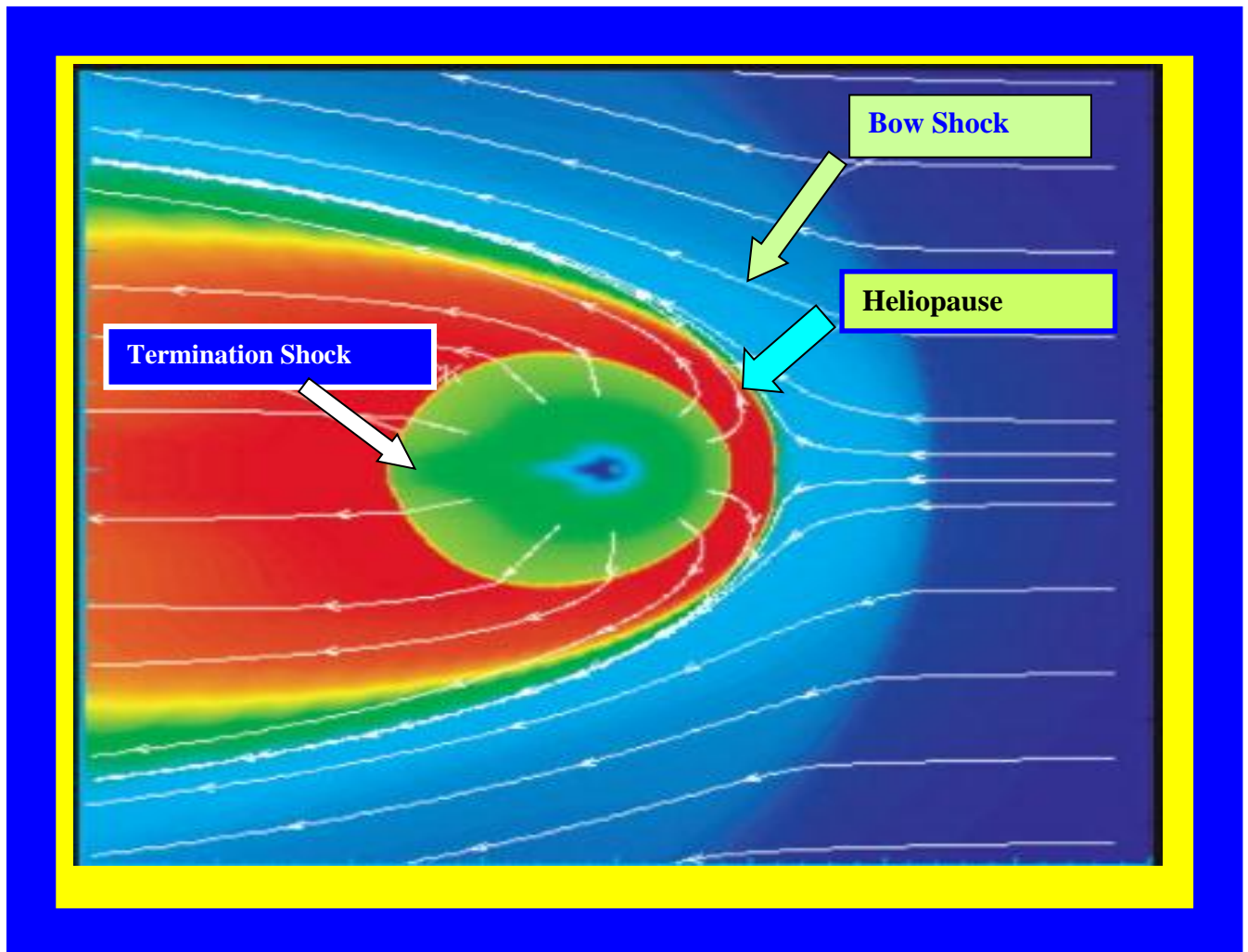


Fig. 3

Image Data Courtesy: G. P. Zank and H. R. Mueller (Diagrammatical Representation)

Fig. 3 flourishes the contemplation of G. P. Zank and H. R. Mueller who jointly put forwarded the simulated configuration of the solar wind's interface with the interstellar plasma. Colour-coding embellished in the figure stand for the temperature of protons while the arrows point towards the direction of the solar wind as well as the flows of interplanetary plasma wave particles.

The features exfoliating the associations of the solar wind with the planetary plasma particles are to some extent still investigatory on an entire sense since till this modern

epoch, the Astrophysicists along with the countrymen are lacked behind from straightforward interpretations of this interstellar interface phenomenon.

Introducing the Heliosphere, the extreme Fascinating Province of the Sun

The heliosphere province of the Sun's ambiance is an enormous, bubble-like structure of space encompassing the solar system which have been created by the Sun's continual ejection of externally- springing out of solar wind that eventually defends the solar system from majority of the strata of interstellar radiation [4].

Formation of the Heliosphere Province of the Sun's Atmosphere:

The heliosphere province has been structured by the solar wind, a torrent of charged particles especially consisting of plasma particles that persistently emanating out in the external direction of the Sun.

Shape and Boundaries:

The shape of the heliosphere is in the structure of a long wind shock since it has been traverses through the interstellar province of space with an end particularly pointing towards the direction of the Sun and stretching a tail like structure spanning in the opposite direction of it.

Termination Shock:

It is that province of space where the solar wind experiences retardation and starts interacting with the interstellar medium of space is referred to as the termination shock.

Heliosheath Province of Space:

It has been the region where the solar wind experiences slowing down effects and became condensed and scorchingly hot is called the heliosheath.

Heliopause Section of the Sun:

It is the boundary segment enclosed between the solar wind and the wind due to the interstellar medium, eventually balancing the pressures generated due to these two winds. This very portion has been named as the heliopause section of the Sun's neighbourhood.

Its functioning is that this heliosphere province of space acts as a shield which correspondingly protects the solar system from a significant amount of harmful cosmic radiation as well as some additional interstellar materials.

The solar wind is configured as a gas of charged particles often referred to as plasma which are ionized particles and exists as the fourth state of matter in the universe. As the solar wind sweeps out into space, this eventually generates cosmological surroundings engrained with radiations as well as magnetic fields that trace all the lines of attack reverse back to the Sun. These surroundings or the cosmological backgrounds of the interstellar space is amplified by the sturdy presence of the planetary cosmic rays and discontinuous concentrated gas clouds of solar material that burst off, known as coronal mass ejections.

This multifaceted cosmological background forms the ambiance of the planets and eventually portrays a vital upshot on the configuration, progression and destiny of terrestrial arrangements of the cosmos. The very fascinating heliosphere executes its functioning as a colossal shield, shielding the planets from galactic cosmic radiation

and thereby defending them from any external terrestrial assets. Furthermore planet Earth is supplementary shielded by its individual magnetic field known as the Earth's Magnetosphere which is providing the vital function of defending the living organisms on Earth from two robust interstellar radiations such as solar and cosmic particle radiation such as cosmic rays where cosmic rays are discharged beams of charged particles emanating from the external terrestrial province that traverse across the cosmos in every permissible direction and strongly stands as protective shield from the erosion caused in the atmosphere due to the presence of solar winds.

The Sun's heliosphere in the broader sense is the expanse neighbouring to the Sun and its pertinent Solar System which is packed with solar magnetic fields accomplished in the sun's magnetosphere together with the protons and electron particles present in the solar wind. The Sun transmits a regular stream of charged particles known as the solar wind which eventually traverse a distance stretching a coverage that past the entire constituent planets of the solar system to a quantifiable numeral which raises to be almost three times the distance to the farthest planet from the Sun i.e., the Pluto beforehand being gets obstructed by the interstellar intermediate material of the cosmos. This conforms to the formation of a gigantic bubble shaped region in the neighbourhood of the Sun and its planets, termed as the heliosphere. The heliosphere performs as a protective shield that secure the planets from harmful interstellar radiation.

Review of Correlated Literary Groundwork and Experimental Evidences Furnished:

Two imperative segments in enduring the edges of the most influential heliosphere are the heliospheric magnetic field and the solar wind from the Sun. Three foremost splinters have been scattered starting right from the heliosphere segment to its ultimate verge viz., the termination shock, the heliosheath and the heliopause. An additional category of particle also has been experientialized along with supplementary cosmological heliospheric observable facts known as Energetic Neutral Atom or abbreviately by ENA.

Five spacecrafts whose names might be voiced in the context of put forwarding a great deal of data regarding this fascinating stratum of the heliosphere are viz.,

- Pioneer 10 [functioning for a tenure of 25 years since 1972 to 1997]
- Pioneer 11 [operational between 1973–1995]
- Voyager 1 and Voyager 2 [come into action in 1977 and are functioning till date] and
- New Horizons [Unleash in the year 2006]

The termination shock was traversed by Voyager 1 spacecraft in the year 2004^[3] and that by the Voyager 2 in the year 2007. It was thought that beyond the heliopause there was a bow shock, but data from interstellar Boundary Explorer (IBEX) recommended that the velocity of the Sun through the interstellar medium is too low for it to structure.^[15] It might be a bit gentler than the experienced bow wave [5].

The data furnished by the Voyager spacecrafts directs to an innovative speculation suggesting that the heliosheath stratum of the cosmos possess bubbles which are magnetic in properties along with a stagnation zone [6]. Additionally, investigations entail about a stagnation region compact within the heliosheath

segment, initializing around 113 Astronomical Unit (A.U.), information has been flourished by the Voyager 1 spacecraft in the year 2010. National Aeronautics and Space Administration (NASA) announced that Voyager 1 had arrive at the interstellar space around 25th August 2012 [7].

In the very year of 2012, NASA proclaimed about the spacecraft that in the later part of August 2012, Voyager 1 at an approximated detachment of 122 AU from the Sun, cross the threshold of a fresh region described as the Magnetic Highway. It is a zone under the stimulus provoke of the Sun. The interpretations harmonize statistics from NASA's Inter Stellar Boundary Explorer or abbreviately IBEX mission to map the boundary line of the solar system. Amidst the Sub Orbital Shields Mission, performed by USA's NASA in 2021, ensemble information on the heliopause section of the cosmos and its remote proximity.

NASA is also exercising a supplementary adventure as Interstellar Mapping and Acceleration Probe or more effectively by IMAP which is all set to begin its action in the year 2025 with a notion to take advantages of Voyager's interpretation and assemble more vivid statistics on cosmological phenomenon [8].

Incongruous Assumption

4.1 Imagination of a Cosmos in the Absence of Heliosphere:

Thinking of a cosmos without the heliospheric structure is basically quite impracticable, unless which we expectantly might not be competent to survive on the planet Earth. This province of interstellar space functions as a protective shield for the living organisms on Earth from the planetary cosmic rays which are proven to be streams of incredibly vigorous particles generated at a great distant which is invented to consistently shower bombardment on the Earth that might cause intense damage to the living cells extant on Earth.

Manoeuvre Grounded on the Diagrammatical Representation of the Sun's Heliospheric Province:

The magnetic field created by the Sun in its heliosphere province bears a unique configuration of dipole moment. The magnetic field lines of force which have been budged or shifted away exterior to the Sun by the hot solar wind are still remain affixed to the Sun's peripheral shell. These magnetic lines of force are traced in the outline of spiral structure since the Sun is constantly rotating in its specified orbit. Due to the revolutionary motion of the Sun around the centre of the Milky Way galaxy, particularly the super-gigantic black hole at its core, commonly recognized as Sagittarius A* [9], the magnetic lines of force have been directed strictly in the inward direction and the other lines of force have been bounded in the externally outward direction in one of the hemispheres and the other in the later hemisphere respectively as per the circumstances demand, exhibited by the Sun i.e., either in the Northern or the other in the Southern hemisphere, this phenomenon of drawing inwards or dragging outwards subsequently transpires. The structure that conforms to the area scraped together between these two hemispheric configurations of Northern and Southern directions has been nomenclature as the heliospheric current sheet.

The solar wind that blows exterior to the Sun's magnetosphere and flows all the way through the solar system which acts as a boundary for the solar wind emanating from the Sun into the interstellar medium (ISM) and eventually it initiates to experience the effects of ISM at the termination shock which is the region where the solar wind institutes to drop its speediness characteristic. The section further than the termination shock region where the speed of the solar wind experiences sluggish behaviour is referred to as the Sun's Helio Sheath. At this stage, neutral atoms inside the heliosheath structure a ribbon liked shape which has been analyzed by the Astrophysicists to be triggered off by the solar wind particles are consequently being bounced back into the solar system by the sturdy magnetic field subsisting in the ISM of the cosmos. The heliopause is the external periphery of the heliosheath. In this region, the outward force (pressure) of the solar wind equilibriums the pressure of inward ISM. The heliopause is habitually well thought-out to be the margin or boundary of the solar system and it results a value of nearly 123 astronomical units for which the mostly appreciated abbreviation is AU. According to the International Standardized Data, 1 astronomical unit is equal to 150-million-kilometre distance from the Sun.

Initially, a very long epoch ago, it was presumed by the space scientists that the heliosphere experienced an amount of stretching out as an outcome of its congregation with ISM present in the cosmos into the shape of an eye tear droplet. At this stage, the astrophysicist and space scientists took the assistance of two U.S. space probes viz., Voyager 1 and 2 as these two devices had already pass through the termination shock at an expanse of 94 and 84 Astronomical Units (A.U.) apart from the Sun in earlier times i.e., in the years 2004 and subsequently in 2007 correspondingly. These two voyagers have eventually crossed the precincts of the prefecture of solar system in multiple possible directions or simply in multi dimensions which automatically directs that the heliosphere configures an asymmetrical shape. In contrast to these observations inferred by Voyager 1 and Voyager 2 Space Probes, subsequent observations carried out atoms present in the heliosheath by the Cassini spacecraft that orbits around the Saturn and the Interstellar Boundary Explorer revolving the Earth authenticated the inference that the heliosphere was essentially presuming the shape of a sphere. Reports have evidenced that Voyager 1 probe have crossed the Sun's heliopause section of space on 25th August in the year 2012 whilst the spacecraft calculated a forty-folded unexpected escalation in the constituent plasma density.

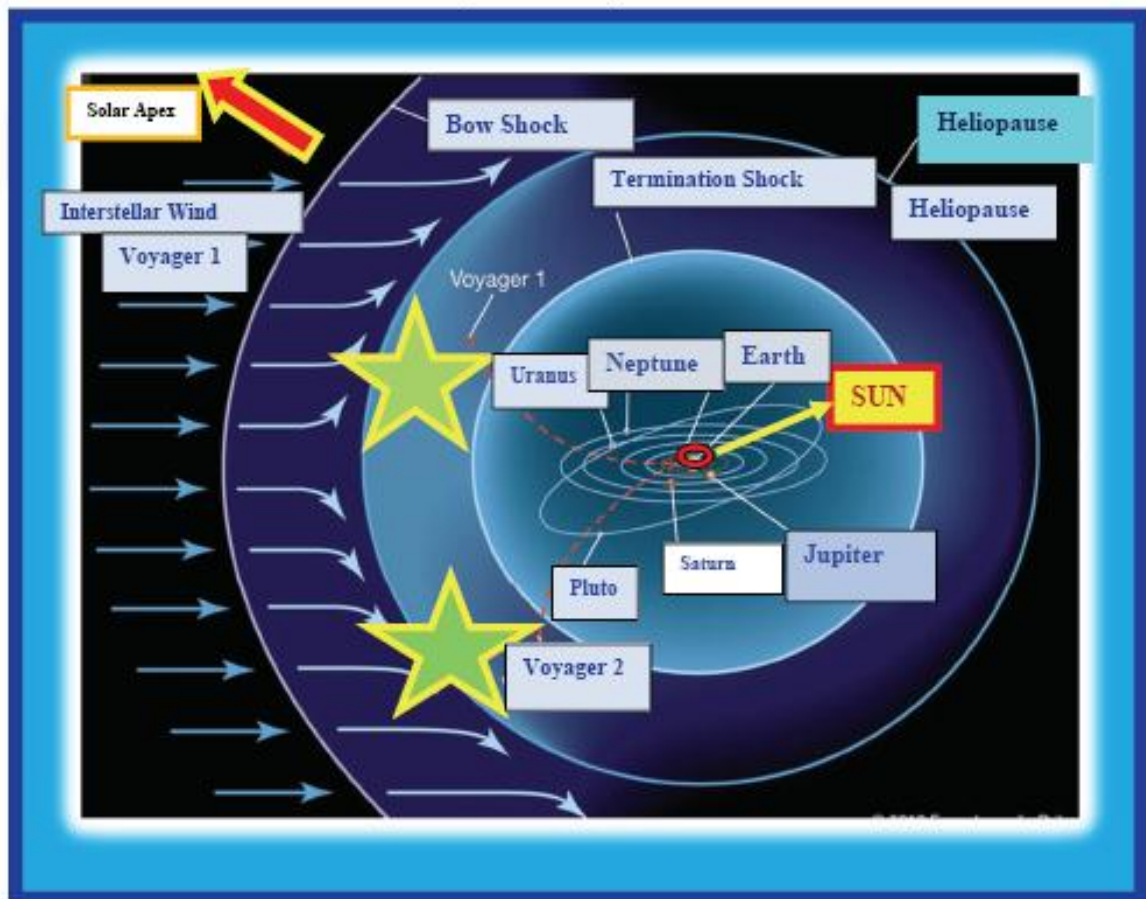
**Fig. 4**

Image Courtesy: NASA

Depiction of the Sun's heliosphere (Diagrammatic Conceptualized Visualization)

The solar wind first encounters the interstellar medium at the bow shock. At the heliopause the outward pressure of the solar wind balances the pressure of the incoming interstellar medium.

The heliosphere is the amalgamation of magnetosphere, astrosphere and the outermost atmospheric layer of the Sun. It takes the shape of an enormous, tailed bubble-shaped expanse of the cosmos. According to plasma physics denotations, the heliosphere is explanatory as the hollow space reckoned by the Sun in the contiguous interstellar medium.

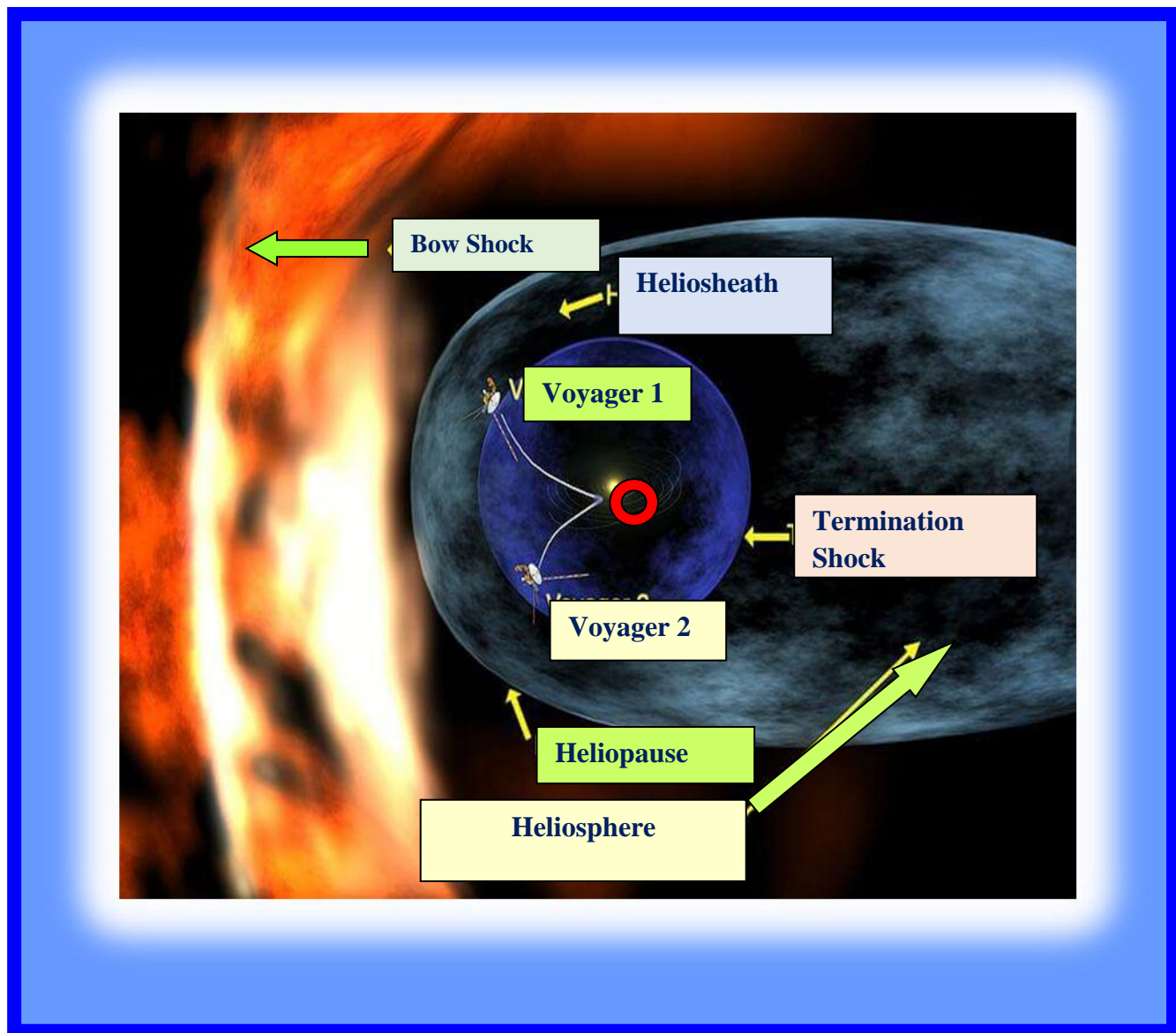


Fig. 5

Image Courtesy: NASA

In the Fig. 5, the labelled portions depict the bow shock region, the heliopause province and the termination shocks of the heliosphere of the Sun.

The bubble shape of the heliosphere is experiencing an unremitting exertion named inflation insinuated by space plasma stemming from the Sun, recognized as the solar wind. On the exterior to the heliosphere, this solar plasma provides means to the interstellar plasma pervading the Milky way. As a component of the interplanetary magnetic field, the heliosphere region of the Sun shields the Solar System from considerable extent of cosmic ionization radiation. During this process, uncharged gamma rays conversely stay unperturbed.

The very nomenclature was highly supposed to be predetermined by Alexander J. Dessler who is accredited with the foremost usage of the word as noted in the scientific literature articulated in 1967. Heliophysics is the scientific investigation of the heliosphere which takes into account of the two supplementary spectrums viz., space weather and space climate.

The National Aeronautics and Space Administration shortly NASA, USA has far flanged the study demarcations on the topic of the sun's heliospheric structure further pedestal on the underlying physics of the space surrounding our Earth. The repercussion of this study promoted by NASA provides further allied information concerning the entire cosmos and grounds the physics of mysteries that make the planets inhabitable.

The Earth is a G-type Major Sequence Star:

A main sequence star is a star enduring in the stable phase of its life, characterized by the fusion of hydrogen in its central core segment and this has been the most profuse type of stars in the universe. The universe has been an abundance of various types of stars those have been flourishing diverse categorizations in case of luminosity, size, colours and behavioural characteristics. It has been investigated to be quite easier for an assortment of stars transforming into another category very swiftly. However, other categories of stars ensue to be relatively unaltered for a tenure which escalates more than trillions of years [10].

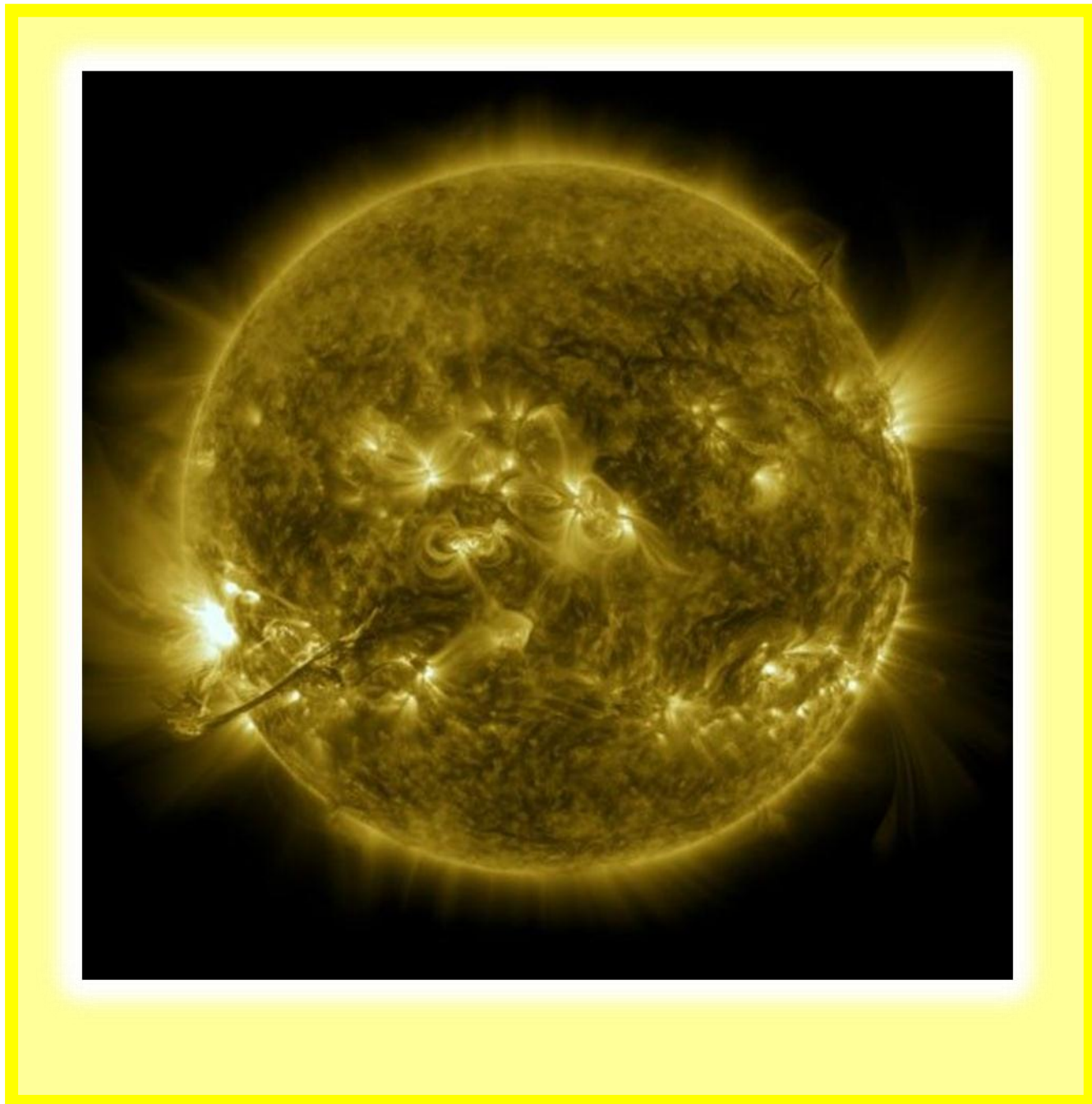


Fig. 6

Image Courtesy: NASA's Scientific Visualization Studio/SDO
NASA's Solar Dynamics Observatory captured this image of the Sun which is approximately 4.6 billion years old. The space scientists demand that the Sun will subsist for another 5 billion years and then it will become a reg giant.

Main sequence stars have been classified into spectral types viz., O, B, A, F, G, K, M. This categorization has been made on the ground of their enduring surface temperatures.

Unveiling Criteria of Spectral Types:

- **O-type:** Blue, Luminous stars which are the hottest among the classes of all main sequence stars.
- **B-type:** Blue-white stars which are very incandescent too.
- **A-type:** White stars like the Sirius.
- **G-type:** Yellow stars such as the Sun.
- **K-type:** Orange stars.
- **M-type:** The smallest and the coolest stars among the main sequence stars which are at the same instance are the red dwarfs.

4.0 Review of the Co-related Evidential Approaches and Literary Apprehensions Completed:

NASA heliophysics missions contributing to heliospheric research are viz., The Advanced Composition Explorer, NOAA's Deep Space Climate Observatory, the Interstellar Boundary Explorer, the Advanced Composition Explorer, the Solar Terrestrial Relations Observatory; Voyager 1, Voyager 2 and wind.

Since the shape of the heliosphere conforms to asymmetric configure due to its motion comparative to the interstellar gas. However, it is compacted in the direction of that motion and is deeply stretched out in the reverse direction. Observations implemented in the external heliosphere strongly recommend that the termination shock is persistently in motion corresponding to the Sun due to a continually-altering solar wind momentum flux, under no circumstances this might accurately attain a stable arrangement. The size and shape of the heliosphere depend on the momentum flux bring about by the solar wind, the pressure of the interstellar substance especially the ionized gas plasma and the movement of the heliosphere corresponding to the interstellar medium.

Lately Voyager 1 probe confirmed the existence of the termination shock, as it went across it in December 2004 at a heliocentric distance of 94 AU approximately in the track of the heliosphere's motion comparative to the interstellar medium. At this time, it is supposed that the heliopause lands on the sphere of influence at a heliocentric distance that counts to be of 115-150 AU and ought to be stumbled upon by Voyager probes in the subsequent decade.

As per the reports envisioned, Voyager 2 Space Probe went across the heliopause on 5th November of 2018. Because the heliopause authenticates the marginal boundary between matter starting off from the Sun and substance starting on from the remnants of the galaxy, spacecraft that go away from the heliosphere like the two voyagers are in interstellar space.

In the year 2020, Merav Opher conducted the squad of space researchers who previously resolute that the shape of the heliosphere is a crescent which could be portrayed as a deflated croissant [11].

The vital expanses coupled with the solar wind spectacle of the cosmos are enlisted below:

- **The Sun's Magnetosphere**
- **The Heliosphere**
- **The Extremely Indispensable splinter of Space i.e., the Heliosheath.**
- **The Heliopause**
- **The Heliotail**

Each of these above stratums have been discussed hereafter.

5.0 The Edge structure Analysis of the Sun's Heliosphere:

The outer constitution of the heliosphere is ascertained by the associations engrained between the solar wind and the winds prevailed in the interstellar space. The solar wind streams away from the Sun in all possible directions drifting with speeds of several hundred km/s in the close proximity of planet Earth. At some quantifiable remoteness from the Sun and far ahead of the orbit of the planet Neptune, this wind possessing supersonic behaviours suffers retardation as it proceeds through the gases in the interstellar medium.

The Earth revolves round the Sun at a speed of in close proximity to 30 kilometre per second. The interstellar medium is possessing exceptionally low density, on the other hand has a comparatively invariable pressure coupled with it. The pressure exerted from the solar wind decreases with the square of the remoteness from the Sun. The mechanism of forming a shock wave is established as an individual reallocates at a far-flanged remoteness away from the Sun, the pressure exerted by the solar wind declines to an instance where it can no longer sustain the flow of supersonic waves, in opposition to the pressure exertion of the interstellar medium, at such a point the solar wind continues to long-drawn-out to a speed below the speed of sound, thereby causing the background of forming a shock wave. Advancement from the Sun, the termination shock is trailed by the Sun's heliopause, the province where the two pressures turn out to be identical and the streaming of the solar wind particles have been blocked by the interstellar medium.

Additional termination shocks might be abundant in terrestrial structure. Evidences accessed at the conference of the American Geophysical Union in May 2005 by Ed. Stone put forwarded that the Voyager 1 spacecraft crossed the termination shock in December 2004, at this stage of time, it was about 94 AU distant apart from the Sun, by means of the alterations in magnetic interpretation taken from the craft. On the contrary, Voyager 2 Space Probe started in detecting the returning particles when it amounts in a numerical value of just 76 AU away the Sun. This observation was manifested in the month of May in the year 2006 which also points in the direction mentioning the shape of the Sun's heliospheric province that it might be sporadically shaped, most frequently swollen or bulging towards the outside in the vicinity of the Sun's Northern hemisphere and pressed interior to the Southern vicinity [12].

6.0 Explaining the Heliosheath:

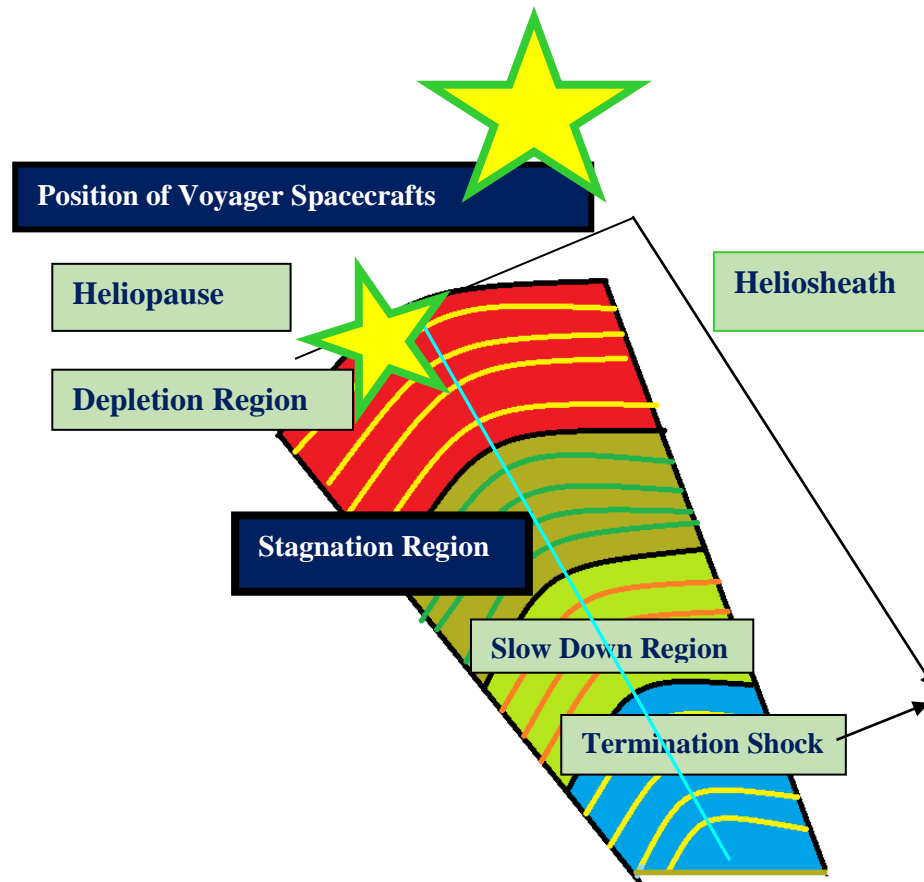


Fig. 7

Image Source: Visual aid of the heliosphere incorporating results from the Voyager spacecraft, as published on 28 June 2013.

The Voyager spacecraft plays an indispensable role in elaborating the structure of heliosheath strap of the terrestrial region which suggests that the mostly acclaimed heliosheath stretch extending between the two regions viz., the heliopause and the termination shock. This information was released by the Voyager spacecraft [13] on 28th June in the year 2013. The spaceship finished an esplanade in the interstellar region of space exploring the heliosheath.

The heliosheath is delineated to be the expanse of the heliosphere spanning at the forefront of the termination shock fragment if we observe in Fig. 4 in the direction starting from bottom to the upper divergent portion of the heliosphere. In this expanse of cosmos, the airstream is experiencing some extent of retarded acceleration or in simpler sense deceleration where it achieves compression and shifting or gearing up to be turbulent in nature as a result of its progression with the interstellar medium. At some point which arises to be the most adjoining to this province, the utmost interior section of the heliosheath spans very nearly ranging between the values of 80 and 100 AU detaching from the Sun.

In this podium, a good numeral of quantifiable models has been evolved signifying the shape and extent of the geometry and structure of the heliosheath. Astrophysicist and Space Scientists take evidences of a coherently designed architecture of the sun's heliosheath. According to this projected model flourishing the hypothesis bestowed upon the presumption that the heliosheath is somehow fashioned, resembling to the coma segment of a comet that traces quite a lot of times the distance traversed in the direction, converse to that of the Sun's pathways in its orbits. Voyager spacecraft led the astrophysicists to take the conclusion that the heliosheath is expected to be a foamy zone packed with magnetic bubbles, each of these spanning about 1 AU in extent. Voyager 1 and Voyager 2 initiated revealing the substantiation of the bubbles in 2007 and 2008 correspondingly. Such magnetic bubbles have emerged as a result of the collision between the solar wind and the interstellar medium [14].

Another probable shape flourished by these bubbles as entailed from hypothesis is the sausage-shaped bubbles. These are formed by magnetic reassociation between the reversely regulated fragments of the solar magnetic field since the solar wind reduces its speed. It is probable that such scenarios symbolize self-restricted configurations, those possessing the criteria of standing apart from the interplanetary magnetic field.

At a remoteness amounting to approximately 113 AU, Voyager 1 spacecraft distinguished a stagnation region inside the heliosheath [15]. Inside this region, the solar wind slowed down to zero [16] here at this stage, the magnetic field intensity gets doubled and the high-energy electrons emanating from the galaxy amplified to 100-fold.

7.0 Giving a Glimpse of the Heliopause Section of the Heliosphere:

As the name itself signifies that the heliopause is illustrated as the speculative border line at which the Sun's solar wind has been blocked-up by the presence of the Interstellar Medium of the cosmos where the solar wind's effectiveness is no longer huge for an adequate amount to thrust back the stellar winds exerted by the contiguous stars of the province. At this boundary of space, an equilibrium gets established where the interstellar medium and the pressure exerted by the solar wind balances one another.

From the experimental evidences experienced by the Voyager spacecrafts ^[21], as it move across the heliopause section of the heliosheath, an acerbic or distinctly sharpened up declination of temperature has been knowledgeable by the charged solar wind constituent particles. As a consequence, the magnetic field experiences some

enforced external aids due to which it alters its track towards which it was heading and the flux of galactic cosmic beam of emission comprehends an intensification in its measures.

8.0 Heliotail Splinter of the Cosmological Heliosphere:

The heliotail is the tail structure of the heliosphere and eventually of the Solar System. The solar wind particles decelerate its speed and finally run away of the heliosphere, along with a lazy gradual faded away mechanism due to swapping of charged particles. The contour of the heliotail as fixed by NASA's Interstellar Boundary Explorer or IBEX Mission is in the structure of a clover possessing four-lobes. The initial annotations furnished by IBEX regarding the heliotail strata can be ascertained by means of measuring the energy encompassed by the energetic neutral atoms where the neutral particles have been formulated by collisions incurred in the frontier province of the Solar System.

The heliosphere has further been hypothesized to subsist in the Local interstellar Cloud inside the Local Bubble shaped expanse is a zone experienced in the Orion Arm of our Milky Way Galaxy.

Table 2
An Up-to-date Data Summary Depicting the Speeds and Distances
Entrenched by the Solar Orbiter from the Sun

Sl. No.	Date	Event	Detachments Measured from the Sun (AU) or a Planet in Km	Orbital Inclination
Cruise Phase				
1	15 th June, 2020	Perihelion #1	0.52	7.7 ^o
2	27 th December, 2020 at 12:39 UTC	Venus flyby #1	7500	
3	10 th February, 2021	Perihelion #2	0.49	
4	9 th August, 2021 at 04:42 UTC	Venus flyby # 2	7995	
5	12 th September, 2021	Perihelion #3	0.59	
6	27 th November, 2021	Earth flyby	460	
Nominal Mission Phase				

7	26 th March, 2022	Perihelion #4	0.32	
8	4 th September, 2022 at 01:26 UTC	Venus flyby #3	6000	
9	12 th October, 2022	Perihelion #5	0.29	
10	10 th April, 2023	Perihelion #6	0.29	
11	7 th October, 2023	Perihelion #7	0.29	
12	4 th April, 2024	Perihelion #8	0.29	
13	30 th September, 2024	Perihelion #9	0.29	
14	18 th February, 2025 at 20:48 UTC	Venus flyby #4	379	
15	31 st March, 2025	Perihelion #10	0.29	
16	16 th September, 2025	Perihelion #11	0.29	
17	3 rd March, 2026	Perihelion #12	0.29	
18	18 th August, 2026	Perihelion #13	0.29	
19	24 th December, 2026 at 23:04 UTC	Venus flyby #5	950	24 ⁰
Extended Mission Phase				
20	6 th February, 2027	Perihelion #14	0.28	
22	3 rd December, 2027	Perihelion #16	0.28	
23	7 th May, 2028	Perihelion #17	0.33	
24	18 th March, 2028 at 08:22 UTC	Venus flyby #6	350	33 ⁰
25	4 th October, 2028	Perihelion #18	0.33	

26	3 rd march, 2029	Perihelion #19	0.33	
27	10 th Jun, 2029 at 17:47 UTC	Venus flyby #7	350	
28	11 th August, 2029	Perihelion #20	0.37	
29	8 th January, 2030	Perihelion #21	0.37	
30	3 rd September, 2030 at 03:03 UTC	Venus flyby #8	2650	
31	6 th Jun, 2030	Perihelion #22	0.37	

Table Data Source: [17], [18]

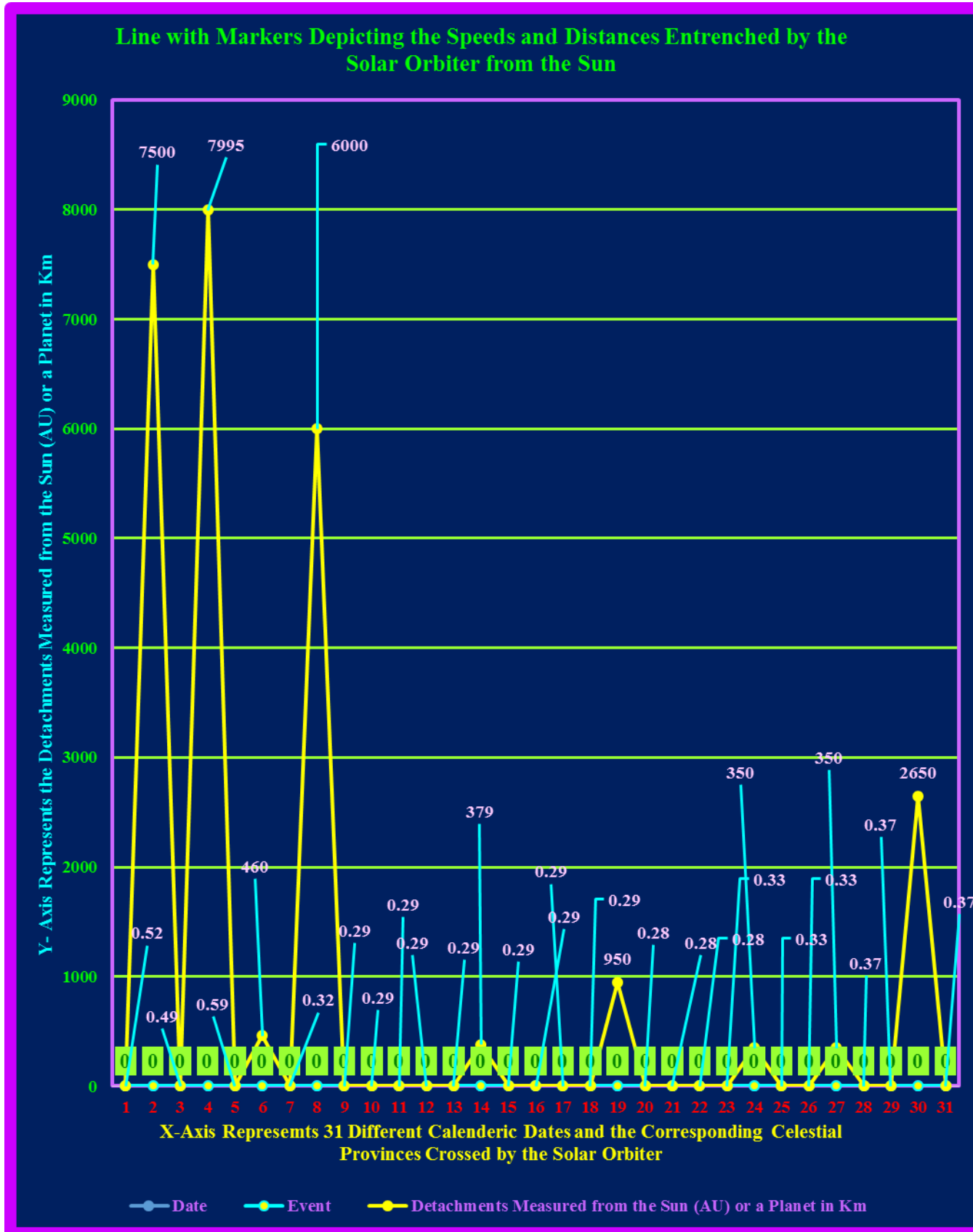


Fig. 8

Prior to 1972, this time was called Greenwich Mean Time (GMT) but is now referred to as Co-ordinated Universal Time or Universal Time Co-ordinated (UTC) which is a co-ordinated time scale.

The Solar Orbiter is a joint ESA and NASA Mission that was launched in February, 2020 which was basically architecture to investigate the properties of the Sun and to carry out some powerful consequent research in analyzing the impetus of the Sun on the entire Solar System with an attempt which accompanies the closest-ever images of the Sun and its polar domains. Reports endorsed that on February 2025, the Solar Orbiter way out the orbital plane of the Solar System after magnificently finishing the 4th Venus flyby.

9.0 The Solar Orbiter and the Parker Solar probe Solar Orbiter and Parker Solar Probe Co-operation:

The Solar Orbiter (or abbreviately SolO) and NASA's parker Solar probe Missions conjoined to trace the solar wind and the ensuing transients from their springs.

Two years back i.e., in 2022, both the two Missions clicked the images of the Sun and investigated the Sun's ambience. In this regard, the Solar orbiter has visualized the Sun from 140 million kilometres while the parker Solar probe visualized the Sun's outermost corona province from nearly much closer which is from an aloofness of only 9 million kilometres [19], [20].

It has been a ground-breaking triumph and glory for the entire mankind that in January, 2024, both these two Missions became proficient of encompassing their respective closest approaches to the Sun of which reports entail the statistic that Parker's Solar Probe could attain the highest adjacency to the Sun at a distance of 7.3 million kilometres, collecting data from the Sun's approaching ambience by sampling the plasma constituents of the solar wind whereas the Solar orbiter could reach the close proximity to the Sun at maintaining a detachment of 45 million kilometres and supplying continual data from the Sun's surroundings. The SolO was launched on 10th February, 2020 from Cape Canaveral, Florida of USA. The nominal mission is planned till the end of the year 2026 with a determination of executing potential extension until the year 2030.

13.0 Availability of up-to-the-minute Data:

The news concerning the Solar Orbiter have been continuously updated which can be gained from the official pages of ESA and also from Bluesky and Twitter/XAccount. Various images captured by the spacecraft with its powerful sophisticated instruments can be received from the official Flickr Account.

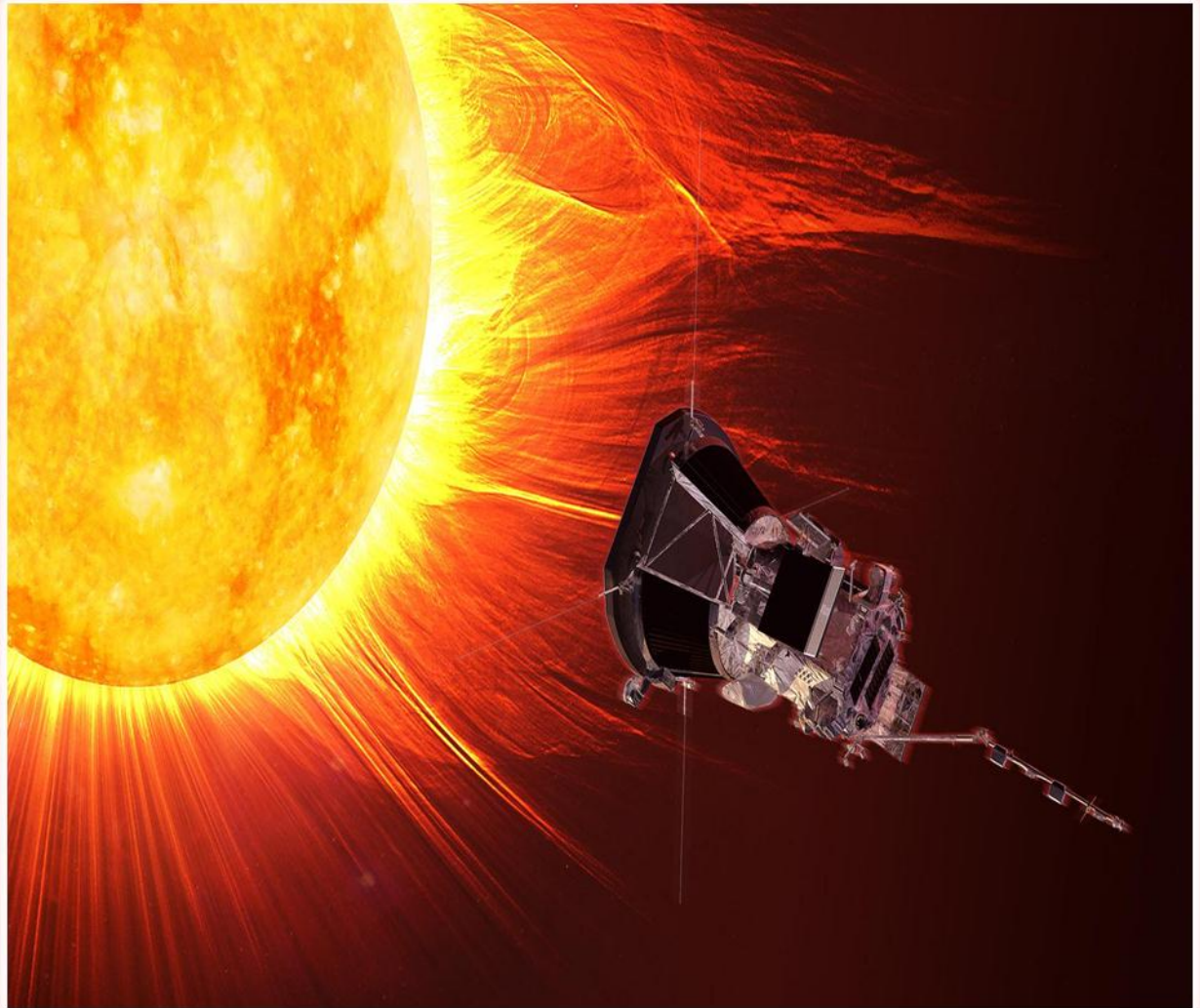


Fig. 9

Photo Courtesy: NASA/Johns Hopkins APL/Ben Smith
Michael Buckley (John Hopkins Applied Physics Laboratory).
Photo Captured on 24th May, 2022

In August 2018, NASA governed Parker Solar Probe set out for an extreme voyage in search of engrained research by perpetuating a profound study of the Sun and its

ambiance and also at the same time to reach the supreme apprehensible close proximity of the Sun that had not been attained by any other spacecraft earlier to this. NASA's Parker Space Probe has been designed, architecture, manufactured and operated by Johns Hopkins Applied physics Laboratory has approached the uttermost closest proximity of the Sun by endorsing a record-breaking flyby near the Sun. In 2021, Parker Solar Probe made its first measurements in the Sun's atmosphere, passing through the Sun's blisteringly hot outermost province, i.e. the Corona segment. Parker's Solar Probe completed the closest approach, called perihelion, encompassed at 22:42 UTC [21]. At that point, it was travelling at an incredible speed of 4,30,000 miles per hour i.e., 6,92,000 kilometres per hour. The Parker Solar Probe (PSP) has accomplished its 23rd adjacent pass by the Sun on March 22nd, 2025, coming within approximately 3.8 million miles or 6.1 million kilometres of the solar province.

13.1 Expressing Solar Wind in Views of Parker Space Probe:

Exploring the expedition of solar wind streaming out from the Sun, this discharged stream plumps up at speeds surpassing one million miles per hour by way it passes through off to the fringe of the terrestrial domain by showering everything in its path [22].

14.0 Deep Penetration of Parker Solar Probe into the Sun's Ambiance:

The NASA governed Parker Solar probe has been plummeting into the Sun's ambiance, encountering tremendous heat and radiation, setting out on a mission to entail the humankind with its first-ever experimentation of a star's atmosphere.

It was 14th December, 2021 when NASA announced that had crossed the Corona segment and also sampled particles and operational magnetic fields in that province that manifested the first-time record in the history of mankind which had touched the Sun.

The space probe was designed to encompass 24 progressive closer passes around the Sun along with three chief aspirations:

- To trace the flow of energy that continually heats the Corona segment, the extreme outermost province of the Sun.
- Have a deep engrained study on the springs that produce the solar wind which is the persistent and continuous flow of extremely energetic material escaping from the Sun.
- To have a deep engrained analysis to explore the embedded mechanism that how the solar energetic powerful particles, a stratum of which become capable of completion of 93-million mile or 150-million-kilometre journey in a matter of minutes i.e., these sturdy particles are transported and accelerated throughout the space and strikes the Earth's ambiance.

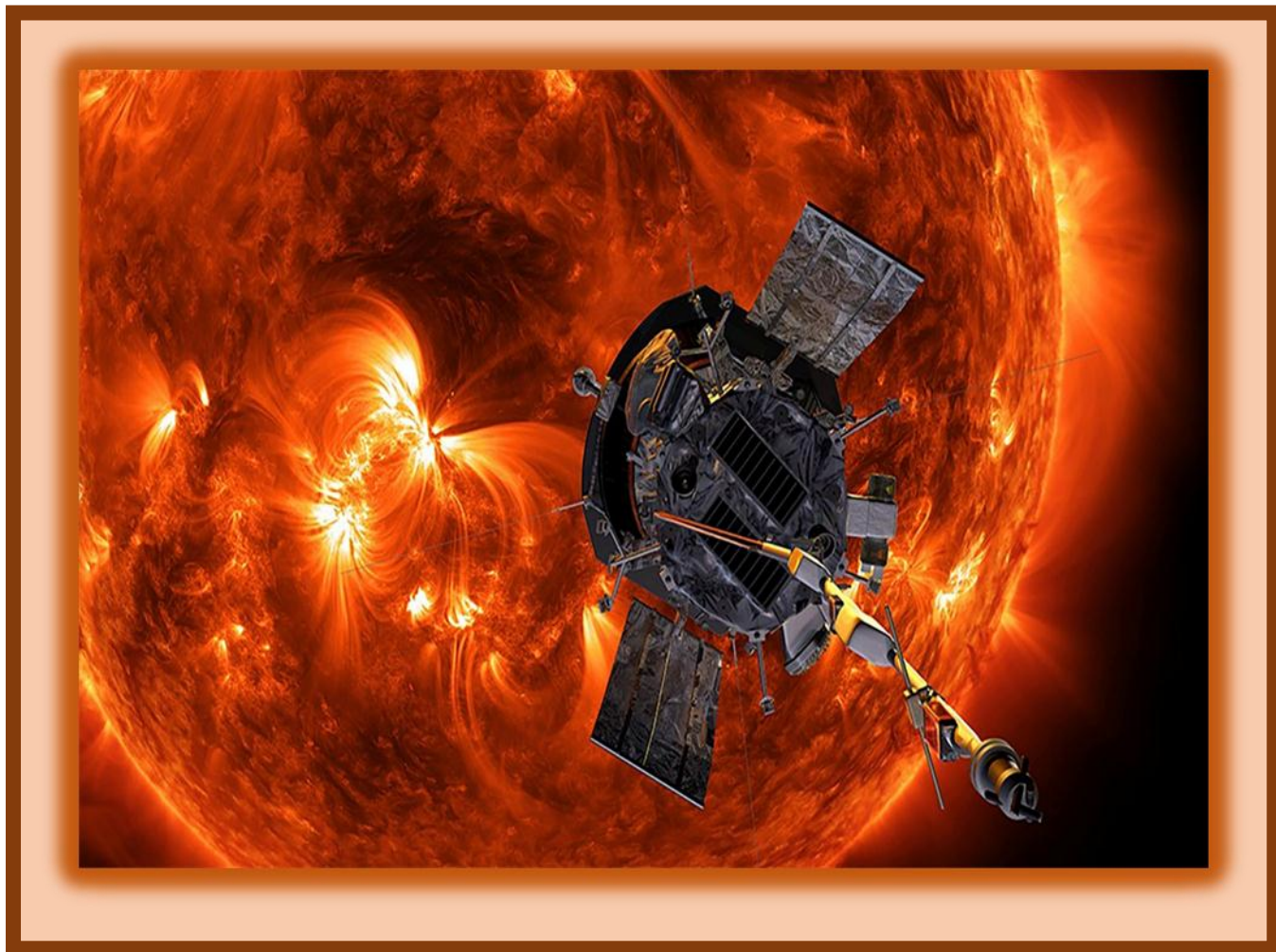


Fig. 10

Photo Courtesy: NASA/Johns Hopkins APL/Ben Smith

On 20th August, 1977, the Voyager 2 Space Probe, launched from Cape Canaveral, Florida was set for a space mission to appraise the four outermost planets of the Solar System that was later on making a gap of 15 days, an identical spacecraft named Voyager 1 had been launched [23].

Table 3

Sl. No.	Spacecraft on Adventure	Launched Year	Detachment from the Sun as Recorded on July, 2017		Speed (AU/Year)	Is in Contact with Earth?
			AU	km		
1	Pioneer 10	1972	114	17.1 billion	2.6	No
2	Pioneer 11	1973	97	14.2 billion	2.4	No
3	Voyager 1	1977	139	20.8 billion	3.5	Yes
4	Voyager 2	1977	115	17.2 billion	3	Yes
5	New Horizons	2006	39	5.9 billion	3	Yes

Table Data Courtesy: NASA

1 AU= The average distance from the Earth to the Sun which is just **< 15,0,000,000** kilometres (km). Here in this above Table 3, the column for speed depicts the speed at which the corresponding space crafts, how hurriedly had been detaching away from the Sun in Astronomical units (AU) which is a unit of length described per year.

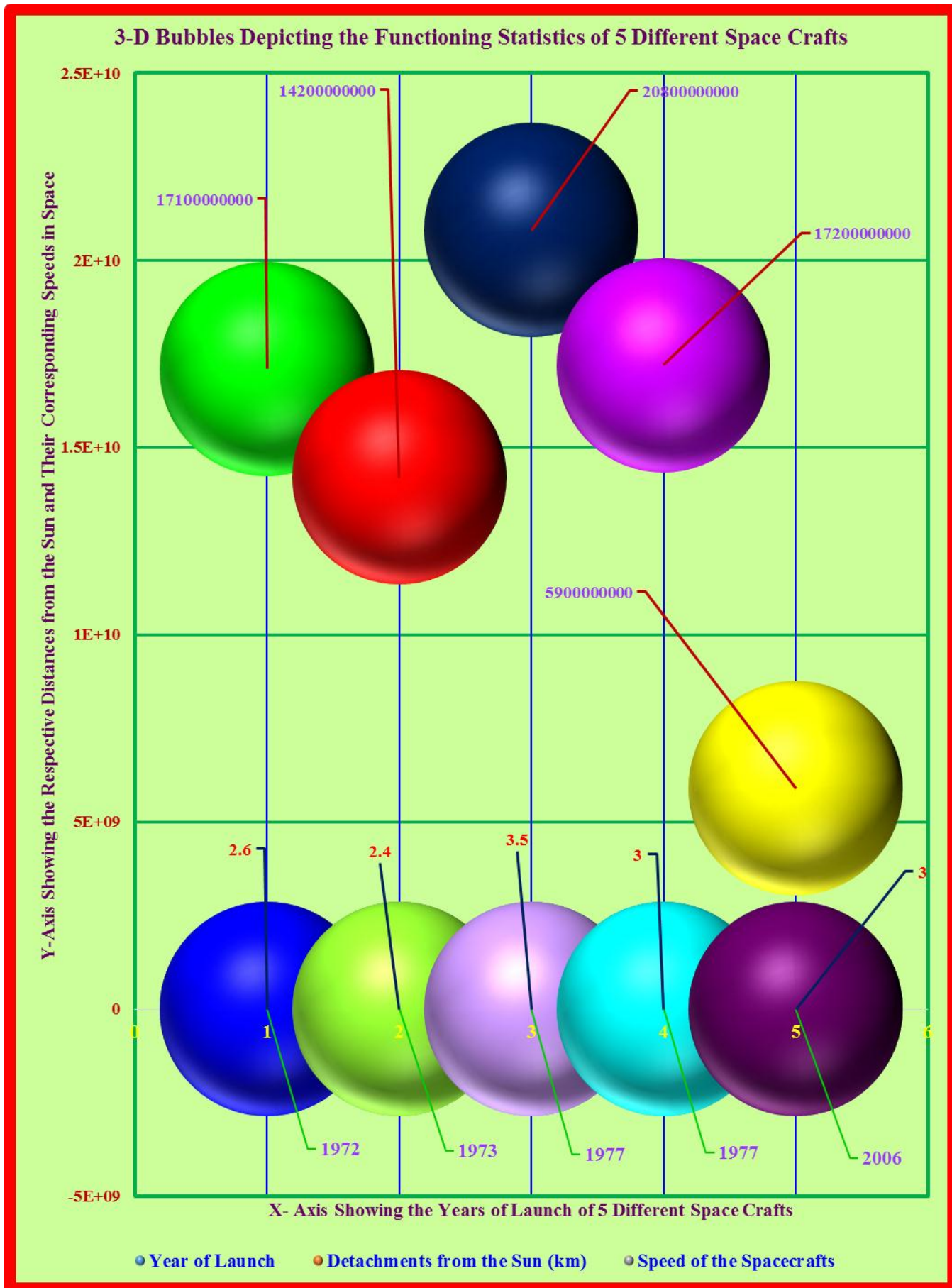


Fig. 11

15.0 The Two Voyager Space Probes:

The Voyager 1 and Voyager 2 spacecrafts are the only two spacecrafts that have travelled exterior to the Sun's heliosphere [24].

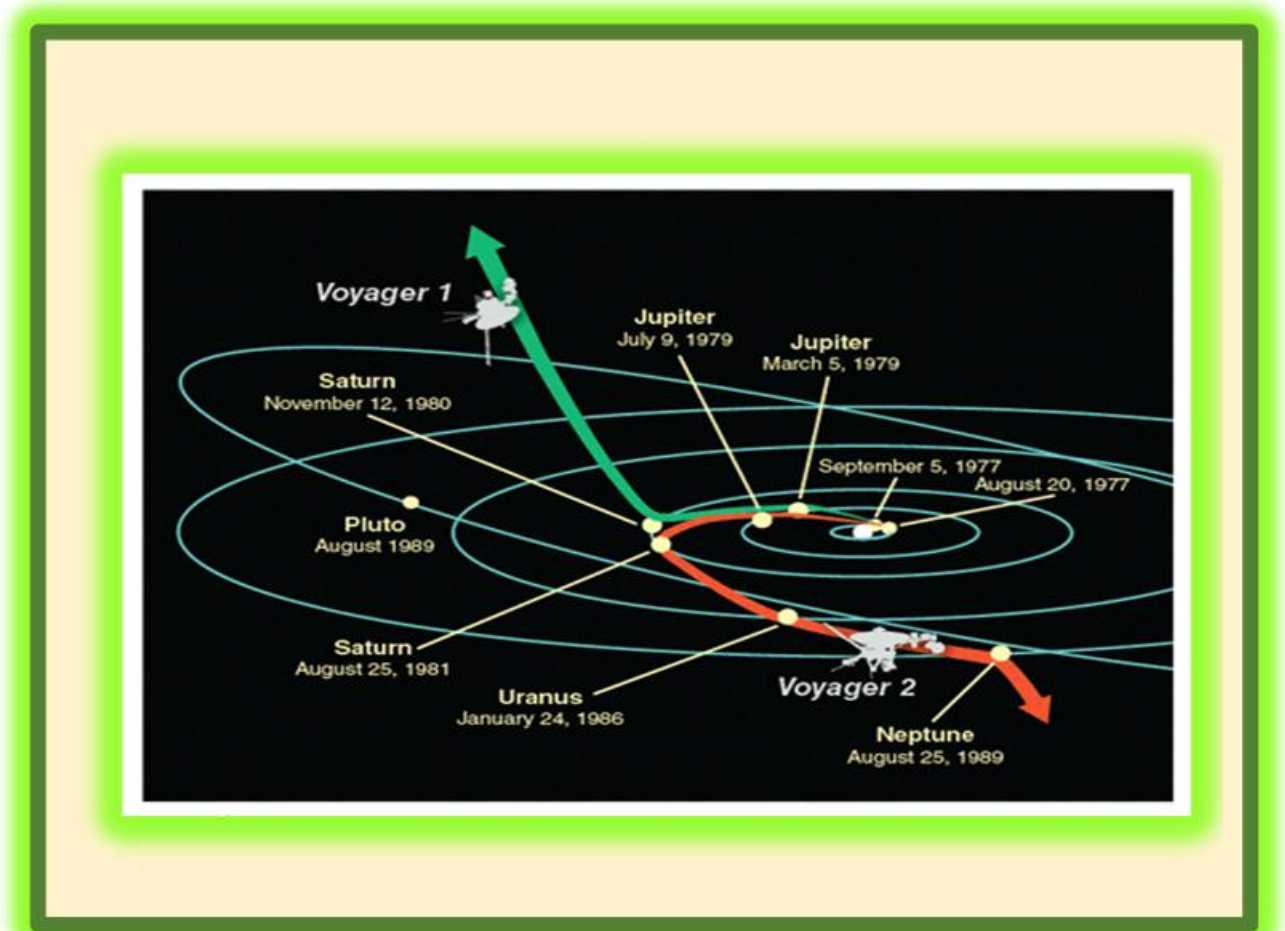


Fig. 12

Image Credit: ESA

The Overall Space Trajectories of Voyager1 and Voyager2 Spacecrafts

16.0 Experimental Inferences Incurred in the Course of Study:

This stream of cosmic rays reportedly mounting in broad spectrums or bands as per the statistics entailed by the Voyager 1 spacecraft which originated to a value of 25 percent. This stage is an additional gradual increment in the cosmic ray band which has been attained from the very value of 9 percent recorded per month with which the cosmic ray spectrum has spelled out its gradual growth. This 25 percent increment in the spectral width of the cosmic rays ranging from the band width of 9 percent has been diagnosed in the year of 2012 in the month of May by the experimental evidences furnished by the Voyager 1 spacecraft indicating a shifting towards the Heliopause segment of the heliosheath of the heliosphere [24].

17.0 Impartial Timely Speculations Drawn on Rigorous Cosmological Investigations:

- **2004:** Voyager 1 arising predominantly as the first spacecraft to accomplish the Termination Shock.
- **2005:** Supplementary investigation performed on the movement of the solar wind particles portray the concept that the shape of the heliosphere is not possessing axi-symmetrical structure, however experiences deformation strongly affirming as per an upshot of the local galactic magnetic field.
- **2009:** Space scientists in the IBEX Mission sketches a cosmological expanse in the contour of a ribbon, encompassing powerful energetic neutral atom discharge in consequence of the discovery advantaged by them. These neutral atoms are supposed to be stemming from the Heliopause segment.
- **2010:** The second arrays of IBEX observations consequently in the month of October of the year, announced significant changes in the ribbon-shaped structure after six months of the initial investigation.
- **2012:** IBEX data necessitates the strong possibility of non-existence of a bow shock.
- **2012:** Voyager 1 crosses the heliopause, stood as the first and foremost model to go forward of the Sun's heliospheric province of the cosmos.
- **2018:** Prolonged explorations concerning the hydrogen wall deployed by the New Horizons spacecraft confirmed upshots those were initially perceived in the 1992's by the two voyager spacecrafts.
- **2018:** Voyager 2 spacecraft traverses the Heliopause terrain of the cosmos. With the aid of these sophisticated scientific equipment or spacecrafts and up-to-the-minute rigorous researches entail humankind in breaking the mysteries of the universe and stimulate the young resilient youngsters across the globe to carry on research in this podium of Modern Cosmology which in turn will implicate the human race to set out for the search of lives in the far-flanged galaxies and beyond.

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Conflicts of Interest:

The author declares no conflicts of interest for this present study.

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