MODEL OF LDS PARTICLES IN CLOSED SPACE GEOMETRY

T.R. MEHDIYEV[1], Sh.N. ALIYEVA[1,2]

[1] *Institute of Physics named after H.M. Abdullayev, Ministry of Science and Education of the Republic of Azerbaijan, 131 H. Javid Ave., Baku, AZ-1073, Azerbaijan*

[2]*ASOIU, Baku, AZ 1010 Azerbaijan*

jophphysics@gmail.com

This work proposes a model of the LDS particle (Localized Dynamical Structure) as a stable form of density existing within the geometry of closed space. The LDS particle is treated not as a point-like object but as a topologically conditioned localization arising from the coupling of medium and excitation curvatures. The trajectory is understood as a tunnel of metric coupling rather than motion along a coordinate grid. The model explains the origin of mass as an effective measure of the medium's resistance to density and phase restructuring and derives antisymmetry and spin as consequences of topological constraints. Experimental data from the Voyager 1/2 missions are interpreted in terms of an extended curvature-coupling region (the heliopause), where diffuse magnetic structures and ion distributions (H^+, He^{2+}) are observed. These results are considered as evidence of the universality of the LDS model, applicable at both microscopic and cosmic scales. The model is further extended by incorporating the concept of a nanoscale layer and its dynamic evolution, allowing a rethinking of trajectory metric coupling as a self-organizing region where geometry, density, and spin states are bound through a dynamic nanoscale interface. This layer acts as an adaptive boundary between the medium and the inhomogeneity, enabling stable trajectories even under varying metrics. Such an approach allows the analysis of systems where surface effects and local anisotropy are critical, such as thin ferrite films and hybrid spin–photon structures. In this paradigm, mass and motion lose their primary status, giving way to the concepts of stable connectivity and effective medium resistance.

Keywords: Voyager 1/2, topology of environment, tunnel effect, magnetic field
DOI: 10.70784/azip.1.2025340

Introduction

The LDS (Localized Dynamical Structure) particle is not a simple point-like object but a structural, topologically conditioned form of wave density, emerging because of the stable interaction of the active geometries of the closed spaces of the particle and the medium. Such geometry is akin to Riemannian geometry and therefore stands in profound contradiction to the postulates of Euclidean geometry, which rigidly define the notions of a point, coordinates, distances, and parallelism of lines. The high integration of structures and their properties, inherent in Euclidean geometry, complicates and obscures the reliability of proposed physical interpretations, sharply reducing the effectiveness of theoretical and experimental investigations. At present, the prevailing view is based on Euclidean geometry of space and the Standard Model of elementary particles [1–6]. In this framework, a particle is treated as a point-like entity, its motion is described through coordinates and time, and interactions are introduced as fields determined by external potentials. Mass is regarded as a fundamental property of the particle, independent of the medium, while quantum properties are interpreted through probabilistic amplitudes without a topological foundation. Reciprocal space, widely used in solid-state physics, is treated as a mathematical abstraction convenient for describing diffraction and band structure, but not as a physical reality. However, accumulated experimental data — from quantum materials to the Voyager missions [6] reveal the limitations of this approach. These results highlight the necessity of a new representation in which a particle is not regarded as a point, but as a localized structure within the Riemannian geometry of the medium. Thus, reciprocal space should be considered not as a subsidiary and convenient abstraction, but as a physically real domain, a manifestation of Riemannian and Lobachevskian geometries [7] in which experimental data are directly recorded: specifically, X-ray diffraction and the distribution of wave vectors. In this context, the LDS model provides a pathway toward a unified description of matter and its interactions as topological structures in the geometry of closed space.

Premises and justification for the existence of LDS particles

Returning to the proposed model of LDS particles, we note that it represents an inseparable unity of trajectory and local inhomogeneity in the distribution of the medium density. Here, the term "trajectory" is not used for a passive description of motion, but rather denotes an active, topologically stable form of coupling between the inhomogeneity and the medium's geometry, embodying the quantum state itself. The density distribution preserves the geometry of the medium, and therefore the trajectory is the result of topological concordance between the metrics and curvature of the LDS and the medium [7], between density and its mirror image, between excitation and response. Thus, a trajectory is not mere motion but a self-consistent form of closed geometry. This statement emphasizes that every LDS particle born in such a medium carries the imprint of its topology. Moreover, within this model, an LDS particle can be any density inhomogeneity capable of polarizing the surrounding space, thereby forming a stable trajectory. This fundamentally broadens the possible classes of objects. Indeed, this follows directly from the wave picture: wave space almost always contains local

131, H.Javid ave, AZ-1073, Baku
Institute of Physics
E-mail: jophphysics@gmail.com

inhomogeneities. LDS space is not set a priori; it emerges as the result of a local disruption of medium homogeneity, originating from some local density irregularity in the material medium, which here is considered as wave space. In this space, such inhomogeneities manifest as soliton structures with interference nodes [8–11], formed by the superposition of waves of various frequencies. The lower layers are formed by slow (low-frequency) waves, and the apex by fast (high-frequency) waves, which determines the shape and stability of the formation. The intensities of all waves forming the soliton can be considered equal, since each wave carries the same quantum of energy from the medium. However, due to frequency differences, the amplitude of each wave differs: the higher the frequency, the shorter the extent and therefore the larger the amplitude required to transfer the same energy. Thus, the shape of the soliton is determined by the difference in amplitudes under the condition of equal energy transfer integrals, generating its characteristic localized structure.

An LDS particle is therefore not an abstract point but a dynamic, geometrically coupled entity carrying information about the structure of space and its response. In the region of a standing wave arising from synchronous counterpropagation, the density distribution becomes so coherent that the distinction between wave and medium disappears. It becomes an analogue of a local Riemann sheet, where geometry, density, and excitation merge into an indivisible structure [7]. Within this region there is no observable wave, as all motions are closed and compensated. What arises is structure, not process. Such an LDS structure is like a single-sheet projection of a multi-sheet surface – a local stitching of states resulting in a geometrically induced density. This state manifests not as motion but as a localized structure. Importantly, in wave space we are not speaking of a coordinate in the ordinary Euclidean sense, but of a vector of the excited state – a wave number describing the oscillation mode. Such a "coordinate" in wave space is not a point but a configuration: frequency, direction, phase. In this sense, LDS geometry does not exist against a background but forms it itself, as a coherent excitation localized in mode space. In classical views, the medium quickly "forgets" a passing particle, leaving no trace. Thus, several key properties of an LDS particle can be postulated:

- Inseparability from the trajectory – a locally inhomogeneous distribution cannot exist without its geometric trajectory.
- LDS particles polarize the surrounding medium, leaving a topological imprint.
- Antisymmetry because of topology – quantum properties, including antisymmetry, follow from boundary conditions on the trajectory.
- Self-consistency – the shape of the LDS particle arises from the balance of density, spin, and the wave medium's geometry.
- Universality – any local inhomogeneity capable of inducing a stable topological restructuring of the medium can be considered an LDS particle, expanding the class of objects with quantum properties through their interaction with the medium's geometry.

It should be noted here that the possibility of a trajectory component coupling the metrics of the particle and medium is not accounted for, as observed, for example, in complex ferromagnetic structures with superexchange [12], where oxygen ions hybridized with trivalent and divalent iron ions in octahedral and tetrahedral environments, serve as the coupling components. Since in the proposed LDS-particle model the trajectory is not external but part of the inhomogeneity itself, it is evident that the inhomogeneity, by polarizing the medium (at least creating a local phase modulation or spin restructuring), jointly builds the trajectory. This polarization, especially in spin-sensitive or weakly dissipative media, still leaves a topological trace – an analogue of a polaronic tail but expressed geometrically. Under strong dissipation, a rapidly decaying trace disappears within the medium's relaxation time, on the order of 10^{-14}–10^{-12} s. In a topologically ordered medium, the quasi-stationary trajectory "freezes" and may serve as a waveguide or resonator. If the medium density is modulated by feedback – the particle excites the medium, which sustains a self-supporting trajectory. Finally, if the LDS particle is associated with a quantum density bearing antisymmetry and spin, its minimum size R_{min} must ensure a phase rotation of 2π along a Möbius trajectory, giving the lower estimate of R_{min} as half the de Broglie wavelength:

$$R_{min} \sim \frac{h}{2p}$$

where p - is the characteristic momentum. Half the de Broglie wavelength arises from the requirement of phase closure on a Möbius trajectory, where antisymmetry requires a 2π shift per loop. This relation serves as the lower boundary for LDS-particle sizes, ensuring phase stability and preservation of quantum properties in closed geometry. These characteristics make the LDS particle a fundamental unit of topologically conditioned quantum matter. Concluding the introduction to the LDS-particle model, note that within this model, based on the Riemannian geometry of excitations, the very concept of motion loses its fundamentality. What classical (Euclidean) mechanics treats as the motion of a particle is a change in the configuration of the medium's excitation. Motion is an illusion of coordinated space imposed by Euclidean metrics. The LDS particle remains localized in phase space, only its state of coupling with the medium changes.

Within the LDS model, the term "mass" turns out to be a notion carried over from coordinate mechanics, where it expresses the inertial property of a point. However, in the model based on topological connectivity of density and medium response, this concept loses fundamental meaning. No "mass" exists independently of the medium, trajectory, and excitation form. Instead of mass, one should speak of trajectory stability, the medium's resistance to restructuring, or the energy density of coupling. Thus, the term "mass of an LDS particle" is not a preset parameter but emerges as the consequence of the LDS-particle trajectory interacting with the medium, i.e., it is defined as some effective mass. This interaction manifests as the medium's resistance to changing local density and trajectory shape, thereby linking mass to spin orientation and self-induction effects.

The effective mass of an LDS particle is essentially a measure of geometric inertia, reflecting the medium's inability to instantly reorganize in response to changes in density or trajectory. Unlike classical mass tied to a stationary object, effective mass in the LDS model reflects the local resistance of the medium to phase and density deformation. It can differ significantly even for geometrically similar inhomogeneities if they are located in different external fields, in different metric regions, or in media with different responsiveness. Effective mass is thus a measure of the complexity of coupling the LDS form with the medium's geometry, depending on conditions rather than on the LDS structure itself. It is essentially a measure of resistance to creating or altering local density in an LDS particle, as this in turn alters its trajectory. Thus, in the LDS-particle model, effective mass acquires physical meaning because of a stable geometric and energetic link between density and medium. At the same time, the very fact of its existence cannot be separated from the specific medium: without knowledge of its properties, topology, and dynamic responsiveness, it is impossible to determine interaction parameters accurately. Such a model essentially renders the search for LDS particles outside a medium meaningless, as they do not exist as independent objects but only as the result of a specific form of interaction of a density inhomogeneity and a medium. Effective mass is not an inherent value but a characteristic of medium resistance arising during LDS structure interaction with the field, geometry, and local responsiveness. Like an entangled state, its manifestation is determined not only by its own parameters but by the context of the medium. It should also be noted that under an expanded definition of LDS particles, subwavelength density formations can be interpreted as LDS structures, provided they induce stable trajectories and a topologically significant deformation of the medium. Their quantum characteristics may differ significantly from fermionic particles known in the Standard Model. If such densities induce local medium deformation and stable trajectories, they too may be interpreted as LDS particles, albeit with different quantum characteristics.

This makes the framework of the model more flexible and applicable to microscopic structures, including presumably substructural levels of fermionic objects. The minimum size of an LDS particle is not a fixed value but the boundary between the ability of a density to localize and the ability of the medium to respond. Since we are not speaking of a classical trajectory but of a phase density structure, the LDS particle can exist only if conditions for stable topological field connectivity are met. This requires coherence between density shape, its gradients, and medium response. Unlike the classical closed trajectory, here the key factor is the ability of the density phase to close upon itself, forming a topologically continuous structure with a 2π phase shift, analogous to a Möbius strip. If the medium geometry or density behavior cannot realize continuous phase linkage with the necessary shift, the LDS particle does not form as a stable bound entity. This is not the destruction of density but the loss of its ability for topological self-organization, which makes a coherent trajectory possible. Thus, the topological structure of an LDS particle requires not only energetic stability and medium response but also coherence of the phase distribution ensuring the continuity and orientation of the trajectory. The next important aspect concerns the nature of LDS-particle mass. The space in which an LDS particle exists itself has no mass characteristic. Therefore, the LDS particle cannot have mass outside the context of medium response, since space by definition provides no resistance to motion – it only sets the conditions for coherent geometry. All the above indicates that using the Lagrangian form of the principle of least action contradicts the geometry of closed space on which the LDS model is based. Within this model, experimentally obtained dependencies are not direct relations between quantities, as assumed in coordinate mechanics. Instead, they are observed projections of deeper geometry – i.e., the results of local coupling of density and medium response already incorporating curvature. Thus, any stable physical dependence revealed in an experiment, in the context of the LDS model, is interpreted as a projection of a trajectory in density-response space and therefore always contains hidden curvature defined by the geometry of LDS coupling.

The concept of a trajectory formed between a medium and an lds particle in the geometry of a closed space

In the proposed spatial model, based on the geometry of closed curvatures, the trajectory ceases to be a simple line. It loses meaning as a path on a coordinate grid and instead becomes the form of coupling between two metrics. The trajectory is not a path but a geometric result of reconciling curvatures, emerging in the phase domain of their wave overlap. This is the region of coherent metric coupling between the curvatures of the LDS-particle and the surrounding medium, where stable phase interaction becomes possible. Within this coupling space, wave functions overlap—by nature analogous to the tunneling effect in quantum mechanics. Thus, a coupling tunnel is formed—an area where phases, shapes, curvatures, and interactions are reconciled. In such a region, a generalized mass is born as a measure of phase compatibility; gravitational interaction manifests as a winding curvature of the reconciled form, and a stable density region arises, observed as motion. Thus, a trajectory is not a line but a resonant shell emerging between the two curvatures of the medium and the LDS-particle. Relying on principles of phase coherence and geometric curvature, the coupling tunnel as a domain of overlapping wave functions of the LDS-particle and the medium can be expressed as [13–16]:

$$T(x) = \psi_{LDS}(x)\, \psi_S(x) = A(x) exp\big(\varphi_{LDS}(x) + \varphi_S(x)\big)$$

where $\psi_{LDS}(x)$is the wave function of the LDS-particle; $\psi_S(x)$is the wave function of the medium near this particle; A(x) is the resulting overlap amplitude; and the sum of phases in the exponent reflects their reconciliation. Introduce the metric curvature functions of the medium $K^S(x)$ and the LDS-particle $K_{LDS}(x)$. Then the condition for metric coupling is:

$$|K_S(x) - K_{LDS}(x)| < \varepsilon$$

for some small ε, defining the geometric admissibility of the tunnel. In the simplest form, by analogy with tunneling, the shape of the "coupling tunnel" can be described by

$$T(x) \sim -\int_a^b \sqrt{\Delta K(x)}\ \ dx$$

where

$$\Delta K(x) = |K_S(x) - K_{LDS}(x)|$$

Thus, the greater the curvature difference between the LDS-particle and the medium, the wider the metric coupling region forming the trajectory. This arises from the need to build a smooth, reconciling shape, analogous to an interpolating spline that connects two geometrically incompatible metrics through an intermediate shell of variable curvature. The width of this region is not a defect or accident but a natural geometric solution to the coupling problem.

This conclusion is supported by experimental data from the Voyager 1 and Voyager 2 missions, where the observed boundary—the heliopause—was not sharp but extended: smooth changes in magnetic fields, stratified energy spectra of plasma particles, and anisotropy in particle flows. In this zone, despite low medium density, magnetic fields, energy spectrum, and particle fluxes change gradually, indicating the presence of an extended coupling region between the curvatures of the solar space and the interstellar medium. This agrees poorly with a sharp-boundary model but fully corresponds to a "smeared" boundary.

Thus, the heliopause is not a boundary but a coupling tunnel, which in this model represents the trajectory itself.

Voyager 1 and Voyager 2 missions

The Voyager 1 and Voyager 2 missions, launched in 1977, were among the most significant in the history of space exploration. These spacecrafts played a key role in studying the boundary of the Solar System, providing unique data on the heliosphere and interstellar medium. As the first observations showed, the naive idea of a "sharp transition" from the Solar System to interstellar space turned out to be erroneous. The boundary is not a clear wall, but a turbulent, diffuse shell, like a torn fabric, in which the solar wind interacts with the interstellar plasma and magnetic field. Note that although the Voyagers have crossed the heliopause, they are still in the zone of gravitational influence of the Sun and have not left the Oort cloud, which extends to distances of about 100,000 AU. According to the observations [6,15], a sharp drop in the flux of solar protons and a surge in galactic cosmic rays were recorded. Radio waves in the range of 2-3 kHz were periodically recorded, apparently corresponding to oscillations of the cold plasma of the interstellar medium. However, the most interesting fact was the absence of a noticeable change in the direction of the magnetic field, which was interpreted as the presence of layering, turbulence of the boundary between the heliosphere and the interstellar field, not a one-time jump, but something like a "foamy structure". A sharp weakening of the Solar magnetic field and a change in its direction to the direction of the interstellar magnetic field (ISMF - Local Interstellar Magnetic Field) was expected. This should have looked like a transition from the Parker spiral to the external field. To explain the reasons for the discrepancy, it was suggested that the fact that the interstellar and solar magnetic field strengths were parallel at this point in Voyager's flight was a result of a random coincidence. Of interest was also the suggestion that there was a zone in which the solar and interstellar fields were conjugated through a complex topology. [17-22]. According to these studies, a phase splitting of the magnetic field into two mutually perpendicular components was observed, one of which, lying in a plane oriented along the original heliospheric structure and stretched by the solar wind, associated with the twisted field, that is, associated with the Sun, is a remnant of the Parker spiral [23]. The second component, which is a more "global", slowly changing, not coordinated with the rotation of the Sun, external field, located perpendicular to the solar field at this point and is introduced inside, is a component of the interstellar medium (ISMF). Note that the mutual orthogonality of the magnetic fields of the medium and the LDS particle indicates that what is observed is not their usual superposition, but some geometric interference, i.e. the formation of a structure. Let us assume that the magnetic field of the medium is a background component that reflects either a long-term stress in space (e.g., from the spin texture) or a wave background phase in which the LDS lives. On the other hand, the magnetic field of the LDS particle can be considered a field generated by the soliton itself, which can be associated with local current circulation in space and with a topological texture (e.g., a skyrmion or a vortex).

Equality of the scalar product $B_{env} \cdot B_{LDS} = 0$ ⇒"there is no interaction energy in the linear approximation", but! their vector product $B_{env} \times B_{LDS}$ ⇒ "a rotational effect arises". Thus, the mutually perpendicular orientation of the magnetic fields means that the medium and the LDS are oriented in different phase directions, and their interaction is not energetic, but resonant-geometric. On the other hand, such an orientation enables the birth of a spiral structure. The direction in which torsion appears is also the direction of structure development. This explains the mechanism of stabilization of LDS soliton, which does not counteract the medium, but fits into its orthogonal direction, receiving energy through the torsion mode. The impulse received by the soliton from the medium is not a longitudinal mode, but a rotational transfer of momentum resulting from the perpendicular arrangement of the fields and generating a stable spiral or vortex structure in the local metric. The quantum of momentum arriving to the soliton is transmitted not by the pressure wave, but by the change in the amplitude of the transverse (magnetic) field located in the orthogonal direction. If this is so, then assuming that $B_{env}(t) = B_0(t)\hat{x}$ is the background component of the magnetic field of the medium; $B_{LDS} = B_S(x,t)\hat{y}$ is the component of the LDS magnetic field, we obtain for the model in which $n = B_{env} \times B_{LDS}$ the change in the amplitude $\delta B_0(t)$ causes rotational excitation:

$$\delta n(t) = \delta B_0(t) \cdot B_S(x,t) \cdot \hat{z}$$

This is the moment, the impulse, the pumping quantum (along with the third direction—perpendicular to both). A change in the medium field amplitude does not carry longitudinal energy but causes the LDS to rotate, i.e., changes its internal phase. This is analogous to the effect of magnetic pumping in nuclear physics, when an alternating field induces spin resonance without shifting the nucleus but exciting a phase rotation. The quantum here is not a photon but an instantaneous change in the medium's field that brings the LDS to a new stable state. This is how phase energy works in a Riemannian structure. The quantum reaching the soliton does not come from outside but from every oscillation constituting its structure. It is not the "arrival" of energy but an internal coherent excitation of the entire system.

The observed effects (from Voyager 1/2 data) can be interpreted as manifestations of a curvature-coupling region within the LDS model, where the transition is not a sharp boundary but an extended coupling tunnel between the inner (solar) and outer (interstellar) metrics.

The naturally arising question about the composition of the medium at the Voyager location turned out to be no less puzzling. The spacecraft traveled through a region where medium parameters behave not as classical variables but as phase markers—linked to topology and coherence, not to local scalar values. According to experiments [24–26], the electron density (from plasma waves) is $n_e \approx 0.08$ cm^{-3}; the plasma temperature (indirect measurements) $T_e \approx 7000$–15000 K; ions observed include H^+,He^+,C^+,O^+; no flux of heavy ions was detected. The predominance of H^+ indirectly confirms that this is not leftover solar wind. After crossing the heliopause, the intensity of galactic protons and nuclei increased sharply: protons up to ~1 GeV; helium-4, carbon, oxygen are present but stable. It is believed the spacecraft is moving sideways relative to the ISMF, allowing it to glide along the magnetic field. The boundary does not "break" but deforms, adapting to the shape of its envelope.

Another characteristic feature [6] of the medium around Voyager 1 should be noted. The spacecraft is not equipped with a specialized alpha-particle detector; however, the Low Energy Charged Particle (LECP) instrument on board recorded ions with energies from ~30 keV/nucleon and above, allowing distinction between protons (H^+), doubly ionized helium (He^{2+}) and other particles. Importantly, doubly ionized helium (He^{2+}) is an alpha-particle. The following distribution is observed: alpha-particles concentrate in the central part of the trajectory—closer to the Sun—while hydrogen ions dominate at the edges, forming two layers: solar and outer (interstellar). This is not just an empirical observation but a structural mass and resonance distribution, clearly reflected in Voyager 1 data (see Fig. 1, showing a simplified profile of He^{2+} and H concentrations along the trajectory from ~90 to ~122 AU). According to Voyager 1, protons (H^+) are stable, forming a halo around the trajectory, especially prominent in the heliosheath and near the HP. Neutral hydrogen creates the so-called "hydrogen wall," a dense layer at ≈ 90–130 AU, detected via Lyman-α spectra from the UVS instrument. Inside the trajectory (≈ 95–120 AU, especially the center of the heliosheath), alpha-particles (He^{2+}) appear along with hydrogen, peaking closer to the central zone. Within the heliosheath (roughly 94–121 AU), alpha-particles comprised about 4–7 % of the total ion flux, especially in the central part. Near the heliopause (~122 AU), their flux drops sharply to nearly zero.

The distributions shown in Fig. 1 are fully consistent with the LDS model, according to which the He^{2+} layer acts as a coupling component between inner and outer metrics. A similar mechanism has been described in the context of Ni-Zn ferrites, where the coupling node between tetrahedral and octahedral sublattices is realized via the oxygen ion [12]. On this basis, it is proposed that in a phase space with dissimilar metrics (e.g., a localized LDS structure and the external medium), stable coupling is possible via a symmetric object capable of carrying two generalized orbitals, each linked to the respective metric. The alpha-particle meets these conditions and represents a topologically stable coupling node. Helium does not appear in a vacuum; it arises only in the coupling zone of phases; it is the physical realization of the minimal stable junction of two metrics—where it appears, the metrics' boundary becomes coherent.

However, in the proposed model the trajectory is not a line and not a path on a coordinate grid, but rather a region of stable metric conjugation between the curvature of the LDS particle and that of the medium. This region emerges as a conjugation tunnel—a geometric overlap of the phases of two curvatures, analogous in form to tunneling, though not probabilistic in nature but due to real structural compatibility. Inside the tunnel, the curvatures themselves do not change—each preserves its form—yet a third configuration arises, possessing its own matching curvature that furnishes a smooth transition between the LDS particle and the medium. This is the trajectory: not a geometric consequence of motion, but a volumetric resonant envelope of interaction of forms. Characteristically, the greater the difference between the curvatures of the LDS particle and the medium, the wider and more pronounced the conjugation tunnel becomes. This is supported, in particular, by Voyager data, where the boundary between solar and interstellar media—the heliopause—is not sharp but a diffuse transition layer with gradually varying characteristics. Such a layer is precisely the experimentally observed region of metric conjugation. Based on these data, one can provisionally describe the shape of the conjugation tunnel using any convenient mathematical procedure—for example, spline interpolation—imposing only the conditions that the conjugated curvature be smooth (at least C^2-continuous) and clamped at the ends, i.e., each original metric remains unchanged at the conjugation boundaries.

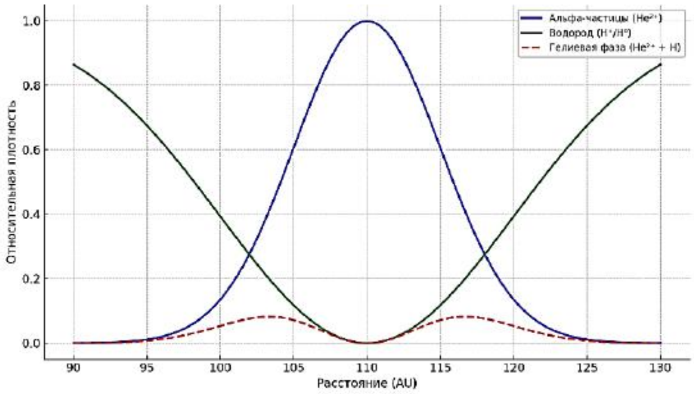

Fig. 1. Distribution of He^{2+}, H, and the helium phase along the Voyager 1 trajectory:

- Blue curve — alpha-particle density (He^{2+}): peaks at the center of the trajectory, corresponding to a stable conjugation zone;
- Green curve — hydrogen density (H^+ / H^0): maxima at the edges (left—solar side, right—interstellar medium), reduced in the center;
- Red dashed curve — "helium phase" (a state of joint presence of He^{2+} and H): manifests in the conjugation region, i.e., where a topological transition occurs and metric overlays are observed.

Let κ_1 be the curvature of the (local) LDS particle, κ_2 the curvature of the (background) medium, $\Delta\kappa = \kappa_2 - \kappa_1$ the curvature interval, and $\kappa(x)$ the conjugated-curvature function on $x \in [0, L]$ forming the tunnel. From the conjugation conditions we require $\kappa(0) = \kappa_1$, $\kappa(L) = \kappa_2$, and $\kappa'(0) = 0$, $\kappa'(L) = 0$, which yields minimal curvature in the middle of the tunnel — i.e., stable conjugation. For a cubic spline $k(x) = ax^3 + bx^2 + cx + d$. Substituting the boundary conditions gives $k(x) = k_1 + \Delta k\left(3\left(\frac{x}{L}\right)^2 - 2\left(\frac{x}{L}\right)^3\right)$

On this basis one may define a density function $\rho(x) \sim k(x)^{\beta}$.

The principal conclusion for describing the conjugation tunnel is straightforward: the larger the curvature mismatch between the LDS particle and the medium, the wider the conjugation region (tunnel), the more intricate the trajectory's form, and the more pronounced the spectral effects. This conclusion also rests on the following observations: the medium's curvature increases due to deformation of the medium's metric (not a "field" in the Euclidean sense), i.e., through geometric change without introducing a separate physical field; effects akin to Zeeman splitting arise, but in the LDS model this is not merely level splitting—it is a real broadening of the conjugation tunnel; as the LDS and medium metrics diverge, the tunnel widens to reconcile phases; non-standard modes and level shifts appear in the spectrum, and even unexpected density structures are possible (as observed for magnetars).

Another, equally sound way to specify the conjugation equation is via a variational principle: introduce an action functional on the curve $\kappa(x)$,

$$S[k] = \int_0^L \left(\frac{d^2\kappa}{dx^2}\right)^2 dx$$

whose minimization yields a smooth shape, since the conjugation profile is an extremum of the second-order curvature (an analogue of a smoothing spline).

Before proposing a new view of metric conjugation between the medium and an LDS particle within a trajectory, consider a real nanosheet whose upper and lower surfaces can be treated as perfectly smooth two-dimensional manifolds. Each is embedded in three-dimensional space and possesses its own metric determined by wave properties, density distribution, excitations, etc. Evidently, both surfaces satisfy all definitions of Riemann surfaces conjugated across the sheet's thickness. They are distinct boundary surfaces of a single nanofilm, each with its own curvature and conjugation conditions. Thus, a nanofilm with two smooth surfaces is not two independent Riemann surfaces, but conjugated structures tied by the common three-dimensional geometry of the layer. They may be isometric (if the sheet is ideally flat) or of different curvature (if it is bent), yet their curvatures are always coordinated: bending one inevitably alters the other, albeit under different local constraints. The sheet's metric is determined by both surfaces—one cannot specify one without affecting the other.

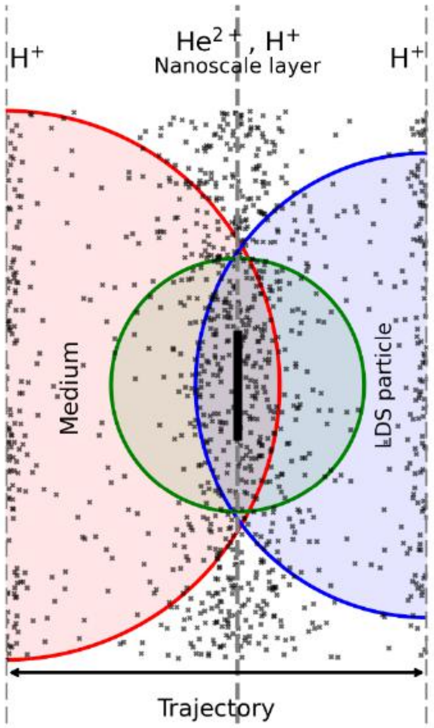

Fig. 2. Visualization of the model combined with plasma-particle distributions from the Voyager data [25–31]. The colored circles mimic the wave functions of the medium (red), the LDS particle (blue), and the nanosheet (green). Dashed lines indicate the putative boundaries of the medium and the LDS particle, as well as the approximate position of the emerging nanosheet. Randomly placed points mimic the distribution of plasma particles H^+ and He^{2+} along the trajectory.

In LDS terms, wave excitations (phonons, plasmons, spin modes) cannot be localized on only one surface of the nanosheet; they always "feel" the second surface because the wave field permeates the entire sheet. Bound states arise: symmetric (surfaces oscillate in phase) and antisymmetric (out of phase). Spectroscopically these appear as doublet modes: in optics—plasmonic doublets; in magnetism—coupled spin states; in mechanics—bending resonances with doubled frequencies. If the two surfaces are not independent but tied by the sheet's rigid geometry, then by definition they are no longer "two Riemann surfaces," but boundaries of a single Riemannian manifold, i.e., projections of one Riemannian geometry seen from two sides. If such closely spaced surfaces begin to "stitch together" via wave functions, this can be interpreted as the formation of a new manifold (via a connected sum or through special boundary conditions). Importantly, in the absence of external perturbations the wave functions on the surfaces may remain unlinked (orthogonal). Under an external field (e.g., magnetic), however, phase coherence can emerge, producing a new conjugation metric: the wave functions on both surfaces merge and form a different topology. This leads to the question: can the trajectory itself create a "nanosheet"—a two-dimensional Riemann surface as a stable conjugation object? Within the trajectory a two-dimensional coherent envelope—an analogue of a nanosheet of metric conjugation—can form. This envelope has two smooth sides which, under external influence (e.g., a magnetic field), may interact and generate localized inhomogeneities. In this case, the trajectory ceases to be a line and acquires the character of a membrane capable of carrying new excitation modes. The reconciliation of the curvatures of the medium and the LDS particle is then affected not directly, but via the field of the nanosheet, which plays the role of an intermediate membrane. Thus, the trajectory becomes not a line of metric conjugation, but a region of phase mediation, where reconciliation is realized by a field.

For a mathematical formulation, suppose M is a three-dimensional Riemannian manifold ("the medium") with metric g, and N⊂M is the LDS region with metric $\tilde{g}$. Introduce the notations: $B_{LDS\to env}(r)$: the carrier's field acting on the medium; $B_{env\to LDS}(r)$ - the medium's field acting on the carrier (LDS) along the envelope Σ; $\psi_{LDS}(r, B_{env\to LDS})$: the carrier's wave function parameterized by the medium's field; $\psi_{env}(r, B_{LDS\to env})$: the medium's wave function parameterized by the carrier's field, where r - indicates a state parameter on the Riemannian manifold (not a Euclidean point, but a parameter of the form's state). Both fields are functionals of the "opposite" wave function:

$$B_{LDS\to env}(r) = B_{LDS}[\psi_{LDS}](r); \quad B_{env\to LDS}(r) = B_{env}[\psi_{env}](r)$$

Note that here B may include spin density, magnetization, tensor susceptibility, etc. Suppose that along the trajectory a two-dimensional shell Σ (nanosheet) arises with induced metric h, coherence field Φ, and a wave function that acts as a binding element between the LDS particle and the environment, where the field Φ is defined through the nanosheet wave function written as

$$\psi_\Sigma = \sqrt{\rho_\Sigma}\, e^{i\Phi}; \quad \rho_\Sigma = |\psi_\Sigma|^2; \quad \Phi = \arg \psi_\Sigma$$

Then the $|\nabla_\Sigma \Phi|^2$ - represents the phase part of the kinetics ψ_Σ. Thus, the nanosheet is perceived as a two-dimensional manifold possessing its own dynamics and spin density. In this way we obtain a "stitching" of wave functions and metrics in the form of a self-consistent functional of the shell geometry:

$$S = \int_\Sigma (\sigma + \kappa H^2) dA + \int_\Sigma \left[\frac{\hbar^2}{2m_\Sigma}|D_\Sigma \psi_\Sigma|^2 + U(\rho_\Sigma)\right] dA + \lambda \int_\Sigma \rho_\Sigma \Delta K dA$$
$$+ g_L \int_\Sigma (\psi_\Sigma^* \psi_{LDS} + \psi_\Sigma \psi_{LDS}^*) dA + g_E \int_\Sigma (\psi_\Sigma^* \psi_{env} + \psi_\Sigma \psi_{env}^*) dA$$
$$- \mu_\Sigma \int_\Sigma B_{eff} \cdot S_\Sigma dA$$

here the first term $\int_\Sigma (\sigma + \kappa H^2) dA$describes the shell geometry; the second $\int_\Sigma \left[\frac{\hbar}{2m_\Sigma}|D_\Sigma \psi_\Sigma|^2 + U(\rho_\Sigma)\right] dA$— the dynamics of the nanosheet; the third - $\lambda \int_\Sigma \rho_\Sigma \Delta K dA$— coupling with curvature; the fourth and fifth terms - $g_L \int_\Sigma (\psi_\Sigma^* \psi_{LDS} + \psi_\Sigma \psi_{LDS}^*) dA + g_E \int_\Sigma (\psi_\Sigma^* \psi_{env} + \psi_\Sigma \psi_{env}^*) dA$ – describe coupling with the LDS carrier and with the environment, respectively; the sixth $- \mu_\Sigma \int_\Sigma B_{eff} \cdot S_\Sigma dA$ corresponds to the Zeeman effect / magnetic pumping.

Here $D_\Sigma = \nabla_\Sigma - \frac{iq_\Sigma}{\hbar} A_{eff}$ is the covariant derivative on Σ; $S_\Sigma = \psi_\Sigma * \hat{S}$ is the spin density of the nanosheet; $B_{eff} = B_{env \to \Sigma} + B_{LDS \to \Sigma}$ is the effective field on Σ (sum of environment and LDS fields restricted to the shell Σ); ΔK is the curvature mismatch; ρ_Σ modulates the stitching of Σ; g_L, g_E are tunneling/exchange coupling constants with LDS and the environment.

The parameter m_Σ in the second term does not reflect the intrinsic mass of the particle but the effective resistance or medium response to changes of the field ψ_Σ on the surface. It shows how much the medium density resists perturbations and serves as a scaling coefficient for the gradient term of the functional.

Since the "environment–particle" trajectory is considered as a curve on a Riemannian manifold with metric $g_{\mu\nu}$, by applying the variational principle to the self-consistent Hamiltonian we write the action as

$$S = \int_\gamma L\left(x^\mu, x^\mu, g_{\mu\nu}(x)\right) d\tau$$

where γ - is the path on the manifold, τ - is the parameter along the trajectory. The stationarity condition $\delta S = 0$ leads to the generalized Euler–Lagrange equations:

$$\frac{D}{D\tau}\left(\frac{\partial L}{\partial x^\mu}\right) - \frac{\partial L}{\partial x^\mu} = 0$$

where $\frac{D}{D\tau}$ - is the covariant derivative along the trajectory. This form naturally accounts for both geometry and medium response, which is crucial for describing LDS objects. After variation, the Euler–Lagrange equations take the form:

$$\frac{\hbar^2}{2m_\Sigma} D_\Sigma^\dagger D_\Sigma \psi_\Sigma + U'(\rho_\Sigma)\psi_\Sigma + \lambda \Delta K \psi_\Sigma - \mu_\Sigma \left(B_{eff} \cdot \hat{S}\right)\psi_\Sigma + g_L \psi_{LDS} + g_E \psi_{env} = 0$$

with analogous equations for ψ_{LDS} and ψ_{env} with mutual field coupling:

$$B_{env \to LDS} = B_{env}[\psi_{env}], B_{LDS} = B_{LDS}[\psi_{LDS}], B_{eff} I_\Sigma = B_{env \to \Sigma} + B_{LDS \to \Sigma}$$

Here $D_\Sigma^\dagger D_\Sigma$ - is the operator accounting for local geometry and derivatives on the manifold; $U'(\rho_\Sigma)$ - is the derivative of the potential with respect to density; λΔK - reflects curvature-induced corrections; $\mu_\Sigma\left(B_{eff} \cdot \hat{S}\right)$— interaction with effective magnetic field and spin; $g_L \psi_{LDS}$, $g_E \psi_{env}$ — coupling terms linking the LDS object with the environment.

The obtained expressions define the desired self-consistent field formed by all subsystems, while ψ_Σ - and the nanosheet acquire the role of mediators, through which both the metric (via ΔK) and the fields (via B_{eff}) "stitch" the LDS and the environment. However, in the present model the nanosheet thickness δ is a function of state and is determined by the overlap of LDS and environment wave functions through the nanosheet itself, i.e. by the effective correlation length — the region where LDS and environment fields overlap through ψ_Σ, with $|\psi_\Sigma|^2 = \rho_\Sigma$ defining the distribution width (interpreted as thickness). It follows that nanosheet thickness is governed by metric matching and only weakly depends on curvature mismatch. It is estimated as

$$\delta(\Delta K) \approx \delta_0 (1 + \varepsilon(\ell_C^2 \Delta K)^2), \quad \varepsilon \ll 1$$

where δ_0 - is the baseline thickness under matched curvatures, ℓ_C - is the coherence length, and $\Delta K = K_{env} - K_{LDS}$ - the thickness defines the effective mass scale and thus links trajectory geometry with its physical manifestation.

The effect of a magnetic field manifests as an increase in overlap of LDS and environment wave functions between the two Riemann surfaces, i.e.:

$$S(B) = \int_{\Sigma} \psi_{LDS}(k,B)\ \psi_{env}(k,B)\rho_{\Sigma}(k,B)d\mu_h(k)$$

It is then evident that if curvatures are matched (ΔK→0), thickness tends to the minimum value determined by the material. With increased overlap of wave functions, the shell compresses, i.e. the coupling becomes stronger. In strong magnetic fields or at maximal overlap, the nanosheet between the LDS particle and the environment may vanish. Thus, the increased overlap of wave functions in an external magnetic field is perceived by an observer as compression of the effective Riemann shell. In contrast to magnetic effects, gravitational "compression" is more difficult to define, since gravity itself is determined by effective mass, and effective mass is already formed from wave-function overlap. Therefore, the influence of gravity on thickness does not appear as an independent mechanism, but is fully accounted for in the expression for δ.

Conclusion

The proposed LDS-particle framework presents a holistic view of matter as a localized density structure arising from the concordance of closed-space geometries. The trajectory ceases to be an external line and becomes a form of metric coupling, ensuring stability and quantum properties. Mass, spin, and antisymmetry emerge as consequences of topology and medium response. Voyager 1/2 data on the heliopause and ion distributions demonstrate that the boundary of the Solar System is not a sharp wall but an extended tunnel of curvature coupling, consistent with the key principles of the LDS model. Thus, the LDS approach unites local (microscopic) and global (cosmic) manifestations into a single topological picture of matter and space. Within the extended LDS-particle model, it is shown that during interaction with the medium, the trajectory may incorporate a nanoscale layer and its dynamic evolution, offering a new perspective on the very nature of trajectory. The LDS particle is no longer a static object but appears as a localized region of self-organization where geometry, density, and spin states are bound through a dynamic nanoscale interface. This layer acts as an adaptive boundary between the medium and the inhomogeneity, forming a stable trajectory even under changing metrics. Such an approach makes the LDS model applicable to systems where surface effects and local anisotropies are crucial—for example, thin ferrite films or hybrid spin–photon structures. In this paradigm, mass and motion give way to the concepts of stable connectivity and effective medium resistance.

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Received: 03.09.2025