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Basic concepts of space drive propulsion - Another view (Cosmology) of propulsion principle-

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Abstract

Assuming that space vacuum is an infinite continuum, the propulsion principle utilizes the pressure field derived from the geometrical structure of space, by applying both continuum mechanics and General Relativity to space. The propulsive force is a pressure thrust that arises from the interaction of space-time around the spaceship external environment and the spaceship itself; the spaceship is propelled by the pressure used against the space-time structure. As is well known in cosmology, the expansion rule of the universe is governed by the Friedman's equations and the Robertson-Walker metric.
In this paper, the propulsion principle of space drive is introduced from another angle (Cosmology), that is, the pressure of the field induced by local expansion of space is completely considered in the propulsion principle.

Keywords

Space drive; Propulsion; Cosmology; Expanding universe; Friedman's equation; Robertson-Walker metric; De Sitter universe; Inflation; Curvature; Spaceship.

INTRODUCTION

A concept of a space drive propulsion system as a paper entitled "Space Strain Propulsion System" is introduced by Minami in 1988[1]. The term of "space strain" is changed to "space drive" receiving the recommendation by Robert L. Forward[2]. After then, the second paper entitled "Possibility of Space Drive Propulsion" is presented at the 45th IAF in 1994[3].
Assuming that space vacuum is an infinite continuum, the propulsion principle utilizes the pressure field derived from the geometrical structure of space, by applying both continuum mechanics and General Relativity to space. The propulsive force is a pressure thrust that arises from the interaction of space-time around the spaceship external environment and the spaceship itself; the spaceship is propelled against the space-time continuum structure. This means that space can be considered as a kind of transparent elastic field. That is, space as a vacuum performs the motions of deformation such as expansion, contraction, elongation, torsion and bending. The latest expanding universe theory (Friedmann, de Sitter, inflationary cosmological model) supports this assumption. Space can be regarded as an elastic body like rubber.
General Relativity implies that space is curved by the existence of energy (mass etc.) and based on Riemannian geometry. If we admit this space curvature, space is assumed as an elastic body. According to continuum mechanics, the elastic body has the property of the motion of deformation such as expansion, contraction, elongation, torsion and bending. General Relativity uses just only the curvature of space. Expansion and contraction of space are used in Cosmology, and a theory using torsion is also studied by Hayasaka[4]. Perhaps, Twistor Theory by Roger Penrose is also applied to the torsion of space[5].
In the latest cosmology, the terms vacuum energy and cosmological term "Λg^{ij}" are used synonymously. Λ is known as the cosmological constant. The term with the cosmological constant is identical to the stress-energy tensor associated with the vacuum energy. The properties of vacuum energy, i.e. cosmological term are crucial to expansion of the Universe, that is, to inflationary cosmol-

ogy.

In the beginning, the acceleration generated by curvature of space induced by a strong magnetic field based on external and internal Schwarzschild solution was studied[1,3]. However, superior acceleration based on the de Sitter solution is obtained at present. Basically: *The acceleration derived from the de Sitter solution does not require a strong magnetic field. At the present day, space drive propulsion system based on the de Sitter solution needs not strong magnetic field but the technology to excite space.*

Inflationary universe which shows rapid expansion of space is based on the phase transition of the vacuum exhibited by the Weinberg-Salam model of the electroweak interaction. The vacuum has the property of a phase transition, just like water may become ice and vice versa. This shows that a vacuum possesses a substantial physical structure such as the material. It coincides with the precondition of a space drive propulsion principle[1,3,6-9].

As is well known in cosmology, the expansion rule of the universe is governed by the Friedman's equations and the Robertson-Walker metric[10-12,14].

In this paper, the propulsion principle for this space drive is introduced from another angle, that is, the pressure of the field induced by local rapid expansion of space is completely considered in the propulsion principle based on the latest cosmology.

BRIEFING OF SPACE DRIVE PROPULSION

The space drive propulsion system proposed here is one of field propulsion system utilizing the action of the medium of strained or deformed field of space, and is based on the propulsion principle of the kind of pressure thrust. As a matter of fact, several kinds of field propulsion can be proposed by making a choice of physical concepts, i.e., General Relativity in the view of macroscopic structure and Quantum Field Theory in the view of microscopic structure[9,15]. Minami summarized the definition and the basic concept of field propulsion in 2003[9]. The various propulsion systems that one may choose can be based on different physical/geometric quantities; for instance, curvature, zero-point fluctuations, statistical entropy, and so forth. However, they share an underlying principle, namely, they utilize the same concept of physical structure of Space. Figure 1 shows the basic propulsion principle of common to all kinds of field propulsion system. As shown in Figure 1, the propulsion principle of field propulsion system is not momentum thrust but pressure thrust induced by a pressure gradient (or potential gradient) of the space-time field (or vacuum field) between bow and stern of a spaceship. Since the pressure of the vacuum field is high in the rear vicinity of spaceship, the spaceship is pushed from the vacuum field. Pressure of vacuum field in the front vicinity of spaceship is low, so the spaceship is pulled from the vacuum field. In the front vicinity of spaceship, the pressure of vacuum field is not necessarily low but the ordinary vacuum field, that is, just as only a high pressure of vacuum field in the rear vicinity of spaceship. The spaceship is propelled by this distribution of pressure of the vacuum field. Vice versa, it is the same principle that the pressure of vacuum field in the front vicinity of spaceship is just only low and the pressure of vacuum field in the rear vicinity of spaceship is ordinary. In any case, the pressure gradient from the vacuum field (potential gradient) is formed over the entire range of the spaceship, so that the spaceship is propelled by pushing from the pressure gradient resulting from the vacuum field.

Here, we must pay attention to the following. The spaceship cannot move unless the spaceship is independent of any pressure gradient in the vacuum field. No interaction is present between the pressure gradient from the vacuum field and spaceship. This spaceship does not move as long as the propulsion engine generates the pressure gradient or potential gradient in the surrounding area of the spaceship, due to the interaction between the pressure gradient of the vacuum field and spaceship. This is because an action of the propulsion engine on space is in equilibrium with a reaction from space. It is consequently necessary to shut off the equilibrium state in order to actually move the spaceship. As a continuum, the space has a finite strain rate, i.e. speed of light. When the propulsion engine stops generating the pressure gradient of the vacuum field, it takes a finite interval of time for the generated pressure gradient from the vacuum field to return to ordinary vacuum field conditions. In the meantime, the spaceship is independent of this pressure gradient from the vacuum field. It is therefore possible for the spaceship to proceed ahead receiving the action from the vacuum field.

In general, a body cannot move carrying or together with a field that is generated by its body from the standpoint of kinematics. In other words, the body cannot move unless the body is independent of the field. This is because an action on the field and a reaction from the field are in the state of equilibrium. As mentioned above, since the propulsion engine must necessarily be shut off for propulsion, the spaceship can get continuous thrust by repeating the alternate ON/OFF change in the engine operation at a high frequency.

Early phase of space drive propulsion theory

The principle of this space drive propulsion system is derived from General Relativity and the theory of continuum mechanics. We assume that the so-called "vacuum" of space acts as an infinite elastic body like rubber. The curvature of space plays a significant role for propulsion theory. The acceleration performance of this system is found by the solution of the gravitational field equation, such as the Schwarzschild solution, Reissner- Nordstrom solution, Kerr solution, and de Sitter solution. The concept and the details of this propulsion system are described below.

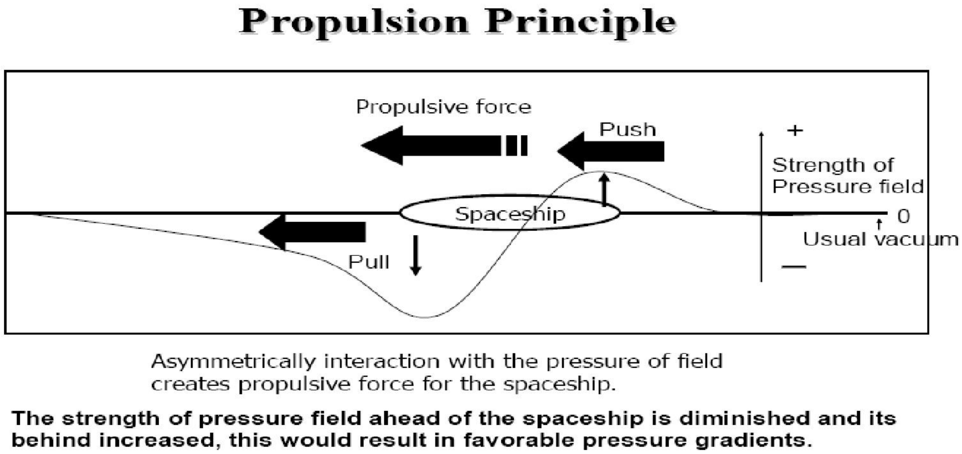


Figure 1 : Basic propulsion principle of field propulsion system.

The theory of the space drive propulsion is summarized as follows[7].

1) On the supposition that space is an infinite continuum, continuum mechanics can be applied to the so-called "vacuum" of space. This means that space can be considered as a kind of transparent elastic field. That is, space as a vacuum performs the motion of deformation such as expansion, contraction, elongation, torsion and bending. The latest expanding universe theory (Friedmann, de Sitter, inflationary cosmological model) supports this assumption. We can regard space as an infinite elastic body like rubber.

2) From General Relativity, the major component of curvature of space (hereinafter referred to as the major component of spatial curvature) R^{00} can be produced by not only mass density but also the magnetic field B as follows:

$$R^{00} = \frac{4\pi G}{\mu_0 c^4}\cdot B^2 = 8.2\times10^{-38}\cdot B^2 \tag{1}$$

Eq.(1) indicates that the major component of spatial curvature can be controlled by a magnetic field.

3) If space curves, then an inward normal stress "–P" is generated.

This normal stress, i.e. surface force serves as a sort of a pressure field.

$$-P = N\cdot(2R^{00})^{1/2} = N\cdot(1/R_1 + 1/R_2) \tag{2}$$

where N is the line stress of membrane of curved surface, R_1, R_2 are the radii of principal curvature of curved surface.

A large number of curved thin layers form the unidirectional surface force, i.e. acceleration field. Accordingly, the spatial curvature R^{00} produces the acceleration field α.

4) From the following linear approximation scheme for the gravitational field equation:

(i) weak gravitational field, i.e. small curvature limit, (ii) quasi-static, (iii) slow-motion approximation (i.e. $v/c<<1$),

we get the following relation between acceleration of curved space and curvature of space:

$$\alpha^i = \sqrt{-g_{00}}\,c^2\int_a^b R^{00}(x^i)dx^i \tag{3}$$

Eq.(3) indicates that the acceleration field α^i is produced in curved space.

5) In the curved space region, the massive body "m(kg)" existing in the acceleration field is subjected to the following force F^i(N), from General Relativity:

$$F^i = m\Gamma^i_{jk}\cdot\frac{dx^j}{d\tau}\cdot\frac{dx^k}{d\tau} = m\sqrt{-g_{00}}\,c^2\Gamma^i_{jk}u^ju^k = m\alpha^i \tag{4}$$

Eq.(4) yields more simple equation from the above-stated linear approximation:

$$F^i = m\sqrt{-g_{00}}\,c^2\Gamma^i_{00} = m\alpha^i = m\sqrt{-g_{00}}\,c^2\int_a^b R^{00}(x^i)dx^i \tag{5}$$

Setting i=3 (i.e. direction of radius of curvature:r), we get Newton's second law:

$$F^3 = F = m\alpha = m\sqrt{-g_{00}}\,c^2\int_a^b R^{00}(r)dr = m\sqrt{-g_{00}}\,c^2\Gamma^3_{00} \tag{6}$$

6) The acceleration (α) of curved space and its Riemannian connection coefficient (Γ^3_{00}) are given by:

$$\alpha = \sqrt{-g_{00}}\,c^2\Gamma^3_{00},\ \Gamma^3_{00} = \frac{-g_{00,3}}{2g_{33}} \tag{7}$$

where c=speed of light, g_{00} and g_{33}=component of metric tensor, $g_{00,3} = \partial g_{00}/\partial x^3 = \partial g_{00}/\partial r$.

We choose the spherical coordinates "$ct=x^0$, $r=x^3$, $\theta=x^1$, $\varphi=x^2$" in space-time. The acceleration α is represented by the equation both in the differential and in the integral form. Practically, since the metric is usually given, the differential form has been found to be advantageous.

7) The acceleration of space drive propulsion system is based on the solutions of the gravitational field equation, which is derived from Eq.(7). The detail is described in Reference[7].

Final phase of space drive propulsion theory: Acceleration induced by the cosmological constant

In the latest cosmology, the terms vacuum energy and cosmological term "Λg^{ij}" are used synonymously. Λ is a constant known as the cosmological constant. The cosmological term is identical to the stress-energy associated with the vacuum energy. The properties of vacuum energy, i.e. cosmological term are crucial to expansion of the Universe, that is, to inflationary cosmology. The vacuum energy in de Sitter solution yields the result that the expansion accelerates with time and the total energy with a comoving volume that grows exponentially[11,12]. These facts are due to the elastic nature of the vacuum and support the basic concept of space drive propulsion system, that is, the space is an infinite continuum. According to the gauge theories, the physical vacuum has various ground states. The potential of vacuum has minima which correspond to the degenerate lowest energy states, either of which may be chosen as the vacuum. Whatever is the choice, however, the symmetry of the theory is spontaneously broken. The particular interest for cosmology is the theoretical expectation that at high temperatures, symmetries that are spontaneously broken today were restored[13].

The most general form of the gravitational field equations which include cosmological constant is given by:

$$R^{ij} - \frac{1}{2}\cdot g^{ij}R = -\frac{8\pi G}{c^4}T^{ij} + \Lambda g^{ij} \tag{8}$$

where R^{ij} is the Ricci tensor, R is the scalar curvature, G is the gravitational constant, c is the speed of light, T^{ij} is the energy momentum tensor, and Λ is the cosmological constant.

It is simple to see that a cosmological term Λg^{ij} is equivalent to an additional form of energy momentum tensor. The cosmological term is identical to the energy momentum tensor associated with the vacuum.

Here, if we multiply both sides of Eq.(8) by g_{ij}, we obtain

$$\frac{8\pi G}{c^4}T = R + 4\Lambda \tag{9}$$

In empty space with all of the components of the energy momentum tensor are equal to zero, that is, $T^{ij} = 0$ and $T = 0$, from Eq.(9) and Eq.(8), we get the following respectively

$$R = -4\Lambda,\ R^{ij} = -\Lambda g^{ij} \tag{10}$$

The scalar curvature R ($1/m^2$) is given by

$$R = R_i^{\ i} = g_{ij}R^{ij} = g_{00}R^{00} + g_{11}R^{11} + g_{22}R^{22} + g_{33}R^{33} \approx g_{00}R^{00} = -R^{00}\ (g_{00} \approx -1:\ \text{weak field}) \tag{11}$$

Hence, from Eq.(10), we get

$$R^{00} = 4\Lambda \tag{12}$$

Eq.(12) means that the cosmological constant Λ generates the major component of curvature of space R^{00}. Therefore, the curvature of space is identical as the cosmological constant.

Now, concerning the de Sitter cosmological model with non-zero vacuum energy (i.e. cosmological constant), the de Sitter line element is written as

$$ds^2 = -(1-\frac{1}{3}\Lambda r^2)c^2dt^2 + \frac{1}{1-\frac{1}{3}\Lambda r^2}dr^2 + r^2(d\theta^2 + \sin^2\theta d\varphi^2) \tag{13}$$

Where the metrics are given by

$$g_{00} = -(1-1/3\cdot\Lambda r^2),\ g_{11} = g_{22} = 1,\quad g_{33} = 1/(1-1/3\cdot\Lambda r^2),\ \text{other}\ g_{ij} = 0 \tag{14}$$

The acceleration α of de Sitter solution can be obtained by combining Eq.(7) with Eq.(14)

$$\alpha = \frac{1}{3}c^2\Lambda r(1 > 1/3\cdot\Lambda r^2) \tag{15}$$

The acceleration induced by the cosmological constant is proportional to the distance "r" from the generative source, i.e. engine system. According to the gauge theories, the physical space as a vacuum is filled with a spin-zero scalar field, called a Higgs field. The vacuum energy fluctuates in proportion to the fluctuation of the Higgs field[13]. The vacuum potential (vacuum energy density) V (ϕ) is given by the vacuum expectation value ϕ of Higgs field, and we get the minimum of the Higgs potential V_0 (ϕ) as follows:

$$V_0(\phi) = \frac{\lambda}{4}\phi_0^{\ 4} \tag{16}$$

Here, λ is arbitrary Higgs self-coupling in the Higgs potential (λ is not known and is not determined by a gauge principle, presumably $\lambda \geq 1/10$).

Since the vacuum potential V_0 (ϕ) shall be invariant under the Lorentz transformation, the energy momentum tensor of vacuum $T^{ij}_{\ vac}$ is written in the form

$$T^{ij}_{\ vac} = V_0(\phi)g^{ij} \tag{17}$$

The energy momentum tensor of vacuum exerts the same action as that for the cosmological term. It should be noted that $T^{ij}_{\ vac}$ is not energy momentum tensor for matter but the vacuum itself.

From Eq.(8) and above Eq.(17), as its metric source, $8\pi G/c^4 \cdot T^{ij}_{\ vac} = 8\pi G/c^4 \cdot V_0(\phi)g^{ij} = \Lambda g^{ij}$, then we get

$$\Lambda = \frac{8\pi G}{c^4}V_0(\phi) = 2.1\times10^{-43}V_0(\phi) \tag{18}$$

In general, since the potential from its source is inversely proportional to the distance "r" from the potential source, assuming that the vacuum potential V_0 (ϕ) in Eq.(16) is the energy source, the potential at distance "r" apart from its energy source is written in the form

$$V_0(\phi) \Rightarrow V_0(\phi)/r = \frac{\lambda}{4r}\phi_0^{\,4} \tag{19}$$

Combining Eq.(18) with Eq.(19) yields:

$$\Lambda = 2\pi G\lambda\phi_0^{\,4} / c^4 r \tag{20}$$

Substituting Eq.(20) into Eq.(15), finally we get:

$$\alpha = \frac{2\pi G\lambda}{3c^2}\phi_0^{\,4} = 1.6\times 10^{-27}\lambda\phi_0^{\,4} \tag{21}$$

Eq.(21) indicates that the vacuum expectation value ϕ_0 for the Higgs field (i.e. vacuum scalar field) produces the constant acceleration field. As a result, we found out that the acceleration becomes constant, that is, we can get rid of the tidal force inside of the spaceship. The scalar field ϕ can be thought of arising from a source in much the same way as the electromagnetic fields arise from charged particles. We have to search for the fields with the source. The size L of spaceship (i.e. length or diameter) is limited to the range r_S, where r_S is the range determined by the following: $V_0(r) \propto V_0/r_S \approx 0$ ($L = r_S$). Within the range of $L = r_S$, the tidal force in the spaceship and in the vicinity of spaceship can be removed, that is, the acceleration becomes constant within the range of a given region "r_S". The vacuum expectation value ϕ of Higgs field can be considered as the strength of the field, i.e. energy of the field.

Using Eq.(16), particular attention is paid to the role of ϕ_0. Here, only ϕ_0 is described in NATURAL UNIT ($c = \hbar = k_B = 1$). In general, natural units are used for the field of elementary particle physics or cosmology. Since the fundamental constants $\hbar = c = k_B = 1$ are used in this unit system, there is one fundamental dimension, energy, can normally be stated in GeV, that is, [Energy]=[Momentum]=[Mass]=[Temperature]=$[\text{Length}]^{-1}$=$[\text{Time}]^{-1}$: in GeV.

GeV^4 implies energy density (J/m^3) in SI unit. GeV^3 implies number density ($1/m^3$).

The following relation: $1\text{GeV}^3 = 1.3\times 10^{47}\text{m}^{-3}$ is used to convert from the natural unit system to SI unit system. The vacuum expectation value ϕ_0 of the present universe is said to be $\phi_0 \sim 10^{-12}$GeV and $\phi_0^{\,4} = 1\times 10^{-46}\text{GeV}^4$, therefore substitution of Eq.(16) and Eq.(21) with setting $\lambda = 1$ gives: $V_0(\phi) = 1/4\cdot\phi_0^{\,4} = 0.5\times 10^{-9}\text{J/m}^3$, $\alpha = 1.6\times 10^{-27}\phi_0^{\,4} = 3.3\times 10^{-36}\ \text{m/s}^2 \approx 0$. Naturally, the acceleration induced by present cosmic space is zero. In addition, from Eq.(18) and Eq.(12), we get $\Lambda = 2.1\times 10^{-43}\,V_0(\phi) = 1.05\times 10^{-52}\,\text{m}^{-2}$, $R^{00} = 4.2\times 10^{-52}\text{m}^{-2} \approx 0$. Therefore, the present cosmic space is flat space.

From Eq.(1), the value of $R^{00} = 4.2\times 10^{-52}\text{m}^{-2}$ gives the magnetic field of $B = 7.2\times 10^{-4}$gauss (7.2×10^{-8}Tesla). This value of magnetic field agrees quite well with the value of the interstellar magnetic field, i.e. $\sim 10^{-5}$gauss. The vacuum expectation value ϕ_0 of present universe is excited and becomes $\phi = 6\times 10^{-3}\text{GeV} = 6\text{MeV}$ (from ϕ_0 to $\phi = \phi_0 + d\phi = \phi_0 + 6\text{MeV}$), similarly we get the following: $V_0(\phi) = 1/4\cdot\phi_0^{\,4} = 6.7\times 10^{27}\text{J/m}^3$, $\alpha = 1.6\times 10^{-27}\phi_0^{\,4} = 43.13\ \text{m/s}^2 = 4.4G$. $\Lambda = 2.1\times 10^{-43}$, $V_0(\phi) = 1.4\times 10^{-15}\text{m}^{-2}$, $R^{00} = 5.6\times 10^{-15}\text{m}^{-2}$. From Eq.(1), the value of $R^{00} = 5.6\times 10^{-15}\text{m}^{-2}$ gives the magnetic field of $B = 2.6\times 10^{11}$Tesla.

The space is a kind of continuum which repeats expansion and contraction. We assume that space as a continuum has two kinds of phases, that is, the elastic solid phase (i.e. Crystalline elasticity) like spring and the visco-elastic liquid phase (i.e. Rubber elasticity=Entropy elasticity) like rubber. The elastic solid phase corresponds to the present universe and the visco-elastic liquid phase corresponds to the early universe. Further, we speculate that the space may get the phase transition easily by some trigger, i.e. excitation of space, and that the elastic solid phase of space is rapidly transformed to the visco-elastic liquid phase of space and vice versa. The space as a vacuum preserves the properties of phase transition even now. In general, the phase transition is accompanied by a change of symmetry. The phase transition has occurred from an ordered phase to a disordered phase and vice versa.

In a cosmological phase transition, the vacuum expectation value of the scalar field ϕ is transferred from high-temperature, symmetric minimum $\phi = 0$, to the low-temperature, symmetry-breaking minimum $\phi = \pm\phi_0$. Accordingly, the phase transition is basically related to the spontaneous symmetry breaking, and it is considered that above-stated phenomenon is the fundamental property of space[10,11,13].

Now, referring to Figure 2, the vacuum expectation value of scalar field "$\pm\phi_0$" indicates the present true vacuum (present universe), and "$\phi = 0$" indicates the metastable false vacuum in early universe. Even if $\phi = \pm\phi_0$ had such a small value, we would expect quantum fluctuations to push ϕ sufficiently far out on the potential from $\phi = \pm\phi_0$ to near the $\phi = 0$ by a trigger. Since the potential $V(\phi)$(J/m^3) means the energy density of the vacuum corresponding to the value of ϕ, the value of $V(\phi)$ directly contributes to the cosmological term. The change in ϕ gives the change in $V(\phi)$. As a result, the control of fluctuations of scalar field (i.e. coherent small oscillations of scalar field) affects the cosmological constant Λ. The enormous vacuum energy of the scalar field then exists in the form of spatially coherent oscillations within the field.

Furthermore Figure 2 shows that a quantum fluctuation to push sufficiently by a trigger gives rise to a large perturbation of vacuum energy. Raising the vacuum potential may produce a large vacuum energy either through quantum or thermal tunneling, that is, pushing $+\phi_0$ by some trigger that gives rise to a large perturbation from the vacuum energy. Therefore, by taking the above mechanism used as an unknown technology, we may produce a large cosmological constant in a local space, i.e. curvature. Here, the excitation of space means that the value of vacuum expectation value ϕ is pushed up slightly from its present value $\phi = +\phi_0$ and therefore the vacuum potential $V(\phi)$ is slightly raised.

As shown in Figure 3, the dotted area stands for the excited space. The excited space produces the visco-elastic liquid field (rubber elasticity = entropy elasticity) in the surrounding area of the spaceship and generates constant acceleration. The un-dotted area stands for the usual space, i.e., elastic solid field (crystalline elasticity). Space may get the phase transition easily by some trigger, i.e., excitation of space. Although the usual space (i.e. elastic solid field) is very rigid and therefore an enormous energy is required to bend the usual space, the rigidity of visco-elastic field is small and therefore a little energy can bend the space. In addition, since the relaxation time generated by the curved visco-elastic field space increases, the pulse width of thrust pulse increases and hence yields the improvement of acceleration.

In conclusion, a condensed summary of the propulsion principle of space drive propulsion system is shown as Figure 4.

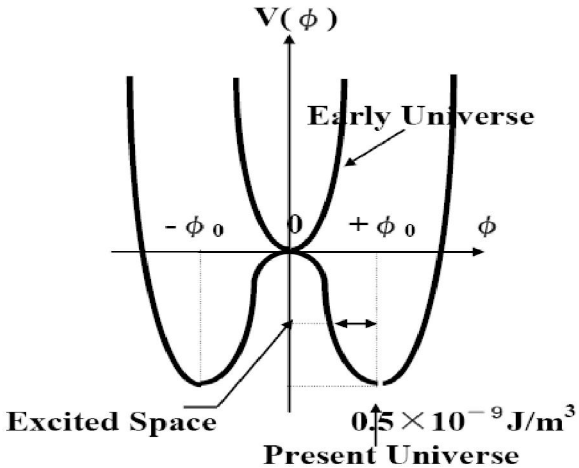


Figure 2 : Vacuum potential.

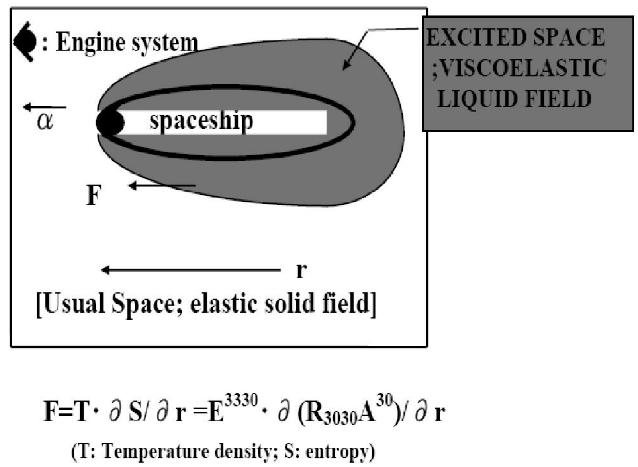
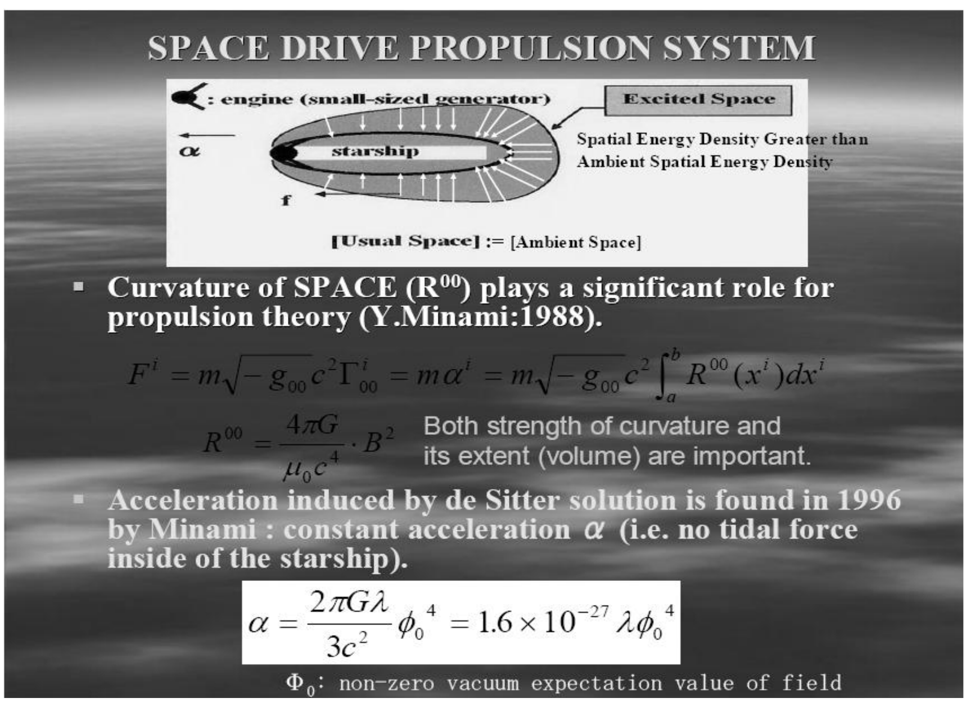


Figure 3 : Excited space around the spaceship.



$$F^i = m\sqrt{-g_{00}}c^2\Gamma^i_{00} = m\alpha^i = m\sqrt{-g_{00}}c^2\int_a^b R^{00}(x^i)dx^i$$

$$R^{00} = \frac{4\pi G}{\mu_0 c^4}\cdot B^2$$

$$\alpha = \frac{2\pi G\lambda}{3c^2}\phi_0^{\ 4} = 1.6\times10^{-27}\lambda\phi_0^{\ 4}$$

Figure 4 : A condensed summary of space drive propulsion principle.

ANOTHER VIEW (COSMOLOGY) OF THE SPACE DRIVE PROPULSION

In previous chapter 2, we ran over the propulsion theory of the space drive propulsion system. However, in this chapter, we explored the possibility that the expanding space generates thrust using the cosmology that is we make a study about the propulsion principle from aspects of cosmology, especially considering the latest expanding universe theory of Friedmann, de Sitter, and inflationary cosmological model.

The inflationary universe shows rapid expansion of space based on the phase transition of the vacuum exhibited by the Weinberg-Salam model of the electroweak interaction. The vacuum has the property of a phase transition, just like water may become ice and vice versa. This shows that a vacuum possesses a substantial physical structure such as the material. It coincides with the precondition of a space drive propulsion principle. In general, phase transitions are associated with a spontaneous loss of symmetry as the temperature of a system is lowered. For instance, the phase transition known as "freezing water", at a temperature $T > 273K$, water is liquid. Individual water molecules are randomly oriented, and the liquid water thus has rotational symmetry about any point; in other words, it is isotropic. However, when the temperature drops below $T = 273K$, the water undergoes a phase transition, from liquid to solid, and the rotational symmetry or molecular geometry of the water is lost. The water molecules are now locked into a 'solid' crystalline structure, and the ice no longer has rotational symmetry about an arbitrary point. In other words, the ice crystal is anisotropic, with preferred directions corresponding to the crystal's axes of symmetry[10].

Supposing that the universe expands, and then what form can the metric of space-time be assumed if the universe is spatially homogeneous and isotropic at all time, and what if distance is allowed to expand as a function of time? The metric they derived is called the Robertson-Walker metric. It is generally written in the form

$$ds^2 = -c^2dt^2 + a(t)^2\left(\frac{dr^2}{1-Kr^2} + r^2(d\theta^2 + \sin^2\theta d\varphi^2)\right) \quad (22)$$

where a(t) is the scale factor that describes how distance grows or decreases with time; it is normalized so that $a(t_0) = 1$ at the present moment. K is the curvature that takes one of three discrete constant values: $K = 1$ if the universe has positive spatial curvature, $K = 0$ if the universe is spatially flat, and $K = -1$ if the universe has negative spatial curvature. The value of scale factor a(t) is obtained by substituting the Robertson-Walker metric for the following gravitational field equation

$$R^i{}_j - \frac{1}{2}\delta^i_j R = -\frac{8\pi G}{c^4}T^i{}_j + \Lambda\delta^i_j \quad (23)$$

where T^i_j is the energy momentum tensor, R^i_j is the Ricci tensor, R is the scalar curvature, G is the gravitational constant, c is the speed of light, $\delta^i_j = 1(i = j)$ or $0(i \neq j)$, and Λ is the cosmological constant.

Although Eq.(23) denoted by mixed tensor is different from Eq.(8), this form is well used in cosmology. The reason is that we can use Dingle rule to calculate easily the Christoffel symbols, Ricci tensor and so on [12:pp253-257].

That is, from the Robertson-Walker metric of equation (22), the Riemannian connection coefficient, the scalar curvature R, the Ricci tensor R^i_j are obtained, and then substituting their value for Eq.(23), we get Eq.(24) as the case of $i = 0$, $j = 0$. Here ε is the energy density of space, $\dot{a}(t) = da(t)/dt$.

$$\frac{\dot{a}(t)^2}{a(t)^2} = \frac{8\pi G}{3c^2}\varepsilon - \frac{c^2K}{a(t)^2} + \frac{1}{3}\Lambda c^2 \quad (24)$$

The equation (24) is called as the Friedmann equation and dominates the law of an expanding universe.

In a spatially flat universe ($K = 0$) and no cosmological constant ($\Lambda = 0$), the Friedmann equation takes a particularly simple form:

$$\frac{\dot{a}(t)^2}{a(t)^2} = \frac{8\pi G}{3c^2}\varepsilon \quad (25)$$

From $\frac{\dot{a}(t)}{a(t)} = \sqrt{\frac{8\pi G}{3c^2}\varepsilon}$, a(t) is obtained as the following:

$$a(t) = a_0 \exp\left[\left(\frac{8\pi G\varepsilon}{3c^2}\right)^{\frac{1}{2}} t\right] = a_0 \exp\sqrt{\frac{\Lambda}{3}}\, ct \quad (26)$$

Here, from Eq.(18):

$$\Lambda = \frac{8\pi G}{c^4}\varepsilon \quad (27)$$

We used the relation of $\varepsilon = \frac{c^4\Lambda}{8\pi G}$ from Eq.(27).

A spatially flat universe with the energy density ε is exponentially expanding. Such a universe is called a *de Sitter universe*. Even if there is no cosmological constant Λ from the outset, in the nature of things, expanding universe is indicated by General Relativity. In initial assumptions, the energy density ε is considered as matter. At the present day, the energy density ε can be considered as the cosmological constant Λ.

Although the Friedmann equation is indeed important, it cannot, all by itself, indicate how the scale factor a(t) evolves with time. We need another equation involving a and ε if we are to solve for a and ε as functions of time (t). They are the fluid equation:

$$\dot{\varepsilon} + 3\frac{\dot{a}}{a}(\varepsilon + P) = 0 \quad (28)$$

and the acceleration equation, using pressure P of the contents of the universe:

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3c^2}(\varepsilon + 3P) \quad (29)$$

The acceleration equation can be derived from both the Friedmann equation and the fluid equation. The fluid equation Eq.(28) is derived from $\nabla T^i_j = 0$. Thus, we have a system of two independent equations in three unknowns – the functions a(t), ε(t), and P(t). To solve for the scale factor a(t), energy density ε(t), and pressure P(t) as a function of cosmic time, we need another equation, that is, the equation of state

$$P = \omega\varepsilon \tag{30}$$

Where ω is a dimensionless number, and is generally considered to take = 0; the contribution of matter, ω = 1/3; the contribution of radiation, and ω = −1; the contribution of cosmological constant Λ.

The time-varying function H(t) is generally known as the "Hubble parameter", while H_0, the value of H(t) at the present day, is known as the "Hubble constant". Hubble parameter H(t) is shown as

$$H(t) = \frac{\dot{a}}{a} \tag{31}$$

So, the Friedmann equation evaluated at the present moment is

$$H_0^2 = \frac{8\pi G}{3c^2}\varepsilon_0 - \frac{c^2 K}{a_0^2} \tag{32}$$

using the convention that a subscript "0" indicates the value of a time-varying quantity evaluated at the present. Incidentally, from $\nabla T^i_j = 0$, the following equation, i.e. the fluid equation, is obtained as time component (j = 0):

$$0 = \nabla_i T^i{}_0 = -\frac{d\varepsilon(t)}{dt} - 3\frac{\dot{a}(t)}{a(t)}\left(P(t)+\varepsilon(t)\right) = -\frac{1}{a(t)^3}\left[\frac{d(\varepsilon(t)a(t)^3)}{dt} + P(t)\frac{d(a(t)^3)}{dt}\right] \tag{33}$$

The energy momentum tensor T^i_j is defined as the following: assuming the fluid of space:

$$T^i{}_j = \begin{pmatrix} -\varepsilon(t) & 0 & 0 & 0 \\ 0 & P(t) & 0 & 0 \\ 0 & 0 & P(t) & 0 \\ 0 & 0 & 0 & P(t) \end{pmatrix} \tag{34}$$

where energy density ε(t) and pressure P(t) are a function of cosmic time.

Now, regarding the cosmological constant Λ as a kind of energy momentum tensor of fluid, the energy density ε and the pressure P of vacuum space give the following from Eq.(28) or Eq.(33):

$$\varepsilon_\Lambda + P_\Lambda = 0 \tag{35}$$

Further, the energy density ε of the field of vacuum space is given by (see Eq.(27) or Eq.(18) ; dimension of vacuum potential V(ϕ) is J/m³)

$$\varepsilon_\Lambda = \frac{c^4\Lambda}{8\pi G} \tag{36}$$

Accordingly the pressure P of the field of vacuum space becomes

$$P_\Lambda = -\varepsilon_\Lambda = -\frac{c^4\Lambda}{8\pi G} \tag{37}$$

In the case of Λ > 0, the pressure P_Λ of the vacuum field in Eq.(37) indicates the negative pressure, i.e. repulsive force.

Applying the value of $\Lambda = 2.1\times10^{-43}V_0(\phi) = 1.4\times10^{-15}\,m^{-2}$ (corresponding to: $\alpha = 1.6\times10^{-27}\phi_0^{\,4} = 43.13\ m/s^2 = 4.4G$) to Eq.(37), the pressure P of the field of vacuum space becomes 7×10^{27}Pa (7×10^{22} atm).

$$P_\Lambda = -\frac{c^4\Lambda}{8\pi G} = \frac{(3\times10^8)^4\times1.4\times10^{-15}}{8\times\pi\times6.67\times10^{-11}} = \frac{81\times1.4\times10^{17}}{167.6\times10^{-11}} = 0.68\times10^{28}\,N/m^2 \approx 7\times10^{27}\,Pa.$$

Applying the value of present universe of $\Lambda = 2.1\times10^{-43}V_0(\phi) = 1.05\times10^{-52}m^{-2}$ to Eq.(37),

$$P_\Lambda = -\frac{c^4\Lambda}{8\pi G} = \frac{(3\times10^8)^4\times1.05\times10^{-52}}{8\times\pi\times6.67\times10^{-11}} = \frac{81\times1.05\times10^{-20}}{167.6\times10^{-11}} = 0.51\times10^{-9}\,N/m^2.$$

The pressure P of the field of the vacuum space becomes 5×10^{-10}Pa $= 5\times10^{-16}$MPa $= 5\times10^{-15}$ at m ≈ 0.

Some early implementations of inflation associated the scalar field ϕ with the Higgs field, which mediates interactions between particles at energies higher than the GUT energy; however, to keep the discussion general, the field ϕ is now referred to as the inflation field. Generally speaking, a scalar field can have an associated potential energy V_0 (ϕ).

Next we states about an inflationary cosmological model. In a cosmological context, inflation can most generally be defined as the hypothesis that there was a period, early in the history of universe, when the expansion was accelerating outward; that is, an epoch when $\ddot{a} > 0$.

The acceleration equation (29), $\frac{\ddot{a}}{a} = -\frac{4\pi G}{3c^2}(\varepsilon + 3P)$, **tells us that $\ddot{a} > 0$ when** $P < -\frac{\varepsilon}{3}$. Thus, inflation would have taken place if the universe were temporarily dominated by a component with equation of state parameter $\omega < -\frac{1}{3}$. Referring to Eq.(30), the usual implementation of inflation states that the universe was temporarily dominated by a positive cosmological constant Λ (with ω = −1), that is, P = −ε.

Then Eq.(29) becomes

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3c^2}(\varepsilon - 3\varepsilon) = \frac{8\pi G}{3c^2}\varepsilon \tag{38}$$

Substituting Eq.(36) into Eq.(38), thus had an acceleration equation that could be written in the form

$$\frac{\ddot{a}}{a} = \frac{8\pi G}{3c^2}\frac{c^4}{8\pi G}\Lambda = \frac{c^2}{3}\Lambda > 0 \tag{39}$$

In an inflationary phase when the energy density was dominated by a cosmological constant, the initial Friedmann equation is described in

$$\frac{\dot{a}^2}{a^2} = \frac{8\pi G}{3c^2}\varepsilon - \frac{c^2 K}{a^2} \tag{40}$$

Setting flat space (K=0), as well as Eq.(39),

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{\Lambda}{3}c^2 \tag{41}$$

Since $\frac{\dot{a}}{a} = \sqrt{\frac{\Lambda}{3}}c$, we get

$$a = a_0 \exp\sqrt{\frac{\Lambda}{3}}ct \tag{42}$$

The scale factor grows exponentially with time. This result corresponds to Eq.(26). The vacuum space causes inflation by the energy of the vacuum and expands exponentially. The inflation mechanism brings up mini space to the macro space. Namely, the space has the property of exponential expanding by thermal energy[10-12,14].

Since the energy momentum tensor T^i_j in the gravitational field equation aims at matter, the gravitation arises between different matters. However, cosmological term "Λg^{ij}" in Eq.(8) or Eq.(23) implies that the force between the vacuum spaces, that is, repulsive force between one vacuum space and another vacuum space.

The vacuum space envelops the spaceship that is pushed by other expanding vacuum space, hence the spaceship is propelled by being pushed from the expanding vacuum space.

Concerning the propulsion principle for the space drive propulsion in the strict sense, it may be easy to understand that the spaceship moves by pushing space itself, that is, by being pushed from space (see chapter 2). The expression of "moves by pushing space or being pushed from space" indicates that the spaceship produces a curved space region and moves forward by being subjected to the thrust from the acceleration field of the curved space. As the motorcar moves by kicking the ground continually infinitely, the spaceship moves by pushing the cosmic space continuously infinitely. The cosmic space as an infinite continuum may be deformed very slightly by being pushed, just like the Earth moves back very slightly by being kicked due to the motorcar. However, this pushing is absorbed by the deformation of space itself continued infinitely. The whole cosmic space is considered as being similar to the ground for kicking. Thus, since the space behaves like an elastic field, the stress between spaceship and space itself is the key of propulsion principle.

Contrary to this, although it may be a loose expression, we can get an easy image of the propulsion principle: since the pressure of vacuum field in the rear vicinity of the spaceship is high due to an expansion of space, the spaceship is pushed from the vacuum field just like blowing up a balloon that can push an object.

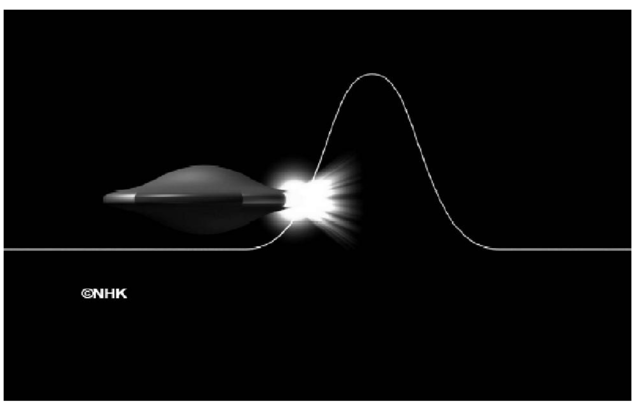


Figure 5

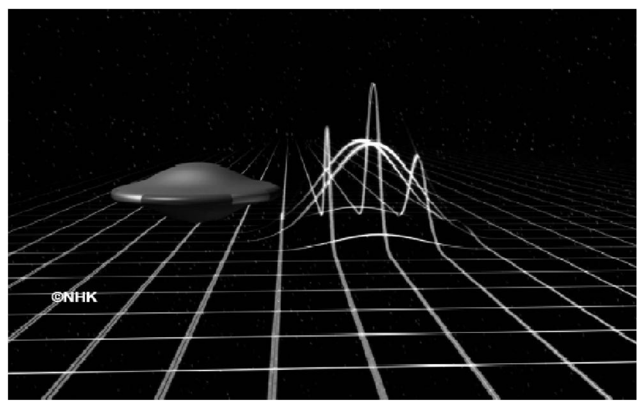


Figure 6

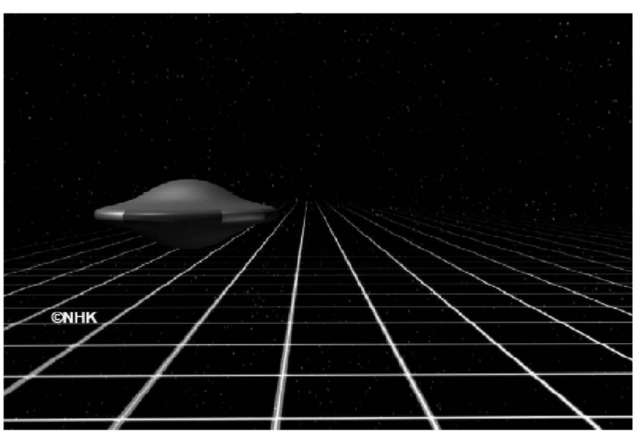


Figure 7

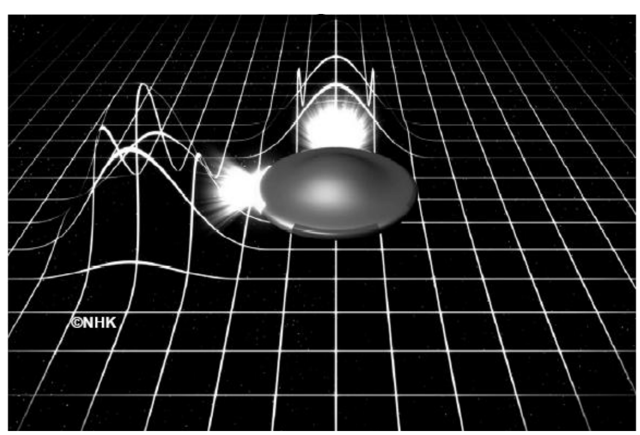


Figure 8

Here, we explain the motion of the spaceship using computer graphics. For the sake of simplicity, the shape of the spaceship is an omnidirectional disk type. As shown in Figure 5, our spaceship is able to permeate its local space with huge amount of energy in a certain direction; this energy should be injected at zero total momentum (in the spaceship-body frame) in order to excite the local space. Then the excited local space expands instantaneously. The space including the spaceship is pushed from the expanded space and advances forward (see Figure 6 and Figure 7). Thus, this spaceship is accelerated to the quasi-speed of light by repeating the pulse-like on/off change of permeating its local space with huge amount of energy operation. Changing a place to blow up, the spaceship can move with flight patterns such as quick start from stationary state to all directions, quickly stop, perpendicular turn, and zigzag turn (see Figure 8).

CONCLUSIONS

We explored another possibility of a space drive propulsion principle where the locally rapid expanding space generates the thrust, using the cosmology, i.e. the latest expanding universe theory of Friedmann, de Sitter, and inflationary cosmological model. Moreover the spaceship is able to permeate its local space with huge amount of energy; this energy should be injected at zero total momentum (in the spaceship-body frame) in order to excite the local space. Then the excited local space expands instantaneously.

Since the pressure of the vacuum field in the rear vicinity of spaceship is high due to expanding of space, the spaceship is pushed from the vacuum field just like blowing up a balloon that can be used to push an object. Thus, the space including the spaceship is pushed from the expanded space and advances forward. Although it may be a loose expression, we can get an easy image of creating a propulsion principle. The most important key seems to be the study of the structure of space that is derived from the expanding universe mechanics. In order to realize this result, we must discover the technology to excite and blow up space locally.

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