Interstellar Flight of Outer Solar System

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Abstract

Authorresearches, discusses and estimates the need parameters of launch systems the mini automatic probe for flight to the nearest star systems “Alpha-Centauri” and others. He shows that problem is very difficult for current and future technology. Launch requests gigantic energy, expensive equipment and large trip time.The conventional nuclear and thermonuclear on-board reactors cannot also solve this problem (Part 1).
Author offers and researches three new possible perspective propulsion systems: multi-reflex light system used new sell-multi-reflex mirror and lasers (Part 2); cold plasma beam from Earth (Part 3) and on-board Micro Black Hole (MBH) nuclear photon rocket (Part 4). In all methods, he offered innovations, which make possible to implement all with current technology. Two first methods request the high altitude (40 ÷ 80 km) mast.

He estimates: the requested launch system (laser multi-reflect propulsion, cold plasma beam propulsion, MBH nuclear propulsion, etc.);grown and board equipment, energy installation (generator and accelerator); interstellar flight; environmental,medium drag; interstellar micro particles; communication with Earth.Author showed – the most realistic interstellar launch system is laser beam used the cell reflective mirror or ultra-cold plasma beam.
Key words: *interstellar launch,interstellar flight, interstellar propulsion and generator systems, laser beam, cell mirror, laser propulsion, plasma beam propulsion, photon rocket, micro black hole generator.*

Introduction

Review of Main Problems and interstellar flight.

Interstellar travel is the term used for hypothetical piloted or unpiloted travel between stars. Interstellar travel will be much more difficult than interplanetary spaceflight; the distances between the planets in theSolar System are less than 30 astronomical units(AU)—whereas the distances between stars are typically hundreds of thousands of AU, and usually expressed in light-years. Because of the vastness of those distances, interstellar travel would require a high percentage of the speed of light, or huge travel time, lasting from decades to millennia or longer.

The speeds required for interstellar travel in a human lifetime far exceed what current methods of spacecraft propulsion can provide. Even with a hypothetically perfectly efficient propulsion system, the kinetic energy corresponding to those speeds is enormous by today's standards of energy production. Moreover, collisions by the spacecraft with cosmic dust and gas can produce very dangerous effects both to passengers and the spacecraft itself.

A number of strategies have been proposed to deal with these problems, ranging from giant arks that would carry entire societies and ecosystems, to microscopic space probes. Many different spacecraft propulsion systems have been proposed to give spacecraft the required speeds, including nuclear propulsion, beam-powered propulsion, and methods based on speculative physics.

In April 2016, scientists announced Breakthrough Stars hot, a Breakthrough Initiativesprogram, to develop a proof-of-concept fleet of small centimeter-sized sail spacecraft, named *Star Chip*, capable of making the journey to Alpha Centauri, the nearest extrasolar star system, at speeds of 20% and 15% of the speed of light, taking between 20 to 30 years to reach the star system, respectively, and about 4 years to notify Earth of a successful arrival.

Interstellar distances.

Because of this, distances between stars are usually expressed in light-years, defined as the distance that a ray of light travels in a year. Light in a vacuum travels around 300,000 kilometers (186,000 miles) per second, so this is some 9.46 trillion kilometers (5.87 trillion miles) or 63,241 AU in a year. Proxima Centauri is 4.243 light-years away.

Another way of understanding the vastness of interstellar distances is by scaling: one of the closest stars to the Sun, Alpha Centauri A (a Sun-like star).

Required energy

The velocity for a manned round trip of a few decades to even the nearest star is several thousand times greater than those of present space vehicles. This means that due to the v^2 term in the kinetic energy formula, millions of times as much energy is required. Accelerating one ton to one-tenth of the speed of light requires at least 450 PJ or 4.5×10^{17} J or 125 terawatt-hours (world energy consumption 2008 was 143,851 terawatt-hours), without factoring in efficiency of the propulsion mechanism. This energy has to be generated on-board from stored fuel, harvested from the interstellar medium, or projected over immense distances.

Interstellar medium

A thorough knowledge of the properties of the interstellar dust and gas through which the vehicle must pass will be essential for the design of any interstellar space mission. A major issue with traveling at extremely high speeds is that interstellar dust may cause considerable damage to the craft, due to the high relative speeds and large kinetic energies involved.

Travel time.

An interstellar ship would face manifold hazards found in interplanetary travel, including vacuum, radiation, weightlessness, and micrometeoroids. Even the minimum multi-year travel times to the nearest stars are beyond current manned space mission design experience.

Communications

The round-trip delay time is the minimum time between an observation by the probe and the moment the probe can receive instructions from Earth reacting to the observation. Given that information can travel no faster than the speed of light, this is for the Voyager 1 about 36 hours, and near Proxima Centauri it would be 8 years. Faster reaction would have to be programmed to be carried out automatically. Of course, in the case of a manned flight the crew can respond immediately to their observations. However, the round-trip delay time makes them not only extremely distant from, but, in terms of communication, also extremely isolated from Earth (analogous to how past long distance explorers were similarly isolated before the invention of theelectrical telegraph).

Interstellar communication is still problematic – even if a probe could reach the nearest star, its ability to communicate back to Earth would be difficult given the extreme distance.

Prime targets for interstellar travel.

There are 59 known stellar systems within 20 light years of the Sun, containing 81 visible stars. The following could be considered prime targets for interstellar missions:

The closest star system to Solar System is Alpha Centauri. Distance is 4.3 light year (ly). System has three stars (G2, K1, M5). Component A is similar to the Sun (a G2 star). Alpha Centauri B was thought to have one confirmed planet, but this was a false positive. The second closest star is Barnard’s Star. Distance is 6 light year. One is small, low-luminosity M5 red dwarf.

Propulsion system

Rocket concepts. All rocket concepts are limited by the rocket equation, which sets the characteristic velocity available as a function of exhaust velocity and mass ratio, the ratio of initial (M_0, including fuel) to final (M_1, fuel depleted) mass.

Very high specific power, the ratio of thrust to total vehicle mass, is required to reach interstellar targets within sub-century time-frames. Some heat transfer is inevitable and a tremendous heating load must be adequately handled.

Thus, for interstellar rocket concepts of all technologies, a key engineering problem (seldom explicitly discussed) is limiting the heat transfer from the exhaust stream back into the vehicle.

Light Beamed propulsion. The power per thrust required for a perfectly collimated output beam is 300 MW/N (half this if it can be reflected off the craft); very high energy density power sources would be required to provide reasonable thrust without unreasonable weight. The specific impulse of a photonic rocket is harder to define, since the output has no (rest) mass and is not expended fuel; if we take the momentum per inertia of the photons, the specific impulse is just *c*, which is impressive. However, considering the mass of the source of the photons, e.g., atoms undergoing nuclear fission, brings the specific impulse down to 300 km/s (*c*/1000) or less; considering the infrastructure for a reactor (some of which also scales with the amount of fuel) reduces the value further. Finally, any energy loss not through radiation that is redirected precisely to aft but is instead conducted away by engine supports, radiated in some other direction, or lost via neutrinos or so will further degrade the efficiency.

A light sail or magnetic sail powered by a massive laser or particle accelerator in the home star system could potentially reach even greater speeds than rocket- or pulse propulsion methods, because it would not need to carry its own reaction mass and therefore would only need to accelerate the craft's payload.

Former interstellarProjects:
Project Orion, manned interstellar ship (1958–1968).
Project Daedalus, unmanned interstellar probe (1973–1978).
Starwisp, unmanned interstellar probe (1985).
Project Longshot, unmanned interstellar probe (1987–1988).
Starseed/launcher, fleet of unmanned interstellar probes (1996).
Project Valkyrie, manned interstellar ship (2009).
Project Icarus, unmanned interstellar probe (2009–2014).
Sun-diver, unmanned interstellar probe.
Breakthrough Starshot, fleet of unmanned interstellar probes, announced in April 12, 2016.
Future Micro Interstellar Project (2030-2040) .
Project*StarChip* is the name used by Breakthrough Initiatives for a very small centimeter-sized, gram-scale, interstellar spacecraft envisioned for the Breakthrough Stars hot program, a proposed mission to propel a fleet of a thousand *StarChips* on a journey to the Alpha Centauri star system, the nearest extrasolar stars, about 4.37 light-years from Earth. The ultra-light *Star Chip* robotic Nano crafts, fitted with light sails, are planned to travel at speeds of 20% and 15% of the speed of light, taking between 20 to 30 years to reach the star system, respectively, and about 4 years to notify Earth of a successful arrival.
Each *StarChip*nano-craftis expected to carry miniaturized cameras, navigation gear, communication equipment, photon thrusters and a power supply. In addition, each nano-craft would be fitted with a meter-scale lightsail, made of lightweight materials, with a gram-scale mass.
Four sub-gram scale digital cameras, each with a minimum 2-megapixels resolution, are envisioned. Four sub-gram scale processors are planned. Four sub-gram scale photon thrusters, each minimally capable of performing at a 1W diode laser level, are planned. A 150 mg atomic battery, powered by plutonium-238 or americium-241, is planned. A coating, possibly made of beryllium copper, is planned to protect the nano-craft from dust collisions and atomic particleerosion.Thelightsail is envisioned to be no larger than 4 by 4 meters (13 by 13 feet), possibly of composite graphene-based material. The material would have to be very thin and, somehow, be able to reflect the laser beam without absorbing any of its thermal energy, or it will vaporize the sail.

Part 1
Research of Space Flight in Outer Solar System

Reasonable humanity, men has always sought to learn about the world. An important part of his knowledge is knowledge of the universe, the search for other intelligent beings, knowledge sharing, and the extension of the Mind existence. They found that in the universe billions of solar systems. It is reasonable to assume that their planets there are other intelligent creatures with which you can establish contact and exchange of acquired knowledge.

Nearest Stars

There are 5 known stellar systems within 12 light years of the Sun, containing 7 visible stars. The following could be considered prime targets for interstellar missions:

Table 1.

Stellar system	Distance (light years)	Brief Information of stellar system

Alpha Centauri (Three stars)	4.3	Closest system. Three stars (G2, K1, M5). Component A is similar to the Sun (a G2 star). Alpha Centauri B was thought to have one confirmed planet, but this was a false positive.
Barnard's Star (2 stars)	6	Small, low-luminosity M5 red dwarf. Second closest to Solar System.
Sirius (2 stars)	8.7	Large, very bright A1 star with a white dwarf companion.
Epsilon Eridani (colder Sun)	10.8	Single K2 star slightly smaller and colder than the Sun. It has two asteroid belts, might have a giant and one much smaller planet,and may possess a Solar-System-type planetary system.
Tau Ceti (similar Sun)	11.8	Single G8 star similar to the Sun. High probability of possessing a Solar-System-type planetary system: current evidence shows 5 planets with potentially two in the habitable zone.

One light year is distance$D=ct\approx 10^{13}$km, which the light having speed $c = 3 \cdot 10^8$ m/s runs in one year$t_1 \approx$ $31.45 \cdot 10^6$ sec.

The time of getting information is

$$T = \left(\frac{c}{v} + 1\right) d \,, \qquad (1)$$

where $T$is flight time in year; $c = 3 \cdot 10^8$ m/s; v is probe speed, m/s; d is distance to star, light year (ly). If we want to get any information in reasonable time (for example, 40 years) the relative probe speed must be 15 – 25% of the light speed. This is gigantic speed v = 45 -75 thousands km/s. We cannot to reach it in present time.For relative speed v/c = 0.15 the flight time and getting information of Alpha-Centauri is 33 years.

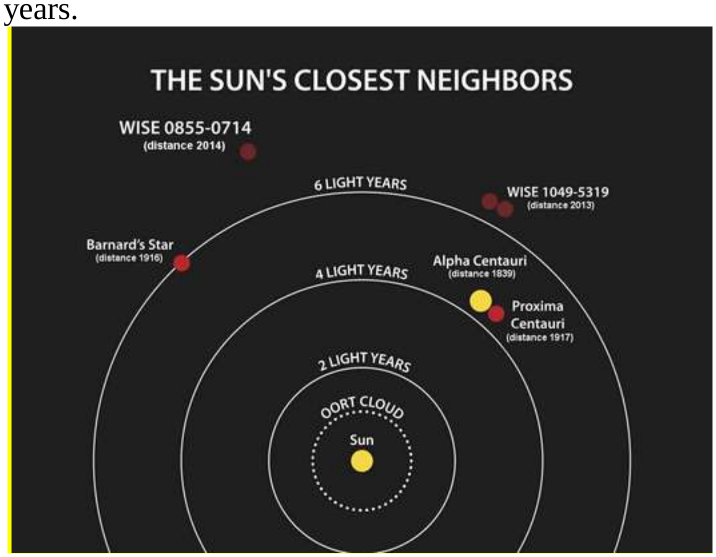

Fig.1.Stars closest to the Sun, including *Alpha Centauri* (25 April 2014).

What we know about the closest star system Alfa-Centauri?It consists of three stars: the pair Alpha Centauri A and Alpha Centauri B and a small and faint red dwarf, Alpha Centauri C, better known as Proxima Centauri. Alpha Centauri A (α Cen A) has 110% of the mass and 151.9% the luminosity of the Sun, and Alpha Centauri B (α Cen B) is smaller and cooler, at 90.7% of the Sun's mass and 44.5% of its visual luminosity. During the pair's 79.91-year orbit about a common center, the distance between them varies from about that between Pluto and the Sun to that between Saturn and the Sun. Proxima is at the slightly smaller distance of 1.29 parsecs or 4.24 light years from the Sun, making it the closest star to the Sun, even though it is not visible to the naked eye. The separation of Proxima from Alpha Centauri AB is about 0.06 parsecs, 0.2 light years or 15,000 astronomical units (AU), equivalent to 500 times the size of Neptune's orbit.

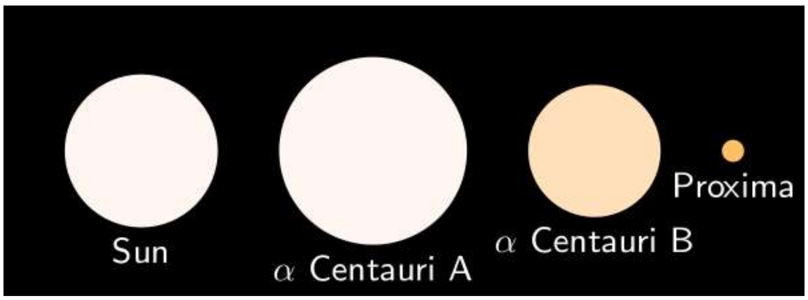

Fig.2.The relative sizes and colors of stars in the Alpha Centauri system, compared to the Sun

Until the 1990s, technologies did not exist that could detect planets outside the Solar System. Since then, exoplanet-detection capabilities have steadily improved to the point where Earth-mass planets can be detected.

Alpha Centauri is envisioned as a likely first target for manned or unmanned interstellar exploration. Crossing the huge distance between the Sun and Alpha Centauri using current spacecraft technologies would take several millennia, though the possibility of nuclear pulse propulsion or laser light sail technology, as considered in the Breakthrough Starshot program, could reduce the journey time to a matter of decades.

Efficiency from Innovations and Explorations

The efficiency from Innovations and Explorations may be approximately estimated by equation

$$E = P/C , \qquad (2)$$

where***E*** – coefficient efficiency; ***P*** – estimation of the future profit; ***C*** – estimation of the R&D.
In given case is very difficult to estimate the efficiency of this profit for humanity. We could only estimate the gigantic expenses for R&D of this exploration(hundreds of billions the USA dollars).
The main problems are:
1. How to launch and reach very high speed ?
2. What useful information the Micro-probe could get about Alfa Centauriin flight by ?
3. How to pass information collected to Earth ?

Let us to research some of these problems in more interesting details.

Request Energy for Interstellar Launch

Consider the simplest case of the constant acceleration:

$$S=\frac{at^2}{2},\quad V=at,\quad S=\frac{V^2}{2a},\quad a=\frac{V^2}{2S},\quad F=am,$$
$$E=FS=\frac{mV^2}{2},\quad P=\frac{E}{t},\quad N_1=cF. \qquad (3)$$

where S is distance of acceleration,m; a is acceleration, m/s^2; t is time of acceleration, sec; V is final speed, m/s; F is force, N; m is mass of probe, kg; E is requested energy for acceleration, J; P isneed power for acceleration, W; N_1 is need power of laser (electric station) for single (one) reflection (conventional mirror) without a mirror loss, W, for laser efficiency0.1; $c = 3{\cdot}10^8$ m/s is the light speed, m/s.

If we take the probe mass m = 0.01 kg and the final speed V/c = 0.15, $V = 0.45{\cdot}10^8$ m/s, the request minimal energy is about $E \approx 10^{13}$ J = 10^7 MJ.

The result of computation Eq.3 for the probe mass m = 0.01 kg and the final speed V/c = 0.15, V = $0.45{\cdot}10^8$ m/s are presented in Table 2.

TABLE 2: Result of computation Eq.3 for the probe mass m = 0.1 kg and the final speed V/c = 0.15, $V = 0.45{\cdot}10^8$ m/s, g = 10 m/s^2 via distance of acceleration.

***S*, m**	10^5	10^6	10^7	10^8	10^9	10^{10}
***a=V²/2S*, m/s²**	10^{10}	10^9	10^8	10^7	10^6	10^5
a, g	10^9	10^8	10^7	10^6	10^5	10^4
***t = V/a*, sec**	$4.5{\cdot}10^{-3}$	$4.5{\cdot}10^{-2}$	$4.5{\cdot}10^{-1}$	$4.5{\cdot}10^0$	$4.5{\cdot}10^1$	$4.5{\cdot}10^2$
***F=ma*, N**	10^8	10^7	10^6	10^5	10^4	10^3
***P=E/t*, W**	$2.2{\cdot}10^{15}$	$2.2{\cdot}10^{14}$	$2.2{\cdot}10^{13}$	$2.2{\cdot}10^{12}$	$2.2{\cdot}10^{11}$	$2.2{\cdot}10^{10}$
$N_1 = cF$, W	$3{\cdot}10^{16}$	$3{\cdot}10^{15}$	$3{\cdot}10^{14}$	$3{\cdot}10^{13}$	$3{\cdot}10^{12}$	$3{\cdot}10^{11}$
N_1, MkW	$3{\cdot}10^7$	$3{\cdot}10^6$	$3{\cdot}10^5$	$3{\cdot}10^4$	$3{\cdot}10^3$	$3{\cdot}10^2$

Now the power of the powerful electric station is about 10 MkW. That means if we accelerate our probe 0.01 kg at distance 10 mln.km with acceleration 10^4 g by laser and conventional mirror, we need in power 30 strong electric station in during 450 sec = 7.5 minutes. The acceleration 10^4 g has projectшle of a big gun.

But the most current lasers have efficiency about 0.02 – 0.06. If in future good laser will has efficiency 0.1, we will need in 300 powerful electric stations.

Possible Launch nuclear propulsion

1. Many people think: the nuclear propulsion can solve the space travel. That is right for travel into Solar system, but it is not correct for the intersteller flight.
Let us show it. Take the kinetic energy of mass and the speed equation of rocket in the rocket system coordinate

$$\text{From } E=\frac{mW^2}{2}, \text{ we have } W=\left(\frac{2E}{m}\right)^{0.5}=E_s^{0.5},\quad \Delta V=-W\ln\frac{M_f}{M_0}, \qquad (4)$$

where E is energy of fuel, J; m is mass of fuel, kg; E_s specific energy of fuel, J/kg; W – exhaust (ejection) velocity of fuel, m/s; ΔV is rocket speed, m/s; M_f is final mass of rocket, M_0 is initial mass of rocket.

For chemical fuel E_s = (4 ÷ 16) MJ/kg and W = 2km/s ÷ 4 km/s. For typical M_f/M_0 = 0.1, ln 0.1 = -2.3, the rocket speed is 4 ÷ 9 km/s. We need in speed 45,000 km/s.

Estimate the speed, which can reach the rocket having thermonuclear reactor. Consider the most perspective reaction

$$D + T = {}^4H_e(3.5\,MeV) + n(14.1\,MeV),$$

$$1\,eV = 1.6\cdot 10^{-19}\,J, \quad E = 17.6\,MeV = 28.2\cdot 10^{-13}\,J, \qquad (5)$$

The energy of neutron, neutrino, gamma rays is very difficult to use because they request a big thickness(mass) of materials to absorb the neutrons or gamma rays.

Assume we can do it. The fuel mass having (5) is $m = \mu m_n = 5\cdot 1.67\cdot 10^{-27} = 8.35\cdot 10^{-27}$ kg. Here μ is number of nucleons take part in reaction, m_n is mass of one nucleon.

From Eq. (4) we get a fuel exhaust speed $W = 26\cdot 10^3$ km/s, a rocket speed (for multi-stagy rocket) $V = 60\cdot 10^3$ km/s.

We need only $V = 45\cdot 10^3$ km/s (see above). But we cannot get the thermonuclear energy now. The installation for it (ITER) is very complex and expensive (>$15 B), has mass many thousands tons and it will may an industrial application after 2040 year.

There is perspective proposals of the cheap small thermonuclear cumulative/impulse [8]and ultra-cold compression [11] reactors of mass about 100 ÷ 300 kg, but they need in R&D. There is very perspective nuclear reactorused Micro Black Hole (MBH) [10] and convert any matter to energy with 100% efficiency. But now we only hope to get MBH by Large Hadron Collider.

Fission nuclear reactors are good developed and there are a lot of space projects used them. But all projects/reactors have a large mass more some tons and their nuclear energy in 2-4 times less that fusion reaction. They not acceptable for macro space probe (0.01 kg) now.

There is idea transferring the energy in space in a long distance by plasma [3 - 4] or electron beam [6] . This idea needs R&D.

There are isotope good developed energy and propulsion systems [3] Ch.17. Their summary energy may be more than fission reaction in the long times. Their main flaw is small power and uncontrollability. They may be used for correction trajectory and getting energy in long time space flight.

Acceleration space probe by laser beam

The many scientists belief the laser beam can solve this problem. They not request the launch fuel and energy in probe. The thin lightweight sail will reflect the laser beam and he light pressure will accelerate the small probe for need speed. There are a lot of research which use the Solar light for flight in Solar system.

However the author shows in previous section (Table 2) for acceleration the probe up gigantic interstellar speed 45 thousands km/s is requested a huge energy. The laser beam isexpanding and requests a large sail and laser diameter. The beam has a maximal distance of acceleration about 10 millions km. But this distance requests a special Continuous Wave (CW) large laser power more N_1 = 3000 MW for 100% efficiency (see last column in Table 2). For 10% efficiency therequested power is ten times more. Currently the conventional continuous wave operation laser produces 3 kW energy, the most impulse power laser installation in the World(NIF - National Ignition Facility) has in impulseenergy 120 kJ. NIF costs $3.5 billion. You can estimate: how will cost the conventional launch beam laser system.

Examples of pulsed systems with high peak power:

1) 700 TW (700×10^{12} W) – National Ignition Facility, a 192-beam, 1.8-megajoule laser system adjoining a 10-meter-diameter target chamber.

2) 1.3 PW (1.3×10^{15} W) – world's most powerful laser as of 1998, located at the Lawrence Livermore Laboratory.

Part2.

Multi-reflex Light Launch Propulsion Systems for Interstellar Flight

It is well-known the solar light is pressing on any surface. In 1900 the Russian scientist P. Lebedev measured the light pressure. It was very small $4 \cdot 10^{-6}$ Pa. In 1982 author offered and researched idea the reflection laser beam by special cell mirror having very high reflection for different waves [7]. That allows to increase efficiency of mirror in millions time and in millions of times increase the light pressure. He also offered the laser engine and accelerator. Later in 2004 author researched the application this idea to space launch and energy transfer for long distance [4, 5].

The purpose of this work is developing and to draw attention to the revolutionary idea of light multi-reflection by cell mirror. This idea allows the design of new engines, space and air propulsion systems, energy transmission over millions of kilometers, creation of new weapons, etc. This method and the main innovations were offered by the author in 1982 in the former USSR[7]. Now the author shows the immense possibilities of this idea in many fields of engineering – astronautics, aviation, energy, optics, direct conversion of light (laser beam) energy to mechanical energy (light engine), to name a few. This part of chapter considers the multi-reflex propulsion systems for space and energy transmission over long distances in Interstellar travel.

Introduction

Brief history: The relatively conventional way to send a spacecraft on an interstellar journey is to use the solar sail [1, P.1] or a laser sail [2,P1]. This method is not effective because the light intensity is very low, with only one reflection. There has been a lot of research in this area and into solar sails in general.

A. Kantrowitz offered the conventional method for using a laser beam for space propulsion [3,P.1]. He transferred energy using laser beam to a space vehicle, converted light energy into heat and evaporated a material, then obtained thrust from the gas pressure of this evaporated material. There is much research on this method [4,P4] However, it is complex, has low efficiency, has limited range (divergence of the laser beam), requires special material located on board the space ship, and requires a very powerful laser.

In 1983 the author offered another method: that of using light beam energy, then the direct conversion of light energy into mechanical pressure (for an engine) or thrust (for launchers and propulsion systems) by multiple reflections [5, P.1].

The author found only one work related to this topic, published in 2001 [6, P.1]. However our work is very different from this. Our suggested system has several innovations which make the proposed method possible improve its parameters millions of times. The difference between our suggested system and the previous system[16] is analyzed in the "Discussion" section, below.

The reflection of light is the most efficient method to use for a propulsion system. It gives the maximum possible specific impulse (light speed is $3 \cdot 10^{8}$ m/s). The system does not expend mass. However, the light intensity in full reflection is very small, about 0.6×10^{-6} kg/ kW. In 1983 the author suggested the idea [7] of increasing the light intensity by a multi-reflex method (multiple reflection of the light beam by special cell mirror) and he offered some innovations to dramatically decrease the losses in mirror reflection (including a cell mirror and reflection by a super–conducting material). This allows the system to make some millions of reflections and to gain some Newtons of thrust per kW of beam power. This allows for the design of many important devices (in particular, beam engines[7]) which convert light directly into mechanical energy and solve many problems in aviation, space, energy and energy transmission.

In the lastyears achievements in optic materials and lasers have decreased the losses from reflection. The author returned to this topic and made it his primary area of research. He solved the main problems: the design of a highly efficient reflector (special cell mirror), a light lock, focusing prismatic lightweight mirrors and lenses, a laser ring, and a beam transfer over very long distances (millions of km) with only very small beam divergence, light storage, a beam amplifier, a modulator of light frequency, balloon suspension of mirrors, and so on [7, P.1].

Brief information about light and light devices. A short description of electromagnetic radiation can be found in the publication [9. P.1].A conventional mirror can reflect a maximum of 98–99% of the incident light energy of some bands of light waves. This gives a maximum of 200–300 reflections which is not enough for propulsion systems and engines. Because the light pressure is so low (about $0.6 \cdot 10^{-6}$ kg/kW), we need at least a million reflections.

There is a well-known method for increasing mirror reflection. The layers of a quarter-wave optical thickness of high and low refractive-index materials increase the reflectance. After more than 12 layers, the reflective efficiency of a dielectric mirror approaches 100%, with virtually no absorption or scattering. Maximum reflectance occurs only in a region around the design wavelength. The size of the region depends on the design of the stack of multiple dielectric coatings. Outside this region the reflectance is reduced. For example, at one-half the design wavelength it falls to the level of the uncoated substrate. The dielectric mirror is also designed for use at a specific angle of incident radiation. At other angles, the performance is reduced, and the wavelength of maximum reflectance is shifted.

Unfortunately, this dielectric mirror method is not suitable for mirrors moving relative to each other as the reflected frequency is shifted slightly, and this frequency shift accumulates over multiple reflections. Also conventional mirrors tend to reflect the beam off in some other direction if the mirrors are not kept in perfect alignment to the beam. The author's proposed cell mirror reflects the beam in the same direction which is very important for decreasing the beam divergence. The small cells provide high reflectance and small absorption.

A narrow laser beam is the most suitable for a light engine and light propulsion. There are many different types of lasers with different powers (peak power up to 10^{12} W), wavelength (0.2–700 μm), efficiency (1% up to about 95%), and pulse rate (up to some thousands of impulses per second) or continuous operations. In publications in the References, the reader will find a brief description of the laser [8, P.1] or more detail [9, P.1].

At the present time we are seeing significant advances in high-power weapons-class lasers[8,P.1]. The laser power reaches 1 million watts.

For our computation the beam divergence is very important. The laser beam divergence[8] (see 8, P1, p. 4) is

$$\theta = \frac{2}{\sqrt{\pi}} \frac{\lambda}{D} = 1.13 \frac{\lambda}{D} , \qquad (1)$$

where θ is the angle of divergence [rad], λ is the wavelength [m], and D is an aperture diameter [m]. In particular, the diameter of the laser beam may be increased by an optical lens for reducing the beam divergence. The aperture diameter may be also increased by offered *laser ring* (Fig. 1). The reflex capacity may be improved by using a super conductive material (this idea needs additional research).

More detailed information is in publication in the references [7 – 9. P1].

Description of Innovation

Multi-reflex launch installation of a space vehicle. In a multiple reflection propulsion system a set of tasks appear: how to increase a mirror's reflectivity, how to decrease the light dispersion (from mirror imperfections and non-parallel surfaces), how to decrease the beam divergence, how to inject the beam between the mirrors (while keeping the light between the mirrors for as long as possible), how to decrease the attenuation (a mirror, prism material, etc), how to increase the beam range, and how much force the system has.

To solve of these problems, the author proposes[7, P1], a special “cell mirror” which is very reflective and reflects light in the same direction from which it came, a *“*laser ring*”* which decreases the beam divergence, *“*light locks” which allows the light beam to enter but keep it from exiting, a “beam transfer*”*, a “focusing prismatic thin lens“, prisms, a set of lenses, mirrors located in space, on asteroids, moons, satellites, and so on.

Cell mirrors. To achieve the maximum reflectance, reduce light absorption, and preserve beam direction the author uses special *cell mirrors* which have millions of small 45^o degree prisms (1 in Fig. 1a,g). Cell mirror are retroreflector cells or cube corner cells. A light ray incident on a cell is returned parallel to itself after three reflections (Fig. 1g). In the mirror, provided the refractive index of the prism is greater than $\sqrt{2}$ (≅1.414), the light will be reflected by total internal reflection. The small losses may be only from prism (medium) attenuation, scattering, or due to small surface imperfections and Fresnel reflections at the entrance and exit faces. Fresnel reflections do not result losses when the beam is perpendicular to the entry surface. No entry losses occur where the beam is polarized in parallel of the entry surface or the entry surface has an anti-reflection coating with reflective index $n_1 = \sqrt{n_0 n_2}$. Heren_0, n_2 are reflective indexes of the vacuum and prism respectively. These cell mirrors turn a beam (light) exactly back at 180^o if the beam deviation is less 5–10^o from a perpendicular to the mirror surface. For incident angles greater than $\sin^{-1}(n_1/n_2)$, no light is transmitted, an effect called total internal reflection. Here n is the refractive index of the medium and the lens ($n \approx 1$–4). Total internal reflection is used for our reflector, which contains two plates (mirrors) with a set of small corner cube prisms reflecting the beam from one side (mirror) to the other side (mirror) (Fig. 1b,c, f). Each plate can contain millions of small (30–100 μm) prisms from highly efficient optic material used in optical cables[19]. For this purpose a superconductivity mirror[5] may also be used.

Laser ring. The small lasers are located in a round ring (Fig. 1c). A round set of lasers allows us to increase the aperture, resulting in a smaller divergence angle θ. The entering round beam (9 in Fig. 1a) has slip θ (or θ/2) to the vertical. The beam is reflected millions of times as is shown in Fig. 1b,c and creates a repulsive force F. This force may be very high, tens of N/kW (see the computation below) for motionless plates. In a vacuum it is limited only by the absorption (dB) of the prism material (see below) and beam divergence. For the mobile mirror (as for a launch vehicle) the wavelength increases and beam energy decreases as the mirrors move apart.

This system[15] can be applied to a space vehicle launch on a planet that has no atmosphere and smallgravity (for example, the Moon; high gravity requires high beam power).

Light lock. The first design of *light lock* allows the laser beam to enter, but closes the exit of a returned ray. The beam (9 in Fig. 1d) of continuous laser passes through a multi-layer dielectric mirror (10 in Fig. 1d). The entering beam runs the full length between mirrors (Fig. 1b,c), reflects a million times, and enters from the other side (11 in Fig. 1d). For moving (separating) mirrors the wavelength is changed because the beam gives up energy to the moving mirrors (see computationsin section

As a result the wavelength increases ($\lambda_{11} > \lambda_9$) when the distance increases, and the wavelength decreases ($\lambda_{11} < \lambda_9$) when the distance decreases. The mirror (10 in Fig. 1d), is designed to pass the laser beam (9 in Fig. 1d) and to reflect back the “used” ray (11 in Fig. 1d). If the beam is not reflected by the mirror (10 in Fig. 1d), it enters into the laser and will be reflected back by the laser’s internal mirror.

The second design of the *light lock* is shown in Fig. 1e. This contains an additional prism 12 and an impulse laser. When laser beam 13 enters the system, the additional prism 12 is pushed into the main prism 1. While the beam runs between the mirrors, the additional prism is disconnected from the main prism and the return beam 14 cannot go back in. It travels inside the reflected mirrors with a lot of reflections if the mirrors have the right focuses. The chink, 15, between the additional and main prisms may be very small, about a light wavelength (1 micron). A piezoelectric plate can be used to move the additional prism.

below)

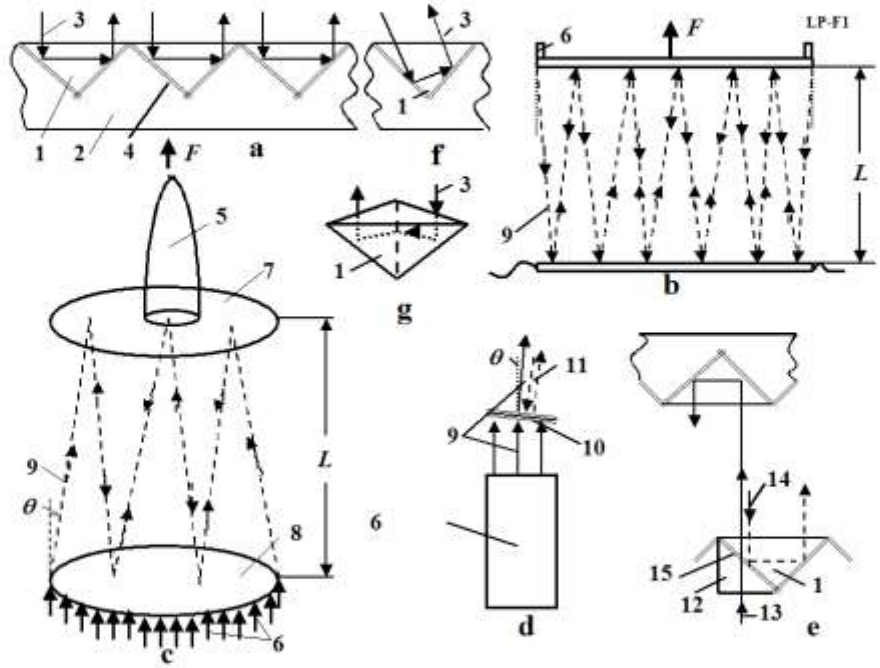

Fig. 1.Space launcher. Notations are: 1 – prism, 2 – mirror base, 3 – laser beam, 4 – mirror after chink (optional), 5 – space vehicle, 6 – lasers (ring set of lasers), 7 – vehicle (ship) mirror, 8 – planet mirror, 9 – laser beam, 10 – multi-layer dielectric mirror, 11 – laser beam after multi-reflection (wavelength $\lambda_{11} > \lambda_9$), 12 – additional prism, 13 – entry beam, 14 – return beam, 15 – variable chink between main and additional prisms. (a) Prism (cell, corner cube) reflector. (b) Beam multi-reflection, (c) Launching by multi-reflection, (d) The first design of the light lock, (e) The second design of the light lock, (f) Reflection in the same direction when the beam is not perpendicular to mirror surface, (g) Mirror cell (retroreflector cell or cube corner cell). A light ray incident on it is returned parallel to itself after three reflections.

A continuous or pulse laser may be used for the first light lock and a pulse laser may be used for the second lock. We compute average laser power.

The details of attenuation of light propagating through an optical material are considered in physics textbooks. To increase the number of reflections, we use a set of very small prisms and a highly efficient optical material (dB = 0.1–0.5).

Space beam transfer. Space *beam transfer* is shown in Fig. 2a. The first lens has a large aperture for the laser beam and focuses the beam which decreases the divergence angle θ. The other Fresnel's lens then continues to focus the beam (Fig. 2a).

Non-focused beam loses intensity through diffracted rays but *beam transfer* has a special focusing lens. If the focus is located at a distance $S_1 = D/2\theta$, the beam does not have losses through up to a diffracted rays in this distance *S*, but after the distance *S* the divergence angle becomes 2θ (Fig.2b). If we need to transmit energy a distance *L* less than *S* (for example, in launching), this method is fine since the distance between the mirrors $L << S$ and the beam is reflected many times without loss. If we want to transfer the energy over very long distance, the method shown in Fig. 2c may be better. In this method the beam is focused on point at a distance $S_2 = D/\theta$. The beam has small amounts of diffraction everywhere, but the losses are smaller after a distance $1.5S_1$ than in the case of Fig. 2b. If an intermediate lens with a much larger diameter than the initial lens (Fig. 2b,c) is added midway, it is possible to decreases the beam diffraction energy losses to a very small value.

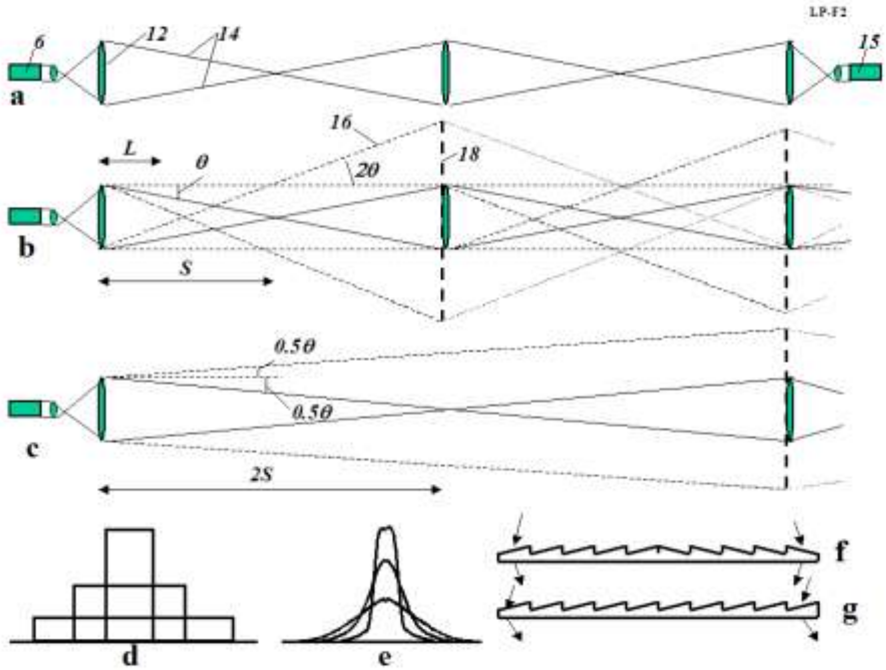

Fig. 2.Laser beam long-distance transfer. Notations are: 12 – lens, 14 – bounds of laser rays, 15 – light receiver, 16 – divergence ray. (a) focused beam, (b) focused beam with angle θ which has part S without divergence,(c) focused beam with angle 0.5θ which has minimum divergence at a long distance, (d) beam with a plate wave front, (e) Gaussian beam with normal distribution of beam front, (f) Fresnel's (prism) lens, (g) lens for changing the beam direction.

The distribution of energy in a gross section area of the beam is also important for divergence and diffraction losses. The plate front (Fig. 2a) of the wave and plate distribution of energy and divergence (Fig. 2d) are worst and give the maximum of energy losses. A normal distribution of beam energy and a Gaussian beam is better because the losses of beam energy trough diffraction are reduces at the edges (Fig. 2e).

Energy transfer is done in the following way. First the Fresnel's lenses (collimators) (Fig. 2f), Fresnel's prisms (Fig. 2g), and mirrors are (permanently) located in space (Fig. 3a). Their trajectories and the receiving space vehicle's trajectory in space are known. Through commands from Earth, a space ship or the vehicle's computer, the mirrors and lenses are turned to the required angles (angular position). A small pilot ray may be used for aiming and focusing. The required angular changes are small (for focusing and small corrections in direction) and may be made by piezoelectric controlled plates. After the pilot ray reaches the space vehicle as required, the full power beam is transmitted to the space vehicle. This beam may be used to launch vehicles from an asteroid or small mass planetary satellites (Fig, 1c), to change the vehicle's trajectory (Fig, 3b), or to increase the acceleration of the space vehicle near an asteroid (Fig. 3c) using the multi-reflex method (Fig. 3a,b,c). This beam energy may be also used by the space vehicle for its rocket engine and internal power requirements. The distance between lenses may reach tens of millions of kilometers (see computation below). The average distances of the nearest planets from the Sun are: Venus 108 $\times 10^6$ km, Earth 150×10^6km, Mars 228×10^6 km. Transfer efficiency of system may be about 0.7–0.9 (see computation below).

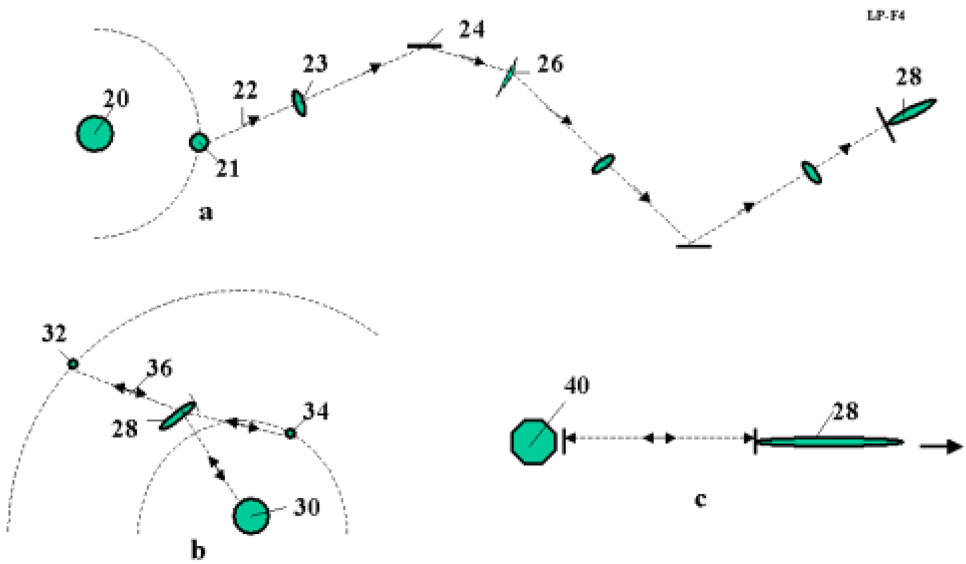

Fig. 3.Space energy transfer over long distance. a. Transferring thrust from Earth to space ship by laser beam, b. Using of satellites (or moons) to change the vehicle's trajectory, c. Using of asteroid for launching of ship. Notations are: 20 – Sun, 21 – Earth, 22 – laser beam, 23 – Fresnel's lens, 24 – mirror, 26 – Fresnel's prism, 28 – Space vehicle, 30 – planet, 32, 34 – planet satellite, 36 – multi-reflection, 40 – asteroid.

Theory (Estimation) of Multi-Reflex Launching and Light Beam Transfer.

Special theory, methods and computation for this case are developed below.

Attenuation of beam. The attenuation of light passingpropagating through an optical material is caused either by absorption or by scattering. In both absorption and scattering, the power is lost over a distance, z, from the power $N(z)$, propagating at that point. So we expect an exponential decay:

$$N(z) = N(0)\exp(-yz) . \qquad (2)$$

The attenuation coefficient, y, is normally expressed in dB km^{-1}, with 1 dB km^{-1} being the equivalent of 2.3×10^{-4} m^{-1}. Absorption is a material property in which the optical energy is normally converted into heat. In scattering processes, some of the optical power in the guided modes is radiated out of the material.

Attenuation in some current and some potential very low loss materials that have been created for fiber communication has a dB value of up to a = 0.0001 ([17], Fig. 4).

We use in our computation conventional values of 0.1 to 0.4 dB/km. Clean air has $\xi = 0.333\times10^{-6}$ m^{-1}. The conventional optical matter widely produced currently in industry has an attenuation coefficient equals to 2 dB.

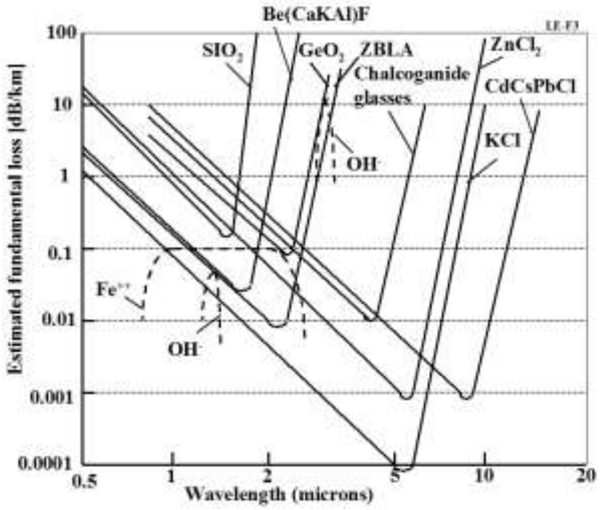

Fig.4.The estimation of basic attenuation of some possible very low loss materials.

However, some of these materials are highly reactive chemically and are mechanically unsuitable for drawing into a fiber. Some are used as infrared light guides, none are presently used for optical communication, but may be useful for our purposes. Our mechanical property and wavelength requirements are less stringent than for optical communications. We use in our computation a = 0.1-0.4 dB km^{-1}. The conventional optical material widely produced by industry for optical cable has an attenuation coefficient of 2 dB km^{-1}.

Change in beam power. The beam power will be reduced if one (or both) reflector is moved, because the wavelength changes. The total relative loss of the beam energy in one double cycle (when the light ray is moved to the reflector and back) is

$$q = 1 - (1-2\gamma)(1-2\xi)(1\pm 2v)\varsigma \,, \qquad (3)$$

where$v = V/c$, V is the relative speed of the mirrors [m/s], $c = 3\times10^8$ m/s is the speed of light. We take the "+" when the distance is reduces (braking) and take "– " when the distance is increased (as in launching, a useful work for light), γ is the light loss through prism attenuation, ξ is the loss (attenuation) in the medium (air) (in clean air $\xi = 0.333\times10^{-6}$ m^{-1}), v is the loss (useful work) through relative mirror (lens) movement, ς is the loss through divergence and diffraction.

Multi-reflex light pressure. The light pressure, T, of two opposed high reflectors after a series ofreflections, n, to one another is

$$T_0 = \frac{2N_0}{c}, \quad T_1 = \frac{2N_0}{c}q, \quad T_2 = \frac{2N_0}{c}q^2, \quad T_3 = \frac{2N_0}{c}q^3, \quad \ldots \quad, \quad T_{n-1} = \frac{2N_0}{c}q^n . \quad (4)$$

When q = const, this is a geometric series. The sum of n members of the geometric series is

$$T = \frac{2N_0}{c}\frac{1-q^n}{1-q}. \quad If \quad n=\infty, \quad then \quad T_\infty = \frac{2N_0}{c}\frac{1}{1-q}, \quad q<1. \qquad (5)$$

Coefficient of efficiency. The efficiency coefficient, η, may be computed using the equation

$$\eta = TV/N_0 \,, \qquad (6)$$

Focusing the beam. If the lens used in focused at a range S_1, the distance, S, without ray divergence is (Fig. 2.2b):

$$S = \frac{D}{2\theta}, \quad \theta = \frac{2}{\sqrt{\pi}}\frac{\lambda}{D}, \quad S = \frac{\sqrt{\pi}}{4}\frac{D^2}{\lambda} = 0.443\frac{D^2}{\lambda}. \qquad (7\text{-}9)$$

Here, D is the diameter of the lens or mirror [m]. This distance is equal to the lens focus distance for the case in Fig. 2.2b ($S_1 = S$). In the case Fig. 2c (transfer over very long distance), the optimal focus distance is $S_2 = 2S_1$.

Some computations. The computation of equation (9) is presented in Figs. 5 and 6. As you will see, the necessary focus distance may be high.

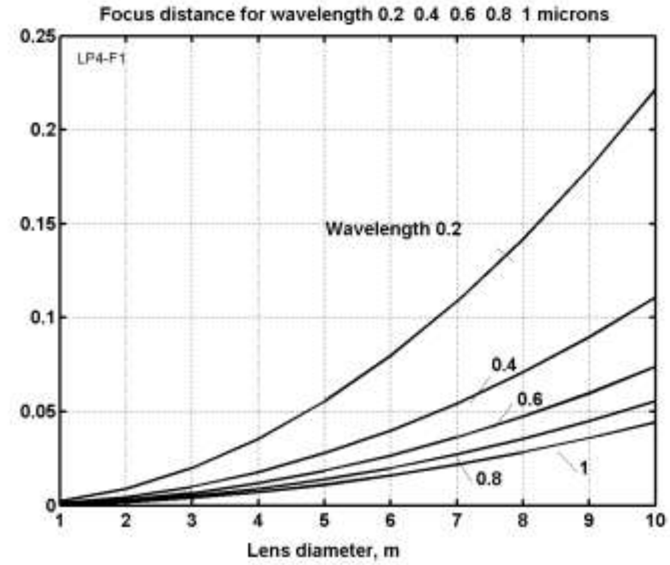

Fig. 5. Focus distances [10^6km, million km] versus lens diameters 1–10 m and wavelength λ= 0.2–1 microns.

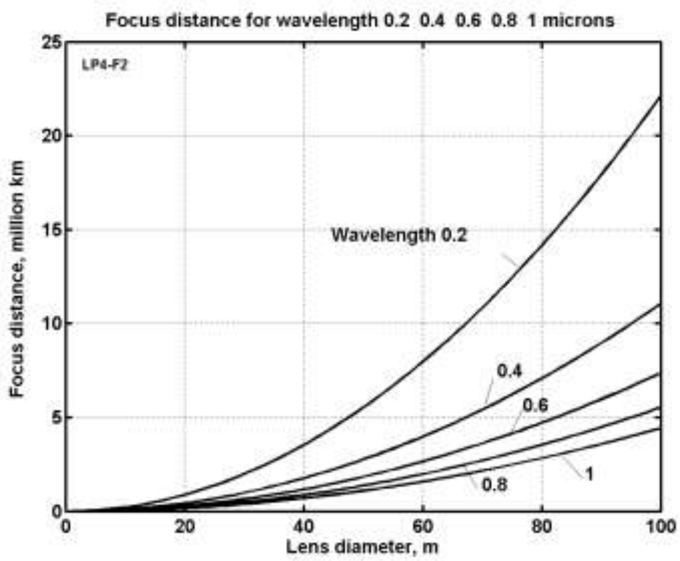

Fig. 6. Focus distances versus lens diameters D = 1–100 m and wavelength λ = 0.2–1 microns.

The values in equation (3) can be computed as

$$\gamma = yz = 0.00023al, \quad l = m\lambda, \quad m \ge 1, \quad \xi = 0.333\cdot 10^{-6} L, \qquad (10)$$

where$a$ is the attenuation coefficient in dB [km^{-1}] ([7], fig.4), m is initial value of the wavelength which can be located in cell size l [m].

The loss through divergence, ς, for the case in Fig. 2b,d is

$$\varsigma = \frac{\pi(D/2)^2}{\pi(D/2 + 2\gamma(L-S))^2}, \quad 2\gamma(L-S) = \frac{4k}{\sqrt{\pi}}\frac{\lambda(L-S)}{D},$$
$$\varsigma = 1/\left(1 + \frac{8k\lambda(L-S)}{\sqrt{\pi}D^2}\right)^2 \ for\ L > S. \qquad (11)$$

Here L is the distance between the mirrors (lenses) [m], and, k is the focus coefficient. In case in Fig. 2b (where the focus distance is $D/2\theta$) k = 0 when L < S (for transfer)or n < S/L (for reflection) and$k$ =

2 when $L > S$, or $n > S/L$; in the case in Fig. 2c (S is absent, $S = 0$) $k = 0.5$ if the focus distance is D/θ; $k = 1$ if focus distance is infinity (no focusing).

The relative beam power along its trajectory for plate power distribution as in Fig. 2d is

$$\overline{N} = N/N_0 = 1 \quad when \quad L \le S_1 \quad and \quad \overline{N} = \varsigma \quad when \quad L > S_1 = D/2\theta . \qquad (12)$$

The force coefficient, A, shows how many times the initial light pressure is increased. For $L < S_1$ it is

$$A = \frac{1-q^n}{1-q} \; . \qquad (13)$$

The multi-reflex launch of a space vehicle from a small planet with low gravity, are without an atmosphere (the Moon or an asteroid) may be computed using the following equations (for focusing Fig. 2b and beam distributions Fig. 2d):

$$T = \frac{2N_0}{c}\frac{q^{n_1}-1}{q-1} + \frac{2N_0}{c}q^{n_1}\frac{q_1^{n_2}-1}{q_1-1}, \quad n_1 = \frac{S_1}{L}, \quad n_2 = n_1 - n_3, \quad n_3 = \frac{\ln m}{2v}, \quad q = 1-(1-2\gamma)(1-2v),$$

$$q_1 = q\varsigma, \quad \Delta V = \left(\frac{T}{M} - g\right)\Delta t, \quad V_{i+1} = V_{i_i} + \Delta V, \quad \Delta L = V_i \Delta t. \quad L_{i+1} = L_i + \Delta L, \quad t_{i+1} = t_i + \Delta t. \qquad (14)$$

Here the first element in T is the thrust when the beam runs the distance S_1 without divergence. The second element in T is the thrust when the beam runs the distance with divergence. M is space vehicle mass [kg],g is the planet's gravity [m/s^2]. When $n_3 < n_1$, we take $n = n_3$ and compute T using equation (2.5). If $n_3 > n_1$, we compute T using equation (14).

Computation of the efficiency co-efficient, η, equation (8) are presented in Figs. 7.

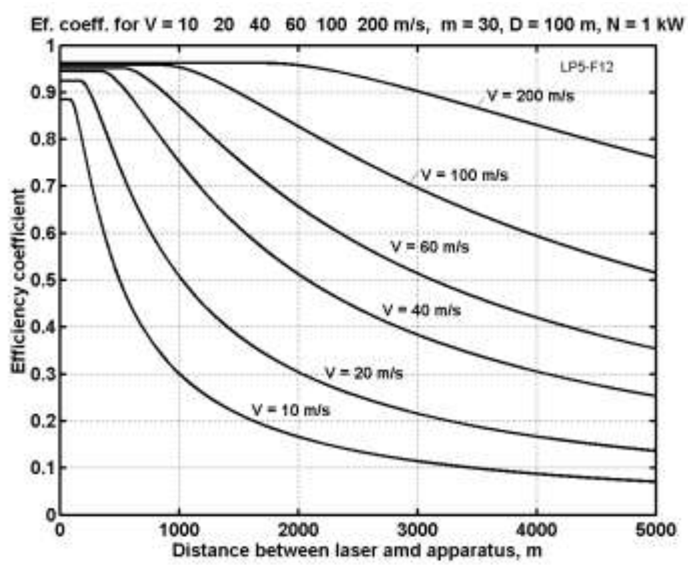

Fig.7. Efficiency coefficient versus distance [m] for vehicle speed V = 10–200 m/s, attenuation coefficient a = 0.5 dB, cell size m = 30, mirror diameter D = 100 m, beam power N = 1 kW.

The thrust and the efficiency coefficient decrease when the distance is above some critical value, then a portion of the energy beam leaves the space between the mirrors through diffraction.

The mirror diameter is large because small mirror diameters decrease the attainable speed. Starting from an asteroid or a planet's moon that has low gravity, improves the attainable speed.Unfortunately, the multi-reflex launch from planets with an atmosphere does not wart well because the multi-reflected rays travel long distances in a gas medium and lose a lot of energy.

Below is the equation for computing the beam power from the divergence and distance when the Gaussian beam has normal distribution (Fig. 2f): For case 1 (the focus is into point $2S_1$, Fig. 2c)

$$\overline{N}_1 = 2\psi\left[s\left(\frac{D}{D+\theta L}\right)^2\right], \quad \theta = \frac{2}{\sqrt{\pi}}\frac{\lambda}{D}, \quad S = 0. \qquad (15)$$

Here ψ is the probability function of normal distribution.
For case 2 (the focus is located at point *S*, Fig. 2b)

$$When \quad L \le S_1, \quad \overline{N}_2 = 1. \quad When \quad L > S_1 \quad \overline{N}_2 = 2\psi\left[s\left(\frac{D}{D+4\theta(L-S_1)}\right)^2\right]. \qquad (16)$$

Here *s* is a relative distribution value. The results of computations for space (vacuum) are presented in Fig. 8. It is shown that the focused beam travels without major losses if the distance between the mirrors (for mirror diameter *D* = 100–200 m) is 10–18 million kilometers, and may travel up to 100 million km with an efficiency of about 0.2. This means the focused beam can permanently transfer (without losses) energy from the Earth to the Moon or back (a distance of 0.4×10^6km), and for 2–3 months (with efficiency 0.2) every two years, to Mars at a distance of $60–150\times10^6$ km.

For computation of the relative beam power in air at altitude *H*, we may use equations (15) and (16) corrected for air attenuation. That is

$$\overline{N}_{a1} = \overline{N}_1(1-b), \quad \overline{N}_{a2} = \overline{N}_2(1-b), \quad where \quad b = 0.334\cdot10^{-6}\frac{\rho_H}{\rho_0}L \quad . \qquad (17)$$

Here ρ_H, $\rho_0$are the air density at altitudes *H* and *H* = 0 respectively.

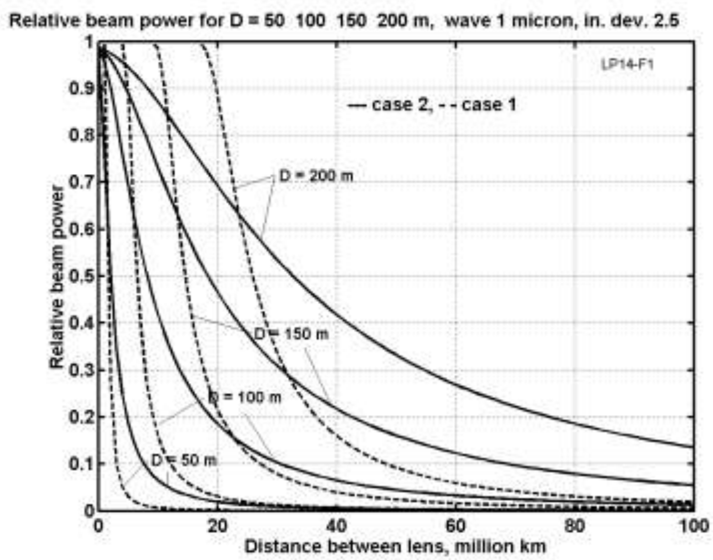

Fig. 8. Relative beam power of the normal (Gaussian) distribution (*s* = σ = 2.5) (Fig. 2f) in a vacuum versus distance in million kilometers between lenses for focusing at *D/2θ* (- - , case 1) and *D/θ* (-, case 2).

The computed parameters are not optimal. Our purpose is to demonstrate the method of computation.

Computations (Fig. 7 and 8) are made for a beam power N_0 = 1 kW. For beam power N_0 = 10, 100, 1000 kW we must multiply the force in Figs. 2.7 and 2.8 by 10, 100, and 1000 respectively.

Estimations for high speed and long distance

1. Maximal decreasing of request energy from multi-reflexing the light-beam.
As we have seen in Table 2 the requested energy (power) for acceleration relativistic probe is very high. Multi-reflexing allowssignificantly decrease it. Let us separately estimate lossand benefits (increasing the thrust from multi-reflection) from cell mirror in atmosphere, spaceandfrom material of the mirror cell.

a) *Loss energy in Earth atmosphere*. It is known in clean atmosphere on Earth surface, the light beam losses the part of energy $\xi = 0.333 \cdot 10^{-6} \quad 1/\mathrm{m}$. The Earth atmosphere has the pressure $p = 10^4$ kg/m^2 and density $\rho = 1.225$ kg/m^3 (on Earth surface). If Earth atmosphere has constant density its thickness is $H = p/\rho = 10^4/1.225 = 8{,}163$ m≈ 8.2 km. The laser instalation may locate on area/altitude 2 km (mountain up 4 km, or the light beam will passed in vacuum tube of artificial tower/mast up 10 – 60 km).

If we take the altitude 5 km, the rest altitude will be about 8 - 5 = 3 km. The loss will be $\xi = 0.333 \cdot 10^{-6} \cdot 3 \cdot 10^{3} = 10^{-3}$ · That means [Eq.(10)]

$n \approx 1/2\xi = 1/2 \cdot 10^{-3} = 500.$ (18)

fullreflections through the Earth atmosphere or increasing the light pressure in 500 times (decreasing the request energy in 500 times!).

b) *Loss energy in the cell mirror.* Let us to estimate the loss energy (reflectivity) the cell mirror [Eq. 10]. Assumetheminimalwavelengthoflightisλ_o= 0.2 μm = $0.2 \cdot 10^{-6}$ m,maximal wavelength is $\lambda = 10^{-5}$, $m = 10^{-5}/0.2 \cdot 10^{-6} = 50$, absorption coefficient is$a = 10^{-2}$ [dB/km] = 10^{-5} [dB/m], length of cell is $l = m\lambda_o = 50 \cdot 0.2 \cdot 10^{-6} = 10^{-5}$m, reflectivity of cell mirror is $\gamma_1 = al = 10^{-5} \cdot 10^{-5} = 10^{-10}$. That is in hundreds of million better than conventional mirror ($\gamma_1 = 10^{-2}$) and many thousands time more than multi-layer mirror ($\gamma_1 = 5 \cdot 10^{-4}$). We can neglect this loss. Number of full reflection is

$n \approx 1/2\gamma_1 = 1/2 \cdot 10^{-10} = 5 \cdot 10^9.$ (19)

c) *Lossfrommovingprobe*.Assume we want to accelerate probe up V = 8 km/s. The average speed is V_a= 8/2 = 4 km/s. The relative speed is $v = V_a/c = 4/3 \cdot 10^5 = 1.33 \cdot 10^{-5}$. That means the number of full reflection is $n = 1/2v = 1/2 \cdot 1.33 \cdot 10^{-5} = 3.76 \cdot 10^4$. If speed of probe is high, the efficiency of cell mirror significantly decreases. In our case of interstellar probe maximal speed is $V = 0.15c = 45 \cdot 10^3$ km/s, average relative speed is$v$ = 0.15/2 = 0.075. Number of full reflection is $n = 1/2v = 1/2 \cdot 0.075 = 6.67$.

Conclusion: The offered cell mirror is very efficiency for intersolar launch and traveling and less efficiency for interstellar launch.

2. Heating of reflect mirror.

Let us estimate the heating (temperature) of mirror. The temperature of mirror is

$$T = 100\left(\frac{P_s}{C_s}\right)^{1/4}, \quad \text{where} \quad P_s = \frac{P\gamma_1}{2s}. \qquad (20)$$

Here T is temperature of mirror, K; P_s is absorbed power, W/m^2; C_s= 5.67 W/m^{2}K^4 is absorbed coefficient; P is power delivered by laser to mirror, W (see Table 1); γ_1 is loss coefficient for one reflection; s is area of mirror, m^2.

Let us take the s = 5 m^2, the power light beam $P = 2.2 \cdot 10^{11}$ W (see last column in Table1).

For cell mirror $\gamma_1 = 10^{-10}$ and T = 80K. For conventional mirror $\gamma_1 = 10^{-2}$ and T = 8000K. Formulti-layermirrorthebest$\gamma_1 = 5 \cdot 10^{-4}$(one wavelength) and$T$= 2100K.

As you can see only cell mirror is acceptable for interstellar probe.

3. Loss probe speed from gravity field of Earth and Sun.The probe losses speed for start from Earth surface and arriving to Earth orbit around Sun: 11.2 km/s. The probe losses speed to arriving from Earth orbit around Sun to space out the solar system: 42.1 km/s. If probe will use the Earth orbit speed (that limit the start time up 2 – 3 month every year), we can save 30 km/s.In last case we loss on gravitation only 11.2 + 42.1 - 30 = 23.2 km/s. Radial velocity Alpha-Centauri Star A is -21.4 km/s, star B is -18.6 km/s. All these velocities are small in comparison the requested Interstellar velocity 45 000 km/s.

4.Interstellar flight drag of environment.

a)*Shortly Information about interstellar medium*.In astronomy, the interstellar medium (ISM) is the matter that exists in the space between the star systems in a galaxy. This matter includes gas in ionic, atomic, and molecular form, as well as dust and cosmic rays. It fills interstellar space and blends smoothly into the surrounding intergalactic space. The energy that occupies the same volume, in the form of electromagnetic radiation, is the interstellar radiation field.

In all phases, the interstellar medium is extremely tenuous by terrestrial standards. In cool, dense regions of the ISM, matter is primarily in molecular form, and reaches number densities of 10^6 molecules per cm^3 (1 million molecules per cm^3). In hot, diffuse regions of the ISM, matter is primarily ionized, and the density may be as low as 10^{-4} ions per cm^3. By mass, 99% of the ISM is gas in any form, and 1% is dust.[2] Of the gas in the ISM, by number 91% of atoms are hydrogen and 9% are helium, with 0.1% being atoms of elements heavier than hydrogen or helium.

Stars form within the densest regions of the ISM, molecular clouds, and replenish the ISM with matter and energy through planetary nebulae, stellar winds, and supernovae.

The Warm Ionized Medium (WIM) holds the 20-50% of the interstellar volume, has scale 1000 pc, temperature about 8000K and density about 0.2 - 0.5 ionized atom in cm^3.

The Sun is currently traveling through the Local Interstellar Cloud, a denser region in the low-density Local Bubble.

b) Let us take for our estimation the interstellar density γ = 1 H/cm^3 = 10^6 H/m^3 (here H is hydrogen atom). One Light Year (ly) has time $t = 31.54\cdot10^6$ seconds. Light speed is $c = 3\cdot10^8$ m/s. Light runs in 1 ly the distance $L = ct \approx 10^{16}$ m/ly $=10^{13}$ km/ly. For probe speed $v = 0.15c = 45\cdot10^6$ m/s the number of atoms getting the 1 m^2 of reflector is $N = \gamma L = 10^6\cdot10^{16} = 10^{22}$. The mass of atoms is $m = m_p N = 1.67\cdot10^{-27}\cdot10^{22} = 1.67\cdot10^{-7}$ kg/m^2ly. Energy is $E = mv^2/2 = 1.67\cdot10^8$ J/m^2ly. If the all atom will be stopped by mirror have mass $m_m = 0.01$ kg/m^2, than the loss of speed by probe will be

$$\Delta V \approx \frac{mv}{m_m} = \frac{1.67\cdot10^{-7}\cdot45\cdot10^6}{10^{-2}} = 750\ [m/s\cdot m^2\cdot ly] \qquad (21)$$

Full probe speed loss for mirror area $s = 5$ m^2 and 4.3 light years of flight is $\Delta V = 0.75\cdot5\cdot4.3 = 16$ km/s.It is permissible part from speed 45,000 m/s.

For breakdown of the mirror having the surface mass density 10g /m^2 is enough energy 0.5 MeV [25,p.935]. Atom of medium for speed V = 45,000 km/s has energy about 10 MeV. That means the most of atom will fly through the mirror and loss only 5% its energy. The loss probe speed decreases in 20 times. The density atoms in Solar system at Earth orbit is about 20 H/cm^3. Estimation gives the loss speed of probe in Solar system about 20 m/s. We can neglect it.

No problem with the interstellar atom drag.

c)*Problem the interstellar dust*.

Cosmic dust can be further distinguished by its astronomical location: intergalactic dust, interstellar dust, interplanetary dust.By one estimate, as much as 40,000 tons of cosmic dust reaches the Earth's surface every year.

The interstellar dust has particles $d = 0.01 \div 0.2$ μm. Mass of dust is about 1% of gas mass. Particles compose from consist of graphite, silicon carbide. Their density is about 3 g/cm^3. The drag from dust we neglect.

Let us to estimate the holes from dust. Take the average size of particles 0.1 μm = 10^{-7} m, volume 10^{-21} m^3, mass one particle is $m_1 = 3\cdot10^{-18}$ kg. Total mass of particles is $M = 1{,}67.10^{-9}$ kg/m^2ly (1% of gas mass). Total number of particles is $N = M/m_1 = 5.33\cdot10^8$ 1/m^2ly. If one particle made the hole area $s_1 = d^2 = 10^{-14}$ m^2, the area total holearea will be approximately$s = s_1 N = 5.33\cdot10^{-6}$1/$m^2$ly. In during flight time t = 4.3 lythe damage will be $S = 2.3\cdot10^{-5}$1/m^2. In reality damage may be in 1 – 2 order more. But we can neglect it. If interstellar drag is big, the mirror can be folded.

Discussionof Part 2(Multi-Reflex Light Proportion System)

Comparing the “Multi-Bounce Laser-Based Sail” system [6,P.1] with the proposed method – the “Multi-Reflex Propulsion System”.

1. The “Multi-Bounce Sail” uses the well-known multi-layer mirror which has high reflectance only in a region around the design wavelength. Outside this region, the reflectance is reduced. For example, at one-half the design wavelength it falls to that of the uncoated substrate. As shown in this work, the wavelength changes by a small amount at each reflection in the mobile mirror. This means that after enough reflections the multi-layer mirror has lost its high reflectivity. It is impossible to use the multi-layer mirror for a multi-bounce space sail that is moving. The author has proposed the innovative new cell-mirror for which the reflectivity does not depend on wavelength for wavelengths that are less than a cell length.
2. The multi-layer mirror [6, P1] is extremely large (1 km^2), with extremely small thickness (1600 nm), density (10 gm/m^2) and weight (7850 kg). A very small angle of deviation at the multi-layer mirror surface (one thousandth of a degree) under beam pressure, leads to complete defocusing at a distance of some millions of kilometers. This means the mirror[16] will make only one reflection. The average mirror angle will also be changed permanently for a moving space ship.

It is impossible to exactly control (turn) the orientation of this gigantic and very thin sail.

The new cell-mirror reflects the laser beam back in exactly the same direction if the surface and sail deviation are less than 5–10 degrees. This means the mirror directorial control is not necessary on the space craft. Also, there may be imperfections in the surface film and the mirror control is not necessary.

3. The maximum reflection at multi-layer mirror is 99.95 [Reference 6, P1]. The reflection of the cell-mirror is $(1-0.4 \cdot 10^{-9})$ or 10^8 times better than the multi-layer mirror. The maximum reflection value of the multi-layer mirror is only 1000 [Reference 6, P1]. Value for reflections of the cell-mirror are in the millions.
4. The diameter of the multi-layer mirror is 1 km, the size of our cell mirror is 100 m (for large and heavy man ships) and 2 m for micro probe.
5. The gigantic multi-layer solar mirror gives an acceleration of only 0.33 m/s^2. This is not enough to launch itself from Earth (Earth’s gravity is 9.8 m/s^2), Mars (3.72 m/s^2) or the Moon (1.62 m/s^2). The author's solar cell-mirror gives an acceleration of 20 m/s^2 (laser up 10^5g), and its size is 100 times smaller. If we were to made solar cell-mirror 1 km in diameter, the capability of a space ship would be fantastic.

The author shows here only some of the advantages of one innovation (changing from the well-known multi-layer mirror to the new *cell-mirror*). There are many deficiencies of the previous system[6] which make its application virtually impossible. For example, with the multi-layer mirror the laser is located on the Earth’s surface and its beam moves (from the laser to the ship and back to the laser) through the Earth’s atmosphere a lot of times. The computation shows that the beam’s energy will quickly be lost due to absorption and scattering by the Earth’s (or Mars) atmosphere when it travels a long distance though it. In our system the beam moves through the atmosphere only once time and reflects between the Moon mirror and the space ship of all other times. This is insured by the innovation of the *light lock*.

Another deficiency of the laser-based sail system is that when the space ship is close to Earth, the sail will reflect the beam back to the laser. If the efficiency of the propulsion system were sufficient, the laser might be damaged or destroyed. This problem is absent in the author system because it uses a "*light lock*", which closes the return path of laser beam.

The suggested *laser ring* (a set of small lasers located in a circle), *beam transfer* and *self-focused mirror* and *Fresnel’s lens* decrease the beam divergence and increase the beam transfer distance. It is possible to install the cell-mirror on the Moon or on Mars and transfer a laser beam to them and then to make a space ship decelerates.

The other system[6] requires a nuclear electric power station (of several Giga Watts Power) to be built and to deliver it, and a super powerful laser on Mars.

I do not mean to criticize other small mistakes in the work [6, P1] as, for example, the computation of multiple reflection acceleration (thrust) is not correct. The beam energy after every reflection will be decreased and the ship acceleration also will be decreased. For a large number of reflections this decrease is quite large (see the equations in this Part 2).

The idea of a multiple reflection engine and cell and superconductivity mirrors was probably offered first by author in 1983 [7, P1]. But as I know, this work [6, P1] (2001) was the first research on this topic which is important.

General discussion. The offered multi-reflex light launcher, space and air focused energy transfer system is very simple (needing only special mirrors, lenses and prisms), and it has a high efficiency. One can directly transfer the light beam into space acceleration and mechanical energy. A distant propulsion system can obtain its energy from the Earth. However, we need very powerful lasers. Sooner or later the industry will create these powerful lasers (and cell mirrors) and the ideas presented here will become possible. The research on these problems should be started now.

Multi-reflex engines[7] may be used in aviation as the energy can be transferred from the power stations on the ground to the aircraft using laser beams. The aircraft would no longer carry fuel and the engine would be lighter in weight so its load capability would double. The industry produces a one Megawatt (1000 kW) laser now. This is the right size for mid-weight aircraft (10–12 tons).

The linear light engine does not have a limit to its speed and may be used to launch space equipment and space ships in non-rockets method described in [1 – 16]. This method is certain also to have many military applications.

Part 3

Plasma Beam Space Propulsion for Interstellar Flight*

Summary

In this Part author offers a revolutionary method - non-rocket transfer of energy and thrust into Space with distance of millions kilometers. The author has developed theory and made the computations. The method is more efficient than transmission of energy by high-frequency waves. The method may be used for space launch and for acceleration the spaceship and probes for very high speeds, up to relativistic speed by current technology. Research also contains prospective projects which illustrate the possibilities of the suggested method.

Keywords: *space transfer of energy, space transfer of thrust, transferor of matter, transfer of impulse (momentum), interplanetary flight, interstellar flight*.

Introduction

Transportation of energy, matter, or impulse is very important for long period space trips especially for lengthy distance voyages. The spaceship crew or astronauts on planets can need additional energy or ship thrust. Most people think that is impossible to transfer energy a long distance in outer space except electromagnetic waves. Unfortunately, electromagnetic waves have a big divergence and cannot be used at a long distance (millions of kilometers) transfer.

However, the space vacuum is very good medium for offered method and special transfer of energy and momentum.

Brief history. About 40 years ago scientists received plasma flow having speed up 1000 km/s, power 10 kW, mass consumption 0.1 g/s, electric current up million amperes.

However, the application of plasma beam into space needs a series of inventions, innovations and researches. In particular, they include methods of decreasing the plasma divergence, discharging, dispersion of velocity, collection the plasma beam in space at long distance from source, conversion of

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the beam energy into electricity and other types of energy, conversion of plasma impulse (momentum) in space apparatus thrust, conversion of plasma into matter, control, etc.
The author started this research more than forty years ago [1]. The solutions of the main noted problems and innovations are suggested by author in early (1982-1983) patent applications [2] - [12] (see also further development in [13]-[34]) and given article. In particularly, the main innovations are:

1. Using neutral plasma (not charged beam);
2. Using ultra-cool plasmaor particle beam in conventional temperature;
3. Control electrostatic collector which separates and collects the ions at spaceship;
4. Control electrostatic generator which convert the ion kinetic energy into electricity;
5. Control electrostatic ramjet propulsion;
6. Special control electrostatic mirror-reflector;
7. Recombination photon engine;
8. Recombination thermo-reactor.
9. Research is made for conventional and relativistic particle speeds.

About 20 years ago the scientists received the ultra-cold plasma having the ion temperature lower than 1×10^{-3}K. Velocity dispersion was $10^{-4} \div 10^{-6}$, beam divergence for conventional temperature was 10^{-3} radian.
If plasma accelerator is designed special for getting the ultra-cold plasma, its temperature may be appreciably decreased. There is no big problem in getting of cold ions from solid electrodes or cold electrons from solid points where molecular speed is small.

Description of Innovation

Innovative installation for transfer energy and impulse includes (Figure 1): the ultra-cold plasma injector, electrostatic collector, electrostatic electro-generator-thruster-reflector, and space apparatus. The plasma injector creates and accelerates the ultra-cold low density plasma.
The Installation works the following way: the injector-accelerator forms and injects the cold neutral plasma beam with high speed in spaceship direction. When the beam reaches the ship, the electrostatic collector of spaceship collects and separates the beam ions from large area and passes them through the engine-electric generator or reflects them by electrostatic mirror. If we want to receive the thrust in the near beam direction ($\pm 90^o$) and electric energy, the engine works as thruster (accelerator of spaceship and breaker of beam) in beam direction and electric generator. If we want to get thrust in opposed beam direction, the space engine must accelerate the beam ions and spend energy. If we want to have maximum thrust in beam direction, the engine works as full electrostatic mirror and produces double thrust in the beam direction (full reflection of beam back to injector). The engine does not spend energy for full reflection.
The thrust is controlled by the electric voltage between engine nets [19], the thrust direction is controlled by the engine nets angle to beam direction. Note, the trust can slow the ship (decrease the tangential ship speed) and far ship (located out of Earth orbit) can return to the Earth by Sun gravity. Note also, the Earth atmosphere absorbs and scatters the plasma beam and the beam injector must be located on Earth space mast or tower (up 40 ÷ 60 km, see [20, 21]) or the Moon. Only high energy beam can break through atmosphere with small divergence. The advantage: the injector has a reflector and when the ship locates not far from the injector the beam will be reflected a lot of times and thrust increases in thousand times at start (Figure 2) (see same situation in [22]).
The proposed engine may be also used as AB-ramjet engine [19], utilizing the Solar wind or interstellar particles.

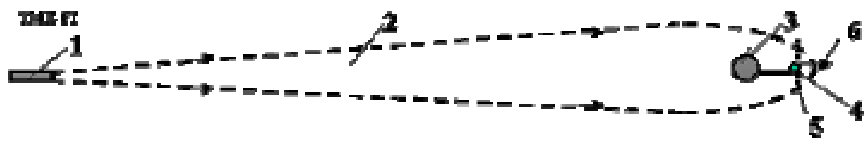

Figure 1. Long distance space transfer of electric energy, matter, and momentum (thrust). Notation are: 1 - injector-accelerator of neutral ultra-cold plasma (ions and electrons), 2 - plasma beam, 3 - space ship or planetary team, 4 - electrostatic ions collector (or magnetic collector), 5 - braking electric nets (electrostatic electro-generator-thruster-reflector), 6 - thrust.

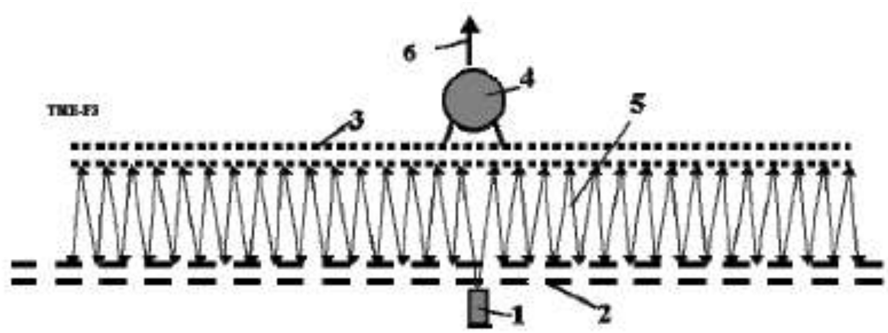

Figure 2.Multi-reflection start of the spaceship having proposed engine. Notation are: 1 - injector-accelerator of cold ions or plasma, 2 , 3 - electrostatic reflectors, 4 - space ship, 5 - plasma beam, 6 - the thrust.

The electrostatic collector and electrostatic generator-thruster-reflector proposed and described in [19]. The main parts are presented below.

A *Primary Ramjet* propulsion engine is shown in [27, Figure 1 or [34, Fig.1, Ch.2]. Such an engine can work in charged environment. For example, the surrounding region of space medium contains positive charge particles (protons, ions). The engine has two plates 1, 2, and a source of electric voltage and energy (storage) 3. The plates are made from a thin dielectric film covered by a conducting layer. The plates may be a net. The source can create an electric voltage U and electric field (electric intensity E) between the plates. One also can collect the electric energy from plate as an accumulator.

The engine works in the following way. Apparatus are moving (in left direction) with velocity V (or particles 4 are moving in right direction). If voltage U is applied to the plates, it is well-known that main electric field is only between plates. If the particles are charged positive (protons, positive ions) and the first and second plate are charged positive and negative, respectively, then the particles are accelerated between the plates and achieve the additional velocity $v > 0$. The total velocity will be $V+v$ behind the engine (Figure 3a). This means that the apparatus will have thrust $T > 0$ and spend electric energy $W < 0$ (bias, displacement current). If the voltage $U = 0$, then $v = 0$, $T = 0$, and $W = 0$ (Figure 3b).

If the first and second plates are charged negative and positive, respectively, the voltage changes sign.

Assume the velocity v is satisfying $-V < v < 0$. Thus the particles will be braked and the engine (apparatus) will have drag and will also be braked. The engine transfers braked vehicle energy into electric (bias, displacement) current. That energy can be collected and used. Note that velocity v cannot equal $-V$. If v were equal to $-V$, that would mean that the apparatus collected positive particles, accumulated a big positive charge and then repelled the positive charged particles.

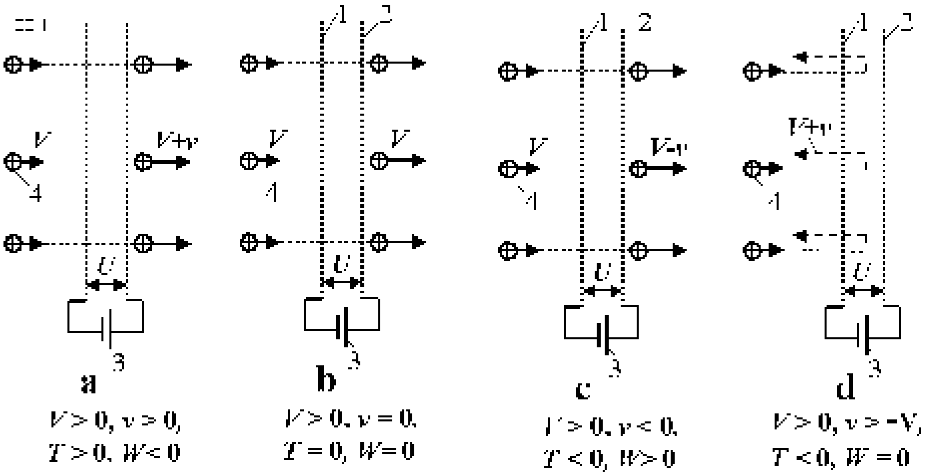

Figure 3. Explanation of primary Space Ramjet propulsion (engine) and electric generator (in braking),a) Work in regime thrust; b) Idle; c) Work in regime brake. d) Work in regime strong brake (full reflection). Notation: 1, 2 - plate (film, thin net) of engine; 3 - source of electric energy (voltage U); 4 - charged particles (protons, ions); V - speed of apparatus or particles before engine (solar wind); v - additional speed of particles into engine plates; T - thrust of engine; W - energy (if W < 0 we spend energy).

If the voltage is high enough, the brake is the highest (Figure3d). Maximum braking is achieved when $v = -2V$ ($T < 0$, $W = 0$). Note, the v cannot be more then $-2V$, because it is full reflected speed.

AB-Ramjet engine. The suggested Ramjet is different from the primary ramjet. The suggested ramjet has specific electrostatic collector 5 (Figure 4a,c,d,e,f,g). Other authors have outlined the idea of space matter collection, but they did not describe and not research the principal design of collector. Really, for charging of collector we must move away from apparatus the charges. The charged collector attracts the same amount of the charged particles (charged protons, ions, electrons) from space medium. They discharged collector, work will be idle. That cannot be useful.

The electrostatic collector cannot adsorb matter (as offered some inventors) because it can adsorb ONLY opposed charges particles, which will be discharged the initial charge of collector. Physic law of conservation of charges does not allow us to change charges of particles.

The suggested collector and ramjet engine have a special design (thin film, net, special form of charge collector, particle accelerator). The collector/engine passes the charged particles ACROSS (through) the installation and changes their energy (speed), deflecting and focusing them. That is why we refer to this engine as the *AB-Ramjet engine*. It can create thrust or drag, extract energy from the kinetic energy of particles or convert the apparatus' kinetic energy into electric energy, and deflect and focus the particle beam. The collector creates a local environment in space because it deletes (repeals) the same charged particles (electrons) from apparatus and allows the Ramjet to work when the apparatus speed is close to zero. The author developed the theory of the electrostatic collector and published it in [26]. The conventional electric engine cannot work in usual plasma without the main part of the AB-engine - the special pervious electrostatic collector.

The plates of the suggested engine are different from the primary engine. They have concentric partitions which create additional radial electric fields (electric intensity) (Figure 4b). They straighten, deflect and focus the particle beams and improve the efficiency coefficient of the engine.

The central charge can have a different form (core) and design (Figure 4c,d,e,f,g,h). It may be:

(1) a sphere (Figure 4c) having a thin cover of plastic film and a very thin (some nanometers) conducting layer (aluminum), with the concentric spheres inserted one into the other (34, Figure 4d),
(2) a net formed from thin wires (Figure 4e);

(3) a cylinder (without butt-end)(Figure 4f); or
(4) a plate (Figure 4g).

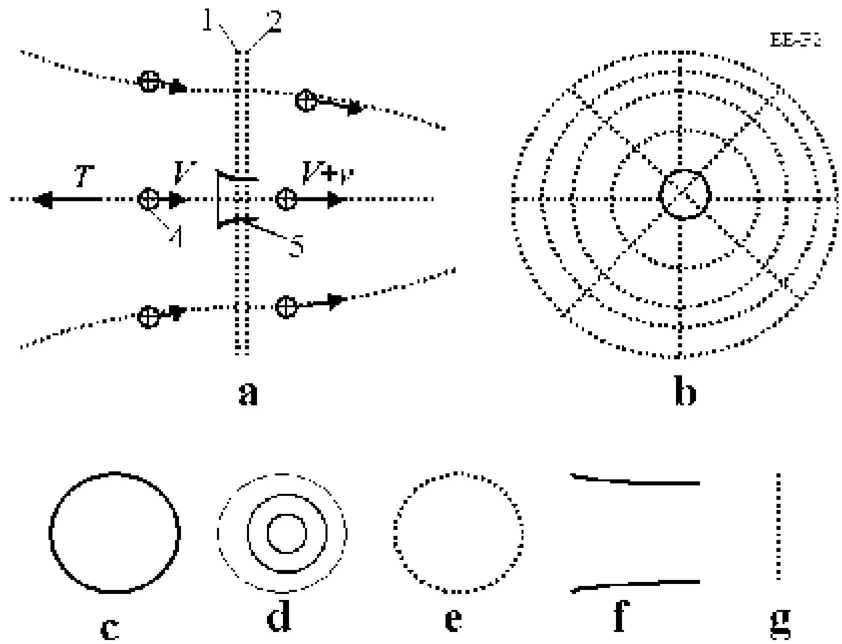

Figure 4. Space AB-Ramjet engine with electrostatic collector (core). a) Side view; b) Front view; c) Spherical electrostatic collector (ball); d) Concentric collector; e) cellular (net) collector; f) cylindrical collector without cover butt-ends; g) plate collector (film or net).

The design is chosen to produce minimum energy loss (maximum particle transparency - see section "Theory"). The safety (from discharging, emission of electrons) electric intensity in a vacuum is 10^8 V/m for an outer conducting layer and negative charge. The electric intensity is more for an inside conducting layer and thousands of times more for positive charge.
The engine plates are attracted one to the other (see theoretical section). They can have various designs (Figure 5a - 5d). In the rotating film or net design (Figure 5a), the centrifugal force prevents contact between the plates. In the inflatable design (Figure 3b, Ch. 2), the low pressure gas prevents plate contact. A third design has (inflatable) rods supporting the film or net (Figure 3c, Ch. 2). The fourth design is an inflatable toroid which supports the distance between plates or nets (Figure 5d).

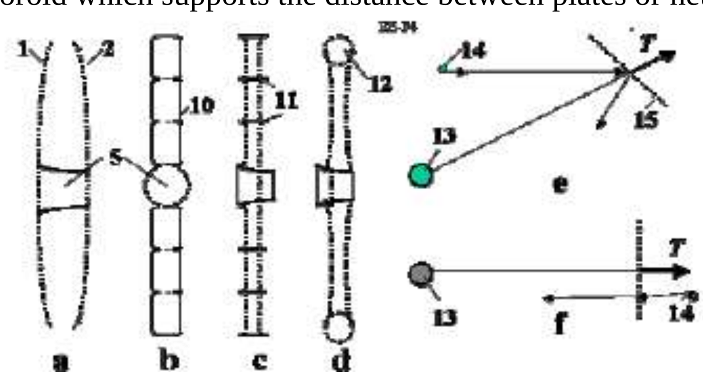

Figure 5.Possible design of the main part of ramjet engine. a) Rotating engine; b) Inflatable engine (filled by gas); c) Rod engine; d) Toroidal shell engine, e) AB-Ramjet engine in brake regime, f) AB-Ramjet engine in thrust regime. Notation: 10 - film shells (fibers) for support thin film and creating a radial electric field; 11 - Rods for a support the film or net; 12 - inflatable toroid for support engine plates; 13 - space apparatus; 14 - particles; 15 - AB-Ramjet

Note, the AB-ramjet engine can work using the neutral plasma. The ions will be accelerated or braked, the electrons will be conversely braked or accelerated. But the mass of the electrons is less then the mass of ions in thousands times and AB-engine will produce same thrust or drag.

Plasma accelerator. The simplest linear plasma accelerator (principle scheme of linear particle accelerator) for plasma beam is presented in Figure 6. The design is a long tube (up 10 m) which creates a strong electric field along the tube axis (100 MV/m and more). The accelerator consists of the tube with electrical isolated cylindrical electrodes, ion source, and voltage multiplier. The accelerator increases speed of ions, but in end of tube into ion beam the electrons are injected. This plasma accelerator can accelerate charged particles up 1000 MeV. Electrostatic lens and special conditions allow the creation of a focusing and self-focusing beam which can transfer the charge and energy long distances into space. The engine can be charged from a satellite, a spaceship, the Moon, or a top atmosphere station (space tower [19, 28]). The beam may also be used as a particle beam weapon.

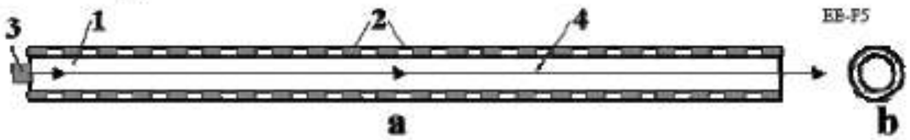

Figure 6.Electric gun for charging AB-Ramjet engine and transfer charges (energy) in long distance.a) Side view, b) Front view. Notations: 1 - gun tube, 2 - opposed charged electrodes, 3 - source of charged particles (ions, electrons), 4 - particles beam.

Approximately ten years ago, the conventional linear pipe accelerated protons up to 40 MeV with a beam divergence of 10^{-3} radian. However, acceleration of the multi-charged heavy ions may result in significantly more energy.

At present, the energy gradients as steep as 200 GeV/m have been achieved over millimeter-scale distances using laser pulses. Gradients approaching 1 GeV/m are being produced on the multi-centimeter-scale with electron-beam systems, in contrast to a limit of about 0.1 GeV/m for radio-frequency acceleration alone. Existing electron accelerators such as SLAC <http://en.wikipedia.org/wiki/SLAC> could use electron-beam afterburners to increase the intensity of their particle beams. Electron systems in general can provide tightly collimated, reliable beams while laser systems may offer more power and compactness.

The cool plasma beam carries three types of energy: kinetic energy of particles, ionization, and dissociation energy of ions and molecules. That carry also particle mass and momentum. The AB-Ramjet engine (described over) can utilize only kinetic energy of plasma particles and momentum. The particles are braked and produce an electric current and thrust or reflected and produce only thrust in the beam direction. If we want to collect a plasma matter and to utilize also the ionization energy of plasma (or space environment) ions and dissociation energy of plasma molecules we must use the modified AB-Ramjet engine described below (Figure 7).

The modified AB-engine has magnetic collector (option), three nets (two last nets may be films), and issue voltage (that also may be an electric load). The voltage, U, must be enough for full braking of charged particles. The first two nets brake the electrons and precipitate (collect) the electrons on the film 2 (Figure 7). The last couple of film (2, 3 in Figure3) brakes and collects the ions. The first couple of nets accelerate the ions that is way the voltage between them must be double.

The collected ions and electrons have the ionized and dissociation energy. This energy is significantly (up 20 - 150 times) more powerful then chemical energy of rocket fuel (see Table 1) but significantly less then kinetic energy of particles (ions) equal U (in eV) (U may be millions volts). But that may be used by ship. The ionization energy conventionally pick out in photons (light, radiation) which easy are converted in a heat (in closed vessel), the dissociation energy conventionally pick out in heat.

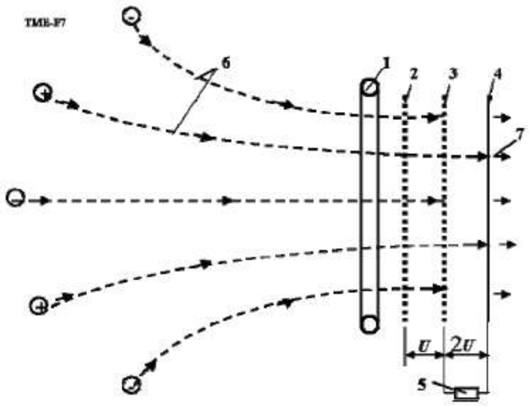

Figure 7.AB-engine which collected matter of plasma beam, kinetic energy of particles, energy ionization and dissociation. Notations: 1 - magnetic collector; 2 - 4 - plates (films, nets) of engine; 5 - electric load; 6 - particles of plasma; 7 - radiation. *U*- voltage between plates (nets).

The light energy may be used in the photon engine as thrust (Figure 8a) or in a new power laser (Figure 8b). The heat energy may be utilized conventional way (Figure 8c). The offered new power laser (Figure 8b) works the following way. The ultra-cool rare plasma with short period of life time located into cylinder. If we press it (decrease density of plasma) the electrons and ions will connect and produce photons of very closed energy (laser beam). If we compress very quickly by explosion the power of beam will be high. The power is only limited amount of plasma energy.
After recombination ions and electrons we receive the conventional matter. This matter may be used as nuclear fuel (in thermonuclear reactor), medicine, food, drink, oxidizer for breathing, etc.

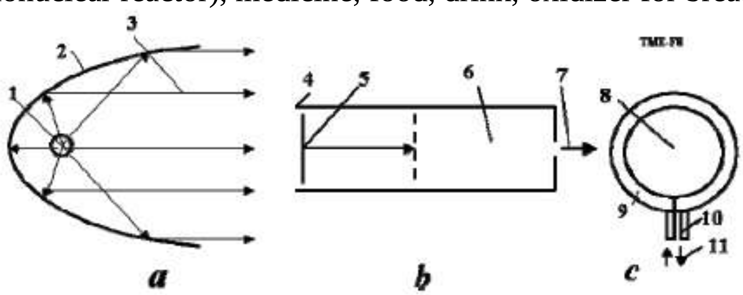

Figure 8.Conversion of ionization energy into radiation and heat.a- photon engine; b - power laser (light beamer); c - heater. Notations: 1 - recombination reactor; 2 - mirror; 3 - radiation (light) beam; 5 - piston; 6 - volume filled by cold rare plasma; 7 - beam; 8 - plasma; 9 - heat exchanger; 10 - enter and exit of hear carrier; 11 - heat carrier.

Transfer Theory of the High Speed Neutral Ultra-Cold Plasma and Particles

Below are the main equations and computations of neutral ultra-cold plasma beam having velocity up to relativistic speed. These equations received from conventional mechanics and relativistic theory. Note a ratio β

$$\beta = \frac{V}{c}, \quad \beta_S = \frac{V_S}{c} \qquad (1)$$

where$V$ is plasma beam speed, m/s; $c = 3\times10^{8}$ is light speed, m/s; V_s is projection of a ship speed in beam direction.

1. *Relative relativistic time,* $\bar{t}$, for observer moving together with beam is

$$\bar{t}' = \frac{t'}{t} = \sqrt{1-\beta^2}\,, \qquad (2)$$

where t' is time for observer moving together with beam (system coordinate connected with beam)[s], t is time for Earth's observer [s]. Computation of Eq. (2) is presented in Figure 9. The beam time decreases for relativistic speed. That means the beam divergence is also decreased and beam energy may be passed for long distance.

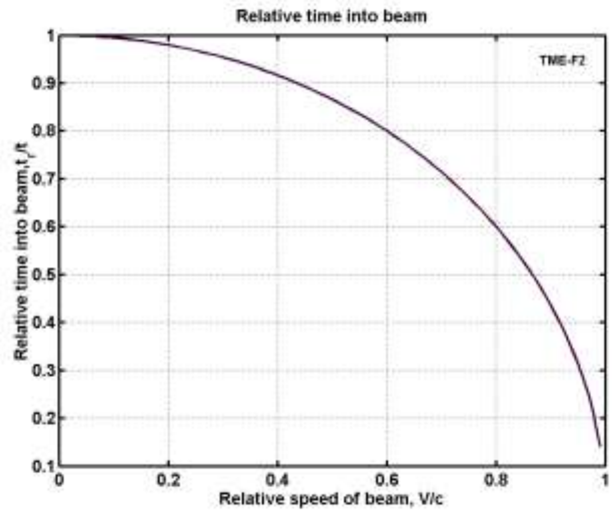

Figure 9. Beam relative time versus beam relative speed for high relativistic beam speed.

2. *The power spent for acceleration plasma beam* in Earth for efficiency = 1 (kinetic power of particle beam) is

$$P_B = \frac{M_0 c^2}{2}\frac{\beta^2}{\sqrt{1-\beta^2}}, \quad \text{or} \quad \text{for} \quad \beta << 1 \quad P_B = \frac{M_0 V^2}{2}\ \text{[W]} \qquad (3)$$

where M_0 is mass flow of beam, kg/s in Earth system of coordinate.
The computations of Eq. (3) for the intervals $(0 \div 0.1)c$ and $(0 \div 0.95)c$ are presented in Figures 6, 6a. The relativistic speed needs very high power in any method because the relativistic beam requires this energy.

3. *The power P_i of dissociation and single ionization* of one nucleon is

$$P_i = 1.6\times10^{-19}\frac{M_0}{m_p n}e_i \quad [J/s] \quad \text{or} \quad P_i = \frac{M_0}{m_p n}e_i \quad \text{[eV/s]} \qquad (4)$$

where $m_p = 1.67\times10^{-27}$ kg is mass of proton, n is number of nucleon in nucleus, e_i is energy of dissociation, ionization, or molecular breakup respectively. The energy of the first ionization (ion lost one electron) approximately equals from 2 to 14 eV. Magnitudes of this energy for some molecules and ions are in Table No.1.

Table 1. Energy ionization, dissociation, and molecular breakup of some molecules and ions in *eV*.

Molecular breakup	$H_2O \rightarrow H_2 + O$	2 eV	$CO_2 \rightarrow C + O_2$	0.093 eV
Dissociation	$H_2 \rightarrow H + H$	4.48 eV	$O_2 \rightarrow O + O$	5.1 eV
Ionization	$H \rightarrow H^+$	13.6 eV	$H_2 \rightarrow H_2^+$	2.65 eV
Ionization	$O_2 \rightarrow O_2^+$	6.7 eV		

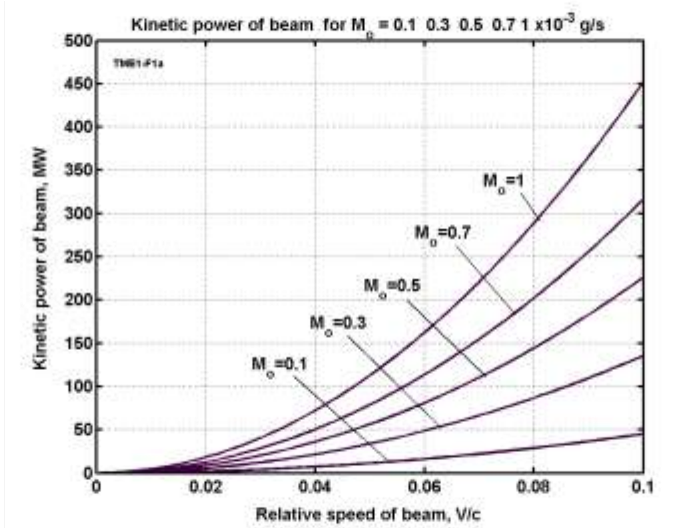

Figure 10.Power for the beam acceleration via beam flow mass and relative beam speed for interval. $(0 \div 0.1)c$.

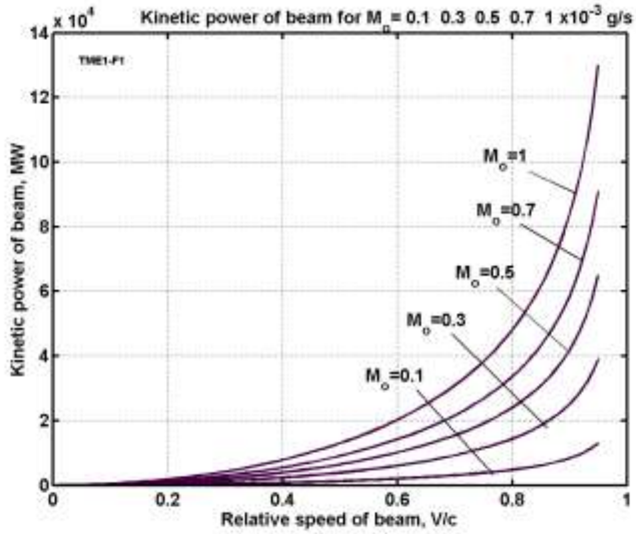

Figure 10a. Power for the beam acceleration via beam flow mass and relative beam speed for interval $(0 \div 0.95)c$.

If speed is relativistic, this energy is small in comparison with kinetic energy of beam. For interplanetary speed (V_S = 8 -15 km/s) the energy of ionization reaches 15 - 50% from kinetic energy of beam. That decreases the coefficient of efficiency launch installation. If we used the heavy ions or a charged matter, the ionization energy decreases but voltage increases. For interplanetary vehicles it is not important because required voltage for low speed are small ($U \approx 5 \div 20$ V).

Figure 11 shows the required energy for different case

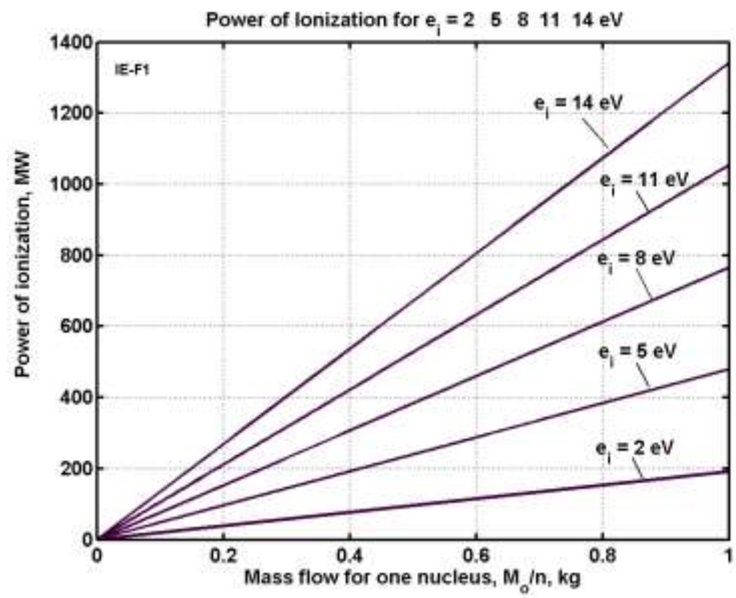

Figure 11.Power of ionization versus mass flow and ionization potencial (Eq. (4)).

4. *The maximal thrust (drag)* from the full reflected one charged plasma beam, for Earth's observer and relativistic speed and non-relativistic speed may be estimated by following equations:

$T_{\max} = 2M(V \mp V_S) \approx \dfrac{2M_0 c(\beta \mp \beta_S)}{\sqrt{1-\beta^2}}$, or for $\beta_S << 1$ the thrust is $T_{nax} = \dfrac{2M_0}{\sqrt{1-}}$

for $\beta << 1$, $\beta_S << 1$, the thrust is $T_{\max} = 2M_0(V - V_S)$ (5)

Here M is calculated mass of a moving relativistic particle flow, kg/s; M_0 is mass of the particle flow measured by Earth's observer, kg/s.

Note: If the space ship move along the beam in same direction, the thrust is decreased (sign is "-"); if that moves in opposed direction, the drag is increased (sing is "+"). This drag (thrust) is not requested the ship propulsion energy.

Result of computation for intervals $(0 \div 0.1)c$, $(0 \div 0.95)c$, $V_S = 0$ are presented in Figure 12, 12a.

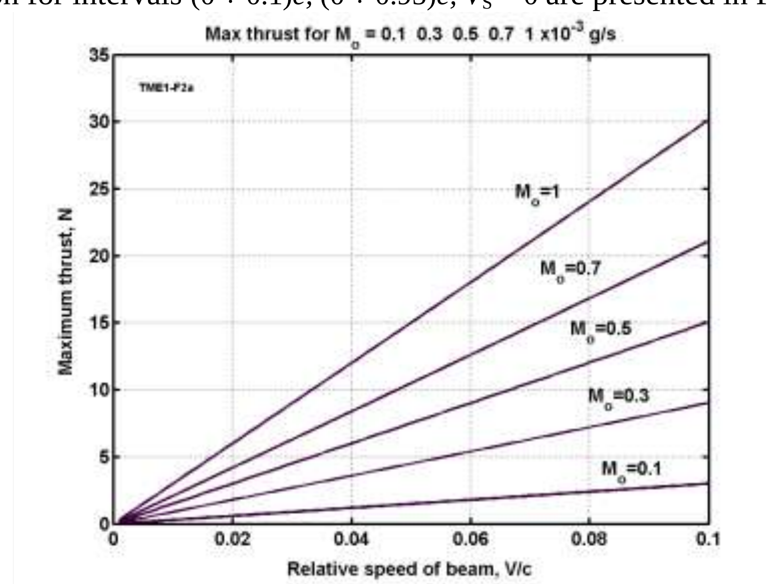

Figure 12. Maximum thrust (drag) is produced by beam in space ship for $V_S = 0$ and the interval (0 ÷ 0.1)c.

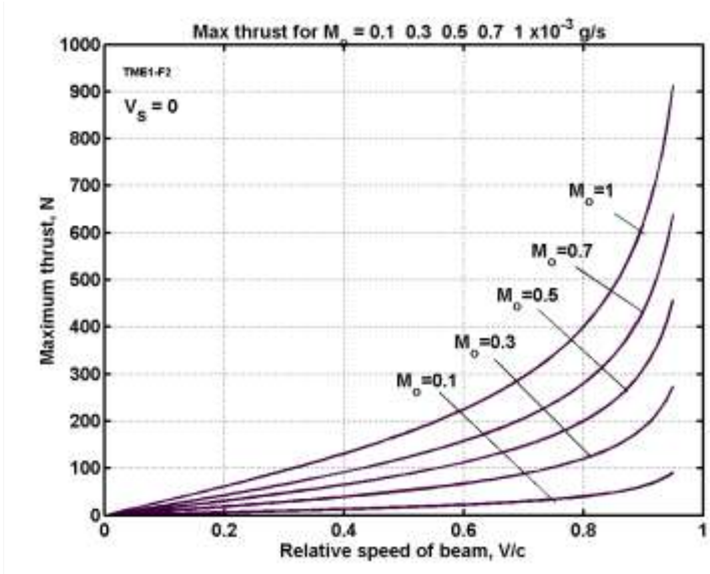

Figure 12a. Maximum thrust (drag) is produced by beam in space ship for $V_S = 0$ and interval (0 ÷ 0.95)c.

5. *The divergence of beam* is a very important magnitude. If divergence is small, we can pass our energy in long distance S:

$$D = \frac{ut'}{Vt} = \frac{u}{c}\frac{\sqrt{1-\beta^2}}{\beta}S, \quad \overline{D} = \frac{D}{S}, \quad S = c\beta t \qquad (6)$$

where$u$ is maximal radial speed, m/s; D is maximal radial distance (radius of plasma beam), m; $\overline{D}$ is relative divergence (angle of divergence, $\theta = 2\overline{D}$ radians); t is time of beam moving, s.
The computation of Eq. (6) is shown in Figure 9. We need in small u (ultra-cold plasma) for decreasing of divergence as small as possible (u = 0.01 - 1 m/s). In this case we can transfer energy in the large distance and accelerate a ship for relativistic speed. The plasma is mixture of ions and electrons. If it is low-density, it can exist a long time. The cold plasma can be emitted from solid electrodes.
Note: Equations (2),(6) shows when $V \to c$, then $t' \to 0$ and deviation $D \to 0$. That means the deviation can be small as we want but we need a big power for it.
The corresponding temperature is

$$T_c = \frac{mu^2}{ik}, \qquad (7)$$

Where$m$ is mass of molecule (ion) [kg]; $m = m_p n$, here m_p=1.67×10 $^{-27}$ is mass of proton, n is number of nucleons into nucleus; i = 3 for single ion (for example O^+), i = 5 for double molecule (for example O_2^+), i = 6 for multi-molecular ions, k = 1.39×10 $^{-23}$ is Boltzmann constant.
For u = 0.1 ÷ 1 m/s the temperature is about 10 $^{-3o}$K, the relative divergence is 10^{-9}.

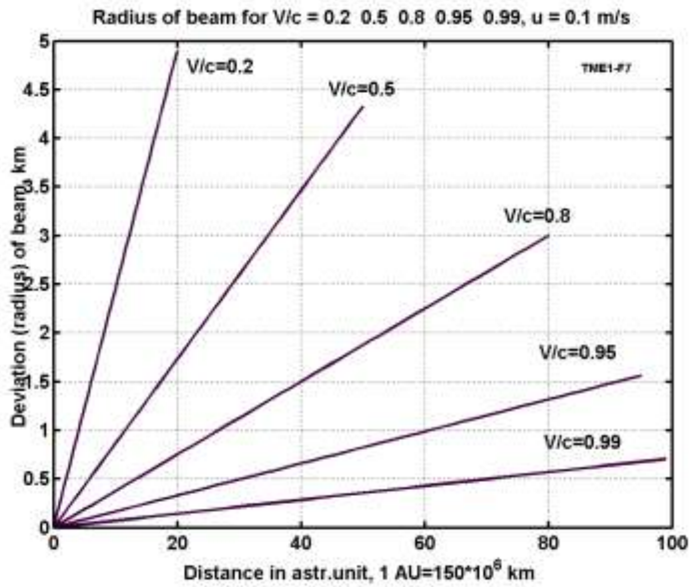

Figure 13.Radius of beam divergence via distance and ratio V/c.

6. *Accelerate voltage is*

$$U = \frac{mV^2}{2q} = \left(\frac{m_p}{q}\right)\frac{nc^2}{2}\frac{\beta^2}{\sqrt{1-\beta^2}}, \qquad (8)$$

where$q = 1.6\times10^{-19}$ C is electron (ion) charge. The computations are presented in Figure 14, 14a. The need voltage may be reduced in Z times if the ion has Z charges (delete Z electrons from ion).

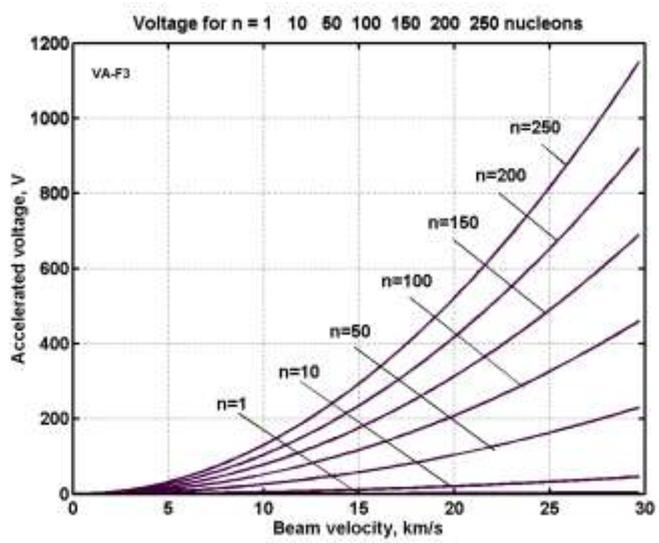

Figure 14.Accelerated voltage versus the conventional beam speed and number of nucleons.

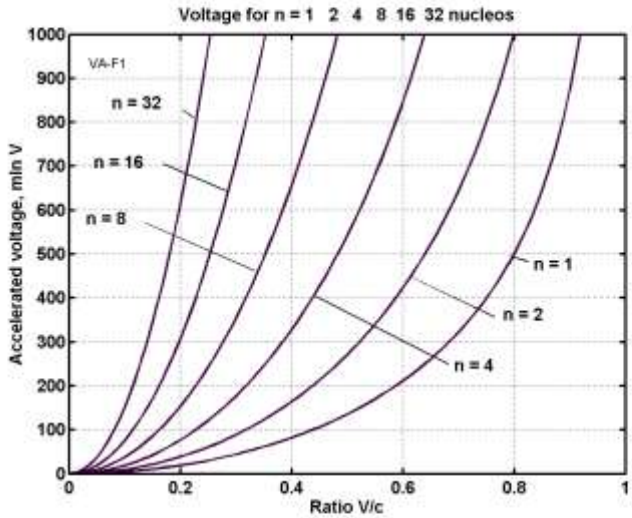

Figure 14a.Accelerated voltage versus a relativistic speed ratio V/c and number of nucleons.

7. *The speed V_s and distance of space shipS* can be computed by conventional method (Earth's observer):

$$V_S = at, \quad S = \frac{at^2}{2}, \quad S = \frac{V_S^2}{2a}, \quad a = \frac{T}{M_S},$$

a is ship acceleration, m/s^2. M_s is ship mass, kg, V_S is ship speed measured by Earth's observer, m/s.

8. *Relative beam speed* for a ship observer is

$$\beta_{BS} = \frac{\beta \pm \beta_S}{1+\beta\beta_S} \qquad (9)$$

where β, β_S is relative speed of beam and space ship respectively measured by Earth's observer. The sign " -" is used for same direction of speeds.

9. *Loss energy of the beam* in the Earth atmosphere may be estimated by the following way:

$$\tau = \frac{100 H_0 \rho_0 \bar{\rho}(h)\bar{p}(h)}{R_t(U)}, \quad R_t = \frac{m}{m_p} R_t\left(\frac{m_p}{m}U\right) \qquad (10)$$

where $H_0 = P_a/\rho = 10^4/1.225 = 8163$ m is thickness (height) of Earth atmosphere having constant density $\rho = 1.225$ kg/m^3, $P_a = 10^4$ kg/m^2 is the atmospheric pressure; $\bar{\rho}(h)$ is relative atmosphere density; $\bar{p}(h)$ is relative atmosphere pressure; R_t is particle track in atmosphere [cm]; m is mass of particle, kg; h is altitude, m; U is beam energy, MeV; ρ_o = 0,001225 g/cm^3 is atmosphere density; 100 is transfer coefficient meter into cm. Magnitudes R_t, $\bar{\rho}(h)$, $\bar{p}(h)$ for proton are given below in Tables 2, 3.

Table 2. Value R_t [g/cm^2] versus energy of proton in MeV, [32], p. 953

*U*MeV	0.1	1	10	50	100	200	300	400	500
R_tg/cm^2	1×10^{-4}	1.09×10^{-2}	$0,99\times10^{-1}$	2.56	8.835	29.64	58.08	93.73	133.3

U	600	700	800	1000	2000	3000	5000	7000	10,000
R_t	176	222	270	370	910	1363	2543	3583	5081

Table 3. Standard Earth atmosphere, [33], p. 261

h km	0	5	10	20	40	60	100
$\bar{\rho}(h)$	1	0.661	0.338	0.072	3.27×10^{-3}	2.71×10^{-4}	4.41×10^{-7}

$\bar{p}(h)$	1	0.533	0.261	0.054	2.92×10^{-3}	8.35×10^{-4}	3.20×10^{-7}

Results of computation Eq. (10) are presented in Figure 15, 15a, 15b.

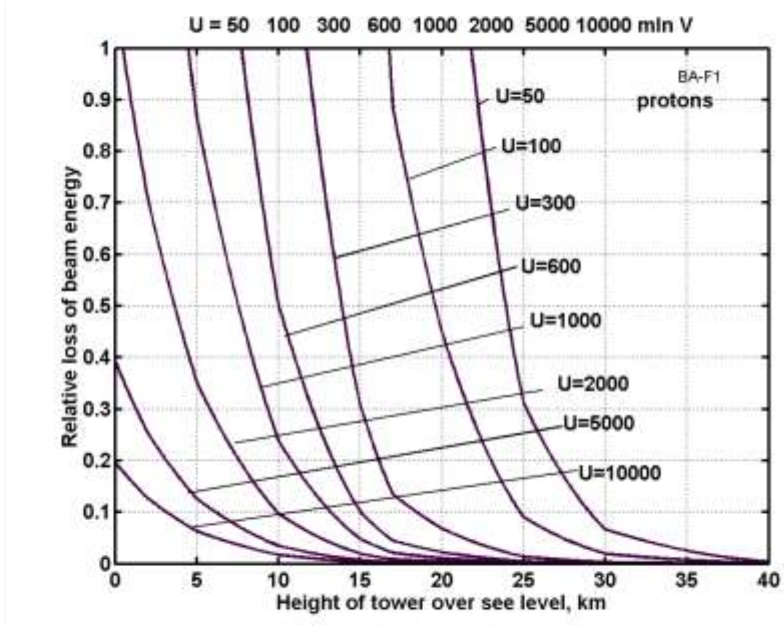

Figure 15.Relative energy loss of the proton particle beam via a tower altitude in Earth atmosphere. Accelerate voltage *U* are in millions volts.

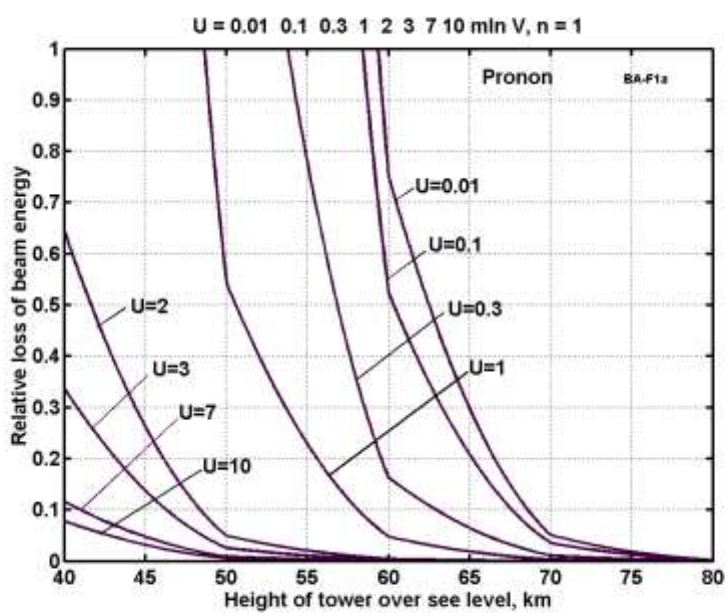

Figure 15a.Relative energy loss of the proton particle beam via a tower altitude in Earth atmosphere. Accelerate voltage *U* are in millions volts. Angles in curve are result of the linearization data of Table 2, 3.

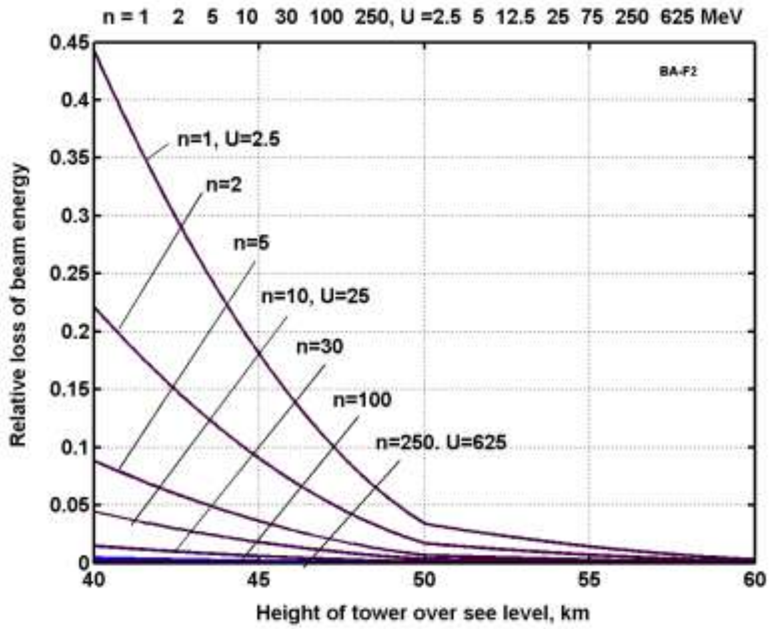

Figure 15b.Relative energy loss of the particle beam via the tower altitude in Earth atmosphere and number *n* of nucleons in nucleus. Accelerate voltage *U* in millions volts.

Evidently, only high energy particle beam break up the Earth atmosphere. There is no problem if the particle beam starts from a space tower [20], [25] of 40 ÷ 80 km altitude or from the Moon.
Last formula in (10) allows recalculation by the particle track for any atom. For example, we want tocalculate the particle track for oxidizer particle having $m = 16m_p$ and energy 8,000 MeV. We take the R_t from Table 2 for U = 8,000/16 = 500 MeV and multiple by 16. Result R_t = 133×16=2128. The particle track $T_r= R_t/\rho_o$ = 2128/0.001225 =1737142 cm = 17.4 km in the air having density 1.225 kg/m^3. That is enough to break the Earth's atmosphere of the constant density 8.163 km, but the loss of energy will be τ = 8.163/17.4 = 0.47 (47%). The divergence may also be increased by atmosphere. Loss and divergence may be improved is the beam station is located on a mountain or special tower having the height about 40 ÷ 60 km.
10. Multi-reflex launch and landing(Figure2).In a starting or braking period the thrust (braking) can be increasingif we use the multi-reflect method developed in [26]. Multi-reflect in launching does not increased the installation power (thrust is increased by increasing of efficiency), multi-reflex in braking converts the apparatus kinetic energy into the electric energy which can be utilized by apparatus or operated station. The theory of multi-reflection is described below (see also [26]).
11.Change in beam power. The beam power will be reduced if one (or both) reflector is moved, because the beam speed changes. The total relative loss, *q*, of the beam energy in one double cycle (when the beam is moved to the reflector and back) is

$$q = (1-2\gamma)(1-2\xi)(1\pm 2v)\varsigma\ , \ q > 0\ , \qquad (11)$$

where$v$ is the loss (useful work) through relative mirror (lens) movement, $v = V_S/V$, V_S is the relative speed of the electrostatic mirrors (space apparatus)[m/s], V = is the speed of the beam (in system of coordinates connected with an power operating station). We take the "+" when the distance is reduces (braking) and take "–" when the distance is increased (as in launching, a useful work for beam), γ is coefficient reflectivity of electrostatic mirror (the loss of beam energy through the electrostatic reflector); ξ is the loss (attenuation) in the medium (air) (see point 8). If no atmosphere, $\xi = 0$; ς is the loss through beam divergence ($\varsigma = 1$ if $D < D_r$, where D_r is diameter of the electrostatic mirror). For a wire net electrostatic reflector $\gamma \approx 2d_w/l$ where d_w is diameter of wire, l is size of mesh. For example, for the net having a mesh 0.1×0.1 m, the l = 0.1 m and a wire d_w= 0.0001 m, the γ= 0.002.

Multi-reflex light pressure. The beam pressure, T, of two opposed high reflectors after a series ofreflections, N, to one another is

$$T(V_S) = T_0 + \frac{2P_B}{V}\sum_{j=1}^{N} q^j(V_S), \quad N(V_S) = \sqrt{\frac{kD_rV}{uS}}. \quad P_B = \frac{M_0V^2}{2}. \quad T_0 = 2M_0(V - V_S) \geq 0 \tag{12}$$

where$S$ is distance between electrostatic reflectors of the station and ship [m], k = 1 ÷ 1.5 is correction coefficient for the case when D>D_r. For primary estimation k = 1.

If V_S is small and V is high, the multi-reflex T may be large. For example, if V_S =10 m/s, V = 30 km/s, S is small, the number of reflection may reach $n \approx$ 30000/10/2 = 1500 times more then regular thrust. That is well for ship trip starting and braking.

12. Limitation of reflection number. If the reflector is moved away, the maximum number of reflections, N, is limited by q> 0, V_S< 0.5V (see Eq. (11)). At ship launch or braking the maximum thrust is limited by a safety acceleration or deceleration.

Coefficient of efficiency. The propulsion efficiency coefficient, η, (without loss for ionization) may be computed using the equation

$$\eta = TV_S/P_B \tag{13}$$

For full reflection Eq. (13) has the form:

$$\eta = \frac{4(V - V_S)V_S}{V^2}, \quad \eta_{\max} = 1 \quad \text{for} \quad V = 2V_S \tag{14}$$

Computation of launch and landing trajectories computed by the usual method of integration

[illegible] (15)

Project

(Interstellar probe having speed 30.000 km/s, weight 0.1 kg)

Let us assume we want to estimate an interstellar probe which can reach the nearest solar systems. As known they are located about 4 - 60 light years from our Sun. That means the apparatus having speed β_S = 0.1c (V_S = 30,000 km/s) can reach them in 40 - 60 years. Reminder, "Voyager-1" was flown for 30+ year, sending information up to present time. But it has speed only 20 km/s and was reached only the boundary of Solar system (about 2 billion km).

Assume, the weight of interstellar probe is 0.1 kg. If distance of acceleration is $S = 1.5\times10^{11}$ m (1 AU) the acceleration and acceleration time must be

$$a = \frac{V_S^2}{2S} = \frac{9\cdot10^{14}}{2\cdot1.5\cdot10^{11}} = 3\cdot10^3 \ \ m/s^2, \quad t = \frac{V_S}{a} = \frac{3\cdot10^7}{3\cdot10^3} = 10^4\,\text{sec} = 167\,\text{min} = 2.78\,\text{hours}.$$

The thrust, requested acceleration energy and power are

$$T = aM_S = 3\cdot10^3\cdot0.1 = 300\,N, \quad W = \frac{M_SV_S^2}{2} = \frac{0.1\cdot9\cdot10^{14}}{2} = 4.5\cdot10^{13} \ \ J, \quad P = \frac{W}{t} = \frac{4.5\cdot10^{13}}{10^4} = 4.5 \ \ GW,$$

The mass of the beam flow, and energy spent by beam station are (Eq. (3),(5))

$$M_0 = \frac{T\sqrt{1-\beta^2}}{2c(\beta - \beta_S)} = \frac{300\sqrt{1-0.01}}{2\cdot3\cdot10^8(0.1-0.05)} \approx 10^{-5} \ \ kg/s,$$

$$P_B = \frac{M_0c^2}{2}\frac{\beta^2}{\sqrt{1=\beta^2}} = \frac{10^{-5}\cdot9\cdot10^{16}0.01}{2\sqrt{1-0.01}} = 4.5 \ \ GW$$

.

Here β_S = 0 ÷0.1 . We take the average value β_S = 0.05 . Notice that P_B = P, that means our installation transfer the station energy to ship with efficiency = 1. Unfortunately, this energy is very high. Tens of

electric power stations must accelerate this probe in 23 days. We cannot decrease this amount by any methods because that is a minimum energy required by space probe.
Divergence D for u = 0.01 m/s, voltage U (n =1), jet speed β = 0.1 and plasma temperature T_p are

$$D = \frac{u}{c}\frac{\sqrt{1-\beta^2}}{\beta}S \approx \frac{0.01}{3\cdot 10^8}\frac{1.5\cdot 10^{11}}{0.1} = 500 \ m, \quad T_p = \frac{mu^2}{ik} = \frac{1{,}67\cdot 10^{-27}10^{-4}}{3\cdot 1.38\cdot 10^{-23}} = 0.4\cdot 10^{-8} \quad {}^0K,$$

$$U = \left(\frac{m_p}{q}\right)\frac{nc^2}{2}\frac{\beta^2}{\sqrt{1-\beta^2}} \approx \left(\frac{1.67\cdot 10^{-27}}{1.6\cdot 10^{-19}}\right)\frac{1\cdot 9\cdot 10^{16}}{2}\frac{0.01}{1} = 4.7\cdot 10^6 \quad V.$$

For jet speed β =0.9 divergence D = 25 m, for jet speed β =0.99 divergence D = 7 m,
The power of dissociations ($H_2 \to H + H$, 2.2 eV) and ionization ($H \to H^+$, 13,6 eV) are equal

$$E_i = 1.6\cdot 10^{-19}(e_d + 2e_i)\frac{M_0}{m_p n} = 1.6\cdot 10^{-19}(2.2 + 2\cdot 13.6)\frac{10^{-5}}{1.67\cdot 10^{-27}\cdot 2} = 14 \ kW .$$

In given case (comparison with P_B above) this value is small and we can negligee it. But into planetary flight ($V \approx$ 8 - 30 km/s and large M_0) this energy is essential.

DiscussionofPart 3

In [33] G.A. Landis writes about using particle beams for interstellar flight. The beam is braked by a magnetic sail. Unfortunately, as with most other works in this field, his work also contains only common speculations. No theory, no mathematical models, no computations. More then ten years authors investigate the magnetic sail, but not its theory, no formulas which allows correct calculation or to estimate the magnetic sail drug. Moreover, the most MagSail works contain a common mistake (see 34 Chapter 4 "Electrostatic MagSail"). Landis offered the beam temperature 45 ^{o}K. The theory in this article is shown that this temperature gives the beam divergence which does not allows the interstellar flights. Absolutely unsubstantiated statement that magnetic sail reflects beam in thousands kilometers diameter. The estimations show for high speed particles especially relativistic particles the affective diameter equals some meters and magnetic field must be powerful. In additional the magnetic sail is impossible at present time: electric ring needs in cryogenic temperature and spaceship must have power cryogenic equipment because the Sun will warm the ring for any heat insulation; for starting the ring needs a power electric station; a special equipment is necessary for displacing the ring of 100 km diameter into space; if the ring temperature exceeds a critical cryogenic temperature in any ring place, the ring explodes. The ring weight is big (22 tons for diameter 100 km), the produced magnetic field is very weak (10^{-6} Tesla). The magnetic sail does not have active control. That means the ship will move in one (non-control) direction and a ship mission will useless. These obvious defects make it impossible the application of the magnetic sail with little or no progress in solution these problems since 1988.
The suggested method does not require a magnetic sail. That used the electrostatic sail [26] and AB-Ramjet engine offered by author early. This sail is light (100 - 300 kg), cheap, and has tens kilometers (hundreds km for low beam density) of the effective radius. For example, for solar wind the magnetic effective radius decreases proportional $1/R^2$ (where R is distance of the sail from the Sun), electrostatic effective radius decreases approximately $1/R$ (see [26]). That is very important advantage.

Conclusion Part 3

The offered idea and method use the AB-Ramjet engine suggested by author in 1982 [3, 4, 6, 8, 9, 12, 14 - 16, 18] and detail developed in [28]. The installation contains an electrostatic particle collector suggested in 1982 and detail developed in [26, 30]. The propulsion-reflected system is light net from thin wire, which can have a large area (tens km) and allows to control thrust and thrust direction without turning of net (Figure1). This new method uses the ultra-cold full neutral relativistic plasma and having small divergence. The method may be used for acceleration space apparatus (up relativistic speed) for launch and landing Space apparatus to small planets (asteroids, satellites) without atmosphere. For Earth offered method will be efficiency if we built the tower (mast) about 40 ÷ 80 km height [19, 24]. At present time that is the most realistic method for relativistic probe.

Part 4

Converting of any Matter to Nuclear Energy andPhoton Rocket for Flight outer Solar System*

Summary

Author offers a new nuclear generator which allows to convert any matter to nuclear energy in accordance with the Einstein equation $E=mc^2$. The method is based upon tapping the energy potential of a Micro Black Hole (MBH) and the Hawking radiation created by this MBH. As is well-known, the vacuum continuously produces virtual pairs of particles and antiparticles, in particular, the photons and anti-photons. The MBH event horizon allows separating them. Anti-photons can be moved to the MBH and be annihilated; decreasing the mass of the MBH, the resulting photons leave the MBH neighborhood as Hawking radiation. The offered nuclear generator (named by author as AB-Generator) utilizes the Hawking radiation and injects the matter into MBH and keeps MBH in a stable state with near-constant mass.

The AB-Generator can produce gigantic energy outputs and should be very small and cheaper than a conventional electric station by a factor of hundreds of times. One also may be used in aerospace as a photon rocket or as a power source for many vehicles.

Many scientists expect the Large Hadron Collider at CERN will produce one MBH every second. A technology to capture them may follow; than they may be used for the AB-Generator.

Key words: Production of nuclear energy, Micro Black Hole, energy AB-Generator, photon rocket.

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Introduction

Black hole. In general relativity, a black hole is a region of space in which the gravitational field is so powerful that nothing, including light, can escape its pull. The black hole has a one-way surface, called the event horizon, into which objects can fall, but out of which nothing can come out. It is called "black" because it absorbs all the light that hits it, reflecting nothing, just like a perfect blackbody in thermodynamics.

Despite its invisible interior, a black hole can reveal its presence through interaction with other matter. A black hole can be inferred by tracking the movement of a group of stars that orbit a region in space which looks empty. Alternatively, one can see gas falling into a relatively small black hole, from a companion star. This gas spirals inward, heating up to very high temperature and emitting large amounts of radiation that can be detected from earthbound and earth-orbiting telescopes. Such observations have resulted in the general scientific consensus that, barring a breakdown in our understanding of nature, black holes do exist in our universe.

It is impossible to directly observe a black hole. However, it is possible to infer its presence by its gravitational action on the surrounding environment, particularly with microquasars and active galactic nuclei, where material falling into a nearby black hole is significantly heated and emits a large amount of X-ray radiation. This observation method allows astronomers to detect their existence. The only objects that agree with these observations and are consistent within the framework of general relativity are black holes.

A black hole has only three independent physical properties: mass, charge and angular momentum.

In astronomy black holes are classed as:

- Supermassive - contain hundreds of thousands to billions of solar masses and are thought to exist in the center of most galaxies, including the Milky Way.
- Intermediate - contain thousands of solar masses.
- Micro (also *mini black holes*) - have masses much less than that of a star. At these sizes, quantum mechanics is expected to take effect. There is no known mechanism for them to form via normal processes of stellar evolution, but certain inflationary scenarios predict their production during the early stages of the evolution of the universe.

According to some theories of quantum gravity, they may also be produced in the highly energetic reaction produced by cosmic rays hitting the atmosphere or even in particle accelerators such as the Large Hadron Collider. The theory of Hawking radiation predicts that such black holes will evaporate in bright flashes of gamma radiation. NASA's Fermi Gamma-ray Space Telescope satellite (formerly GLAST) launched in 2008 is searching for such flashes.

Fig 1. Artist’s conception of a stellar mass NASA.

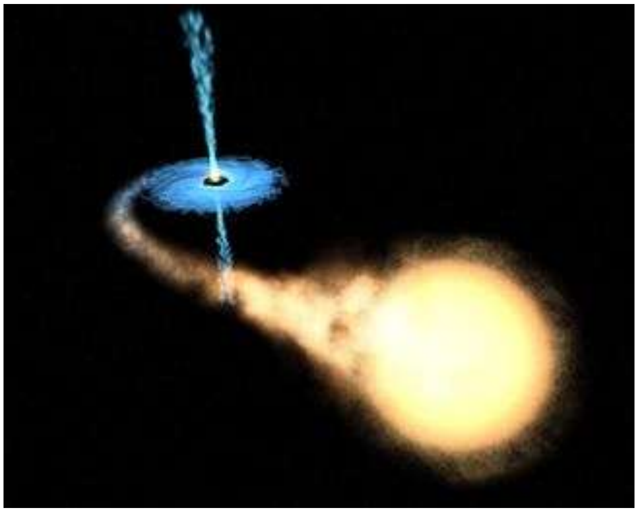

Fig.2 (left). Artist's impression of a binary system consisting of a black hole and a main sequence star. The black hole is drawing matter from the main sequence star via an accretion disk around it, and some of this matter forms a gas jet.

Fig.3 (right). Ring around a suspected black hole in galaxy NGC 4261.Date: Nov.1992. Courtesy of Space Telescope Science

The defining feature of a black hole is the appearance of an *event horizon*; a boundary in spacetime beyond which events cannot affect an outside observer.

Since the event horizon is not a material surface but rather merely a mathematically defined demarcation boundary, nothing prevents matter or radiation from entering a black hole, only from exiting one.

For a non-rotating (static) black hole, the *Schwarzschild radius* delimits a spherical event horizon. The Schwarzschild radius of an object is proportional to the mass. Rotating black holes have distorted, non-spherical event horizons. The description of black holes given by general relativity is known to be an approximation, and it is expected that quantum gravity effects become significant near the vicinity of the event horizon. This allows observations of matter in the vicinity of a black hole's event horizon to be used to indirectly study general relativity and proposed extensions to it.

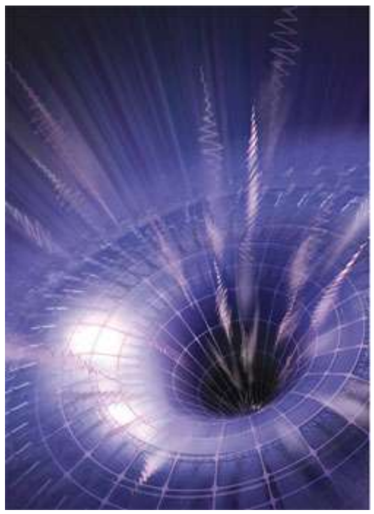

Fig.4. Artist’s rendering showing the space-time contours around a black hole. Credit NASA.

Though black holes themselves may not radiate energy, electromagnetic radiation and matter particles may be radiated from just outside the event horizon via *Hawking radiation*.

At the center of a black hole lies the *singularity*, where matter is crushed to infinite density, the pull of gravity is infinitely strong, and space-time has infinite curvature. This means that a black hole's mass becomes entirely compressed into a region with zero volume. This zero-volume, infinitely dense region at the center of a black hole is called a *gravitational singularity*.

The singularity of a non-rotating black hole has zero length, width, and height; a rotating black hole's is smeared out to form a ring shape lying in the plane of rotation. The ring still has no thickness and hence no volume.

The *photon sphere* is a spherical boundary of zero thickness such that photons moving along tangents to the sphere will be trapped in a circular orbit. For non-rotating black holes, the photon sphere has a radius 1.5 times the Schwarzschild radius. The orbits are dynamically unstable, hence any small perturbation (such as a particle of in falling matter) will grow over time, either setting it on an outward trajectory escaping the black hole or on an inward spiral eventually crossing the event horizon.

Rotating black holes are surrounded by a region of space-time in which it is impossible to stand still, called the *ergosphere*. Objects and radiation (including light) can stay in orbit within the ergosphere without falling to the center.

Once a black hole has formed, it can continue to grow by absorbing additional matter. Any black hole will continually absorb interstellar dust from its direct surroundings and omnipresent cosmic background radiation.

Much larger contributions can be obtained when a black hole merges with other stars or compact objects.

Hawking radiation. In 1974, Stephen Hawking showed that black holes are not entirely black but emit small amounts of thermal radiation.[1] He got this result by applying quantum field theory in a static black hole background. The result of his calculations is that a black hole should emit particles in a perfect black body spectrum. This effect has become known as Hawking radiation. Since Hawking's result many others have verified the effect through various methods. If his theory of black hole radiation is correct then black holes are expected to emit a thermal spectrum of radiation, and thereby lose mass, because according to the theory of relativity mass is just highly condensed energy ($E = mc^2$). Black holes will shrink and evaporate over time. The temperature of this spectrum (Hawking temperature) is proportional to the surface gravity of the black hole, which in turn is inversely proportional to the mass. Large black holes, therefore, emit less radiation than small black holes.

On the other hand if a black hole is very small, the radiation effects are expected to become very strong. Even a black hole that is heavy compared to a human would evaporate in an instant. A black hole the weight of a car ($\sim 10^{-24}$ m) would only take a nanosecond to evaporate, during which time it would briefly have a luminosity more than 200 times that of the sun. Lighter black holes are expected to evaporate even faster, for example a black hole of mass 1 TeV/c^2 would take less than 10^{-88} seconds to evaporate completely. Of course, for such a small black hole quantum gravitation effects are expected to play an important role and could even – although current developments in quantum gravity do not indicate so – hypothetically make such a small black hole stable.

Micro Black Holes. Gravitational collapse is not the only process that could create black holes. In principle, black holes could also be created in high energy collisions that create sufficient density. Since classically black holes can take any mass, one would expect micro black holes to be created in any such process no matter how low the energy. However, to date, no such events have ever been detected either directly or indirectly as a deficiency of the mass balance in particle accelerator experiments. This suggests that there must be a lower limit for the mass of black holes. Theoretically this boundary is expected to lie around the Planck mass ($\sim 10^{19}$ GeV/c^2, $m_p = 2.1764 \cdot 10^{-8}$ kg), where quantum effects are expected to make the theory of general relativity break down completely. This would put the creation of black holes firmly out of reach of any high energy process occurring on or near the Earth. Certain developments in quantum gravity however suggest that this bound could be much lower. Some brane-world scenarios for example put the Planck mass much lower, maybe even as low as 1 TeV. This would make it possible for micro black holes to be created in the high energy collisions occurring when cosmic rays hit the Earth's atmosphere, or possibly in the new Large Hadron Collider at CERN. These theories are however very speculative, and the creation of black holes in these processes is deemed unlikely by many specialists.

Smallest possible black hole. To make a black hole one must concentrate mass or energy sufficiently that the escape velocity from the region in which it is concentrated exceeds the speed of light. This condition gives the Schwarzschild radius, $r_o = 2GM / c^2$, where G is Newton's constant and c is the speed of light, as the size of a black hole of mass M. On the other hand, the Compton wavelength, $\lambda = h / Mc$, where h is Planck's constant, represents a limit on the minimum size of the region in which a mass M at rest can be localized. For sufficiently small M, the Compton wavelength exceeds the Schwarzschild radius, and no black hole description exists. This smallest mass for a black hole is thus approximately the Planck mass, which is about 2×10^{-8} kg or 1.2×10^{19} GeV/c^2.
Any primordial black holes of sufficiently low mass will Hawking evaporate to near the Planck mass

within the lifetime of the universe. In this process, these small black holes radiate away matter. A rough picture of this is that pairs of virtual particles emerge from the vacuum near the event horizon, with one member of a pair being captured, and the other escaping the vicinity of the black hole. The net result is the black hole loses mass (due to conservation of energy). According to the formulae of black hole thermodynamics, the more the black hole loses mass the hotter it becomes, and the faster it evaporates, until it approaches the Planck mass. At this stage a black hole would have a Hawking temperature of $T_P / 8\pi$ (5.6×10^{32} K), which means an emitted Hawking particle would have an energy comparable to the mass of the black hole. Thus a thermodynamic description breaks down. Such a mini-black hole would also have an entropy of only 4πnats, approximately the minimum possible value.

At this point then, the object can no longer be described as a classical black hole, and Hawking's calculations also break down. Conjectures for the final fate of the black hole include total evaporation and production of a Planck mass-sized *black hole remnant*. If intuitions about quantum black holes are correct, then close to the Planck mass the number of possible quantum states of the black hole is expected to become so few and so quantized that its interactions are likely to be quenched out. It is possible that such Planck-mass black holes, no longer able either to absorb energy gravitationally like a classical black hole because of the quantized gaps between their allowed energy levels, nor to emit Hawking particles for the same reason, may in effect be stable objects. They would in effect be WIMPs, weakly interacting massive particles; this could explain dark matter.

Creation of micro black holes. Production of a black hole requires concentration of mass or energy within the corresponding Schwarzschild radius. In familiar three-dimensional gravity, the minimum such energy is 10^{19}GeV, which would have to be condensed into a region of approximate size 10^{-33} cm. This is far beyond the limits of any current technology; the Large hadron collider (LHC) has a design energy of 14 TeV. This is also beyond the range of known collisions of cosmic rays with Earth's atmosphere, which reach center of mass energies in the range of hundreds of TeV. It is estimatedthat to collide two particles to within a distance of a Planck length with currently achievable magnetic field strengths would require a ring accelerator about 1000 light years in diameter to keep the particles on track.

Some extensions of present physics posit the existence of extra dimensions of space. In higher-dimensional space-time, the strength of gravity increases more rapidly with decreasing distance than in three dimensions. With certain special configurations of the extra dimensions, this effect can lower the Planck scale to the TeV range. Examples of such extensions include large extra dimensions, special cases of the Randall-Sundrum model, and String theory configurations. In such scenarios, black hole production could possibly be an important and observable effect at the LHC.

Virtual particles. In physics, a virtual particle is a particle that exists for a limited time and space, introducing uncertainty in their energy and momentum due to the Heisenberg Uncertainty Principle.

Vacuum energy can also be thought of in terms of virtual particles (also known as vacuum fluctuations) which are created and destroyed out of the vacuum. These particles are always created out of the vacuum in particle-antiparticle pairs, which shortly annihilate each other and disappear. However, these particles and antiparticles may interact with others before disappearing.

The net energy of the Universe remains zero so long as the particle pairs annihilate each other within Planck time.

Virtual particles are also excitations of the underlying fields, but are detectable only as forces.

The creation of these virtual particles near the event horizon of a black hole has been hypothesized by physicist Stephen Hawking to be a mechanism for the eventual "evaporation" of black holes.

Since these particles do not have a permanent existence, they are called *virtual particles* or vacuum fluctuations of vacuum energy.

An important example of the "presence" of virtual particles in a vacuum is the Casimir effect. Here, the explanation of the effect requires that the total energy of all of the virtual particles in a vacuum can be added together. Thus, although the virtual particles themselves are not directly observable in the laboratory, they do leave an observable effect: their zero-point energy results in forces acting on suitably arranged metal plates or dielectrics.

Thus, virtual particles are often popularly described as coming in pairs, a particle and antiparticle, which can be of any kind.

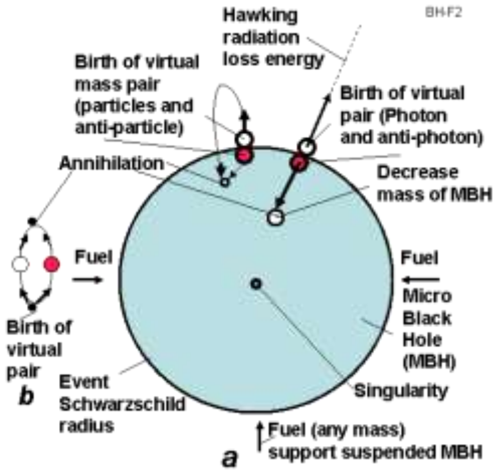

Fig.5. Hawking radiation. ***a***. Virtual particles at even horizon.
b. Virtual particles out even horizon (in conventional space).

The evaporation of a black hole is a process dominated by photons, which are their own antiparticles and are uncharged.

The uncertainty principle in the form $\Delta E \Delta t \geq \hbar$ implies that in the vacuum one or more particles with energy ΔE above the vacuum may be created for a short time Δt. These *virtual particles* are included in the definition of the vacuum.

Vacuum energy is an underlying background energy that exists in space even when devoid of matter (known as free space). The vacuum energy is deduced from the concept of virtual particles, which are themselves derived from the energy-time uncertainty principle. Its effects can be observed in various phenomena (such as spontaneous emission, the Casimir effect, the van der Waals bonds, or the Lamb shift), and it is thought to have consequences for the behavior of the Universe on cosmological scales.

AB-Generator of Nuclear Energy and some Innovations

Simplified explanation of MBH radiation and work of AB-Generator (Fig.5). As known, the vacuum continuously produces, virtual pairs of particles and antiparticles, in particular, photons and anti-photons. In conventional space they exist only for a very short time, then annihilate and return back to nothingness. The MBH event horizon, having very strong super-gravity, allows separation of the particles and anti-particles, in particular, photons and anti-photons. Part of the anti-photons move into the MBH and annihilate with photons decreasing the mass of the MBH and return back a borrow energy to vacuum. The free photons leave from the MBH neighborhood as Hawking radiation. That way the MBH converts any conventional matter to Hawking radiation which may be converted to heat or electric energy by the AB- Generator. This AB- Generator utilizes the produced Hawking radiation and injects the matter into the MBH while maintaining the MBH in stable suspended state.
Note: The photon does NOT have rest mass. Therefore a photon can leave the MBH's neighborhood (if it is located beyond the event horizon). All other particles having a rest mass and speed less than

light speed *cannot* leave the Black Hole. They cannot achieve light speed because their mass at light speed equals infinity and requests infinite energy for its' escape—an impossibility.

Description of AB- Generator. The offered nuclear energy AB- Generator is shown in fig. 6. That includes the Micro Black Hole (MBH) 1 suspended within a spherical radiation reflector and heater 5. The MBH is supported (and controlled) at the center of sphere by a fuel (plasma, proton, electron, matter) gun 7. This AB- Generator also contains the 9 – heat engine (for example, gas, vapor turbine), 10 – electric generator, 11 – coolant (heat transfer agent), an outer electric line 12, internal electric generator (5 as antenna) with customer 14.

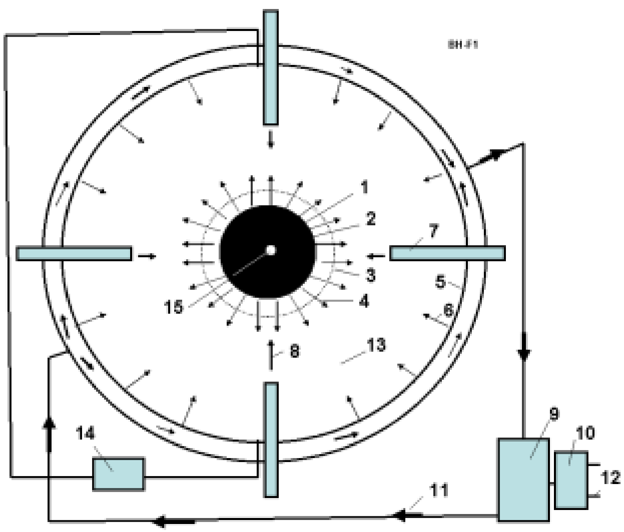

Fig.6. Offered **nuclear-vacuum energy AB- Generator**. *Notations*: 1- Micro Black Hole (MBH), 2 - event horizon (Schwarzschild radius), 3 - photon sphere, 4 – black hole radiation, 5 – radiation reflector, antenna and heater (cover sphere), 6 – back (reflected) radiation from radiation reflector 5, 7 – fuel (plasma, protons, electrons, ions, matter) gun (focusing accelerator), 8 – matter injected to MBH (fuel for Micro Black hole), 9 – heat engine (for example, gas, vapor turbine), 10 – electric generator connected to heat engine 9, 11 – coolant (heat transfer agent to the heat machine 9), 12 – electric line, 13 – internal vacuum, 14 – customer of electricity from antenna 5, 15 – singularity.

Work. The generator works the following way. MBH, by selective directional input of matter, is levitated in captivity and produces radiation energy 4. That radiation heats the spherical reflector-heater 5. The coolant (heat transfer agent) 11 delivers the heat to a heat machine 9 (for example, gas, vapor turbine). The heat machine rotates an electric generator 10 that produces the electricity to the outer electric line 12. Part of MBH radiation may accept by sphere 5 (as antenna) in form of electricity.

The control fuel guns inject the matter into MBH and do not allow bursting of the MBH. This action also supports the MBH in isolation, suspended from dangerous contact with conventional matter. They also control the MBH size and the energy output.

Any matter may be used as the fuel, for example, accelerated plasma, ions, protons, electrons, micro particles, etc. The MBH may be charged and rotated. In this case the MBH may has an additional suspension by control charges located at the ends of fuel guns or (in case of the rotating charged MBH) may have an additional suspension by the control electric magnets located on the ends of fuel guns or at points along the reflector-heater sphere.

Innovations, features, advantages and same research results

Some problems and solutions offered by the author include the following:
1) A practical (the MBH being obtained and levitated, details of which are beyond the scope of this paper) method and installation for converting any conventional matter to energy in accordance with Einstein's equation $E = mc^2$.
2) MBHs may produce gigantic energy and this energy is in the form of dangerous gamma radiation. The author shows how this dangerous gamma radiation Doppler shifts when it moves against the MBH gravity and converts to safely tapped short radio waves.
3) The MBH of marginal mass has a tendency to explode (through quantum evaporation, very quickly radiating its mass in energy). The AB- Generator automatically injects metered amounts of matter into the MBH and keeps the MGH in a stable state or grows the MBH to a needed size, or decreases that size, or temporarily turns off the AB- Generator (decreases the MBH to a Planck Black Hole).
4) Author shows the radiation flux exposure of AB- Generator (as result of MBH exposure) is not dangerous because the generator cover sphere has a vacuum, and the MBH gravity gradient decreases the radiation energy.
5) The MBH may be supported in a levitated (non-contact) state by generator fuel injectors.

Theory of AB- Generator

Below there are main equations for computation the conventional black hole (BH) and AB-Generator.

General theory of Black Hole.

1. Power produced by BH is

$$P = \frac{\hbar c^6}{15360\pi G^2}\frac{1}{M^2} \approx 3.56\cdot 10^{32}\frac{1}{M^2}, \quad \text{W}, \qquad (1)$$

where $\hbar = h/2\pi = 1.0546\cdot 10^{-34}$ J/s is reduced Planck constant, $c = 3\cdot 10^8$ m/s - light speed, G = 6.6743·10^{-11} m^3/kg.s^2 is gravitation constant, M – mass of BH, kg.
2. Temperature of black body corresponding to this radiation is

$$T = \frac{\hbar c^3}{8\pi G k_b}\frac{1}{M} \approx 1.23\cdot 10^{23}\frac{1}{M}, \quad \text{K}, \qquad (2)$$

where k_b = 1.38.10^{-23} J/k is Boltzmann constant.
3. Energy E_p [J] and frequency ν_o of photon at event horizon are

$$E_p = \frac{hc^3}{16\pi G}\frac{1}{M}, \quad \nu_0 = \frac{E_p}{h} = \frac{c^3}{16\pi G}\frac{1}{M} = 8.037\cdot 10^{33}\frac{1}{M}, \quad \lambda_0 = \frac{c}{\nu_0} = 3.73\cdot 10^{-26} M. \qquad (3)$$

where c = 3·10^8 m/s is light speed, λ_o is wavelength of photon at even radius, m. h is Planck constant.
4. Radius of BH event horizon (Schwarzschild radius) is

$$r_0 = \frac{2G}{c^2}M = 1.48\cdot 10^{-27} M, \quad \text{m}, \qquad (4)$$

5. Relative density (ratio of mass M to volume V of BH) is

$$\rho = \frac{M}{V} = \frac{3c^2}{32\pi G^3}\frac{1}{M^2} \approx 7.33\cdot 10^{79}\frac{1}{M^2}, \quad \text{kg/m}^3. \qquad (5)$$

6. Maximal charge of BH is

$$Q_{\max} = 5\cdot 10^9 eM \approx 8\cdot 10^{-10} M, \quad \text{C}, \qquad (6)$$

where e = -1.6·10^{-19} is charge of electron, C.

7. Life time of BH is

$$\tau = \frac{5120\pi G^2}{\hbar c^4} M^3 = 2.527 \cdot 10^{-8} M^3 \ ,s \ . \qquad (7)$$

8. Gravitation around BH (r is distance from center) and on event horizon

$$g = \frac{GM}{r^2}, \quad g_0 = \frac{c^4}{4G}\frac{1}{M} = 3\cdot 10^{42}\frac{1}{M}, \qquad \text{m s}^{-2} \ . \qquad (8)$$

Developed Theory of AB-Generator

Below are research and the theory developed by author for estimation and computation of facets of the AB- Generator.

9.Loss of energy of Hawking photon in BH gravitational field. It is known the theory of a redshift allows estimating the frequency of photon in central gravitational field when it moves TO the gravity center. In this case the photon increases its frequency because photon is accelerated the gravitational field (wavelength decreases). But in our case the photon moves FROM the gravitational center, the gravitational field brakes it and the photon loses its energy. That means its frequency decreases and the wavelength increases. Our photon gets double energy because the black hole annihilates two photons (photon and anti-photon). That way the equation for photon frequency at distance $r>r_o$ from center we can write in form

$$\frac{\nu}{\nu_0} \approx 1 + \frac{2\Delta\varphi}{c^2}, \qquad (9)$$

Where $\Delta\varphi = \varphi - \varphi_o$ is difference of the gravity potential. The gravity potential is

$$\Delta\varphi = \varphi - \varphi_0, \quad \varphi = \frac{GM}{r}, \quad \varphi_0 = \frac{GM}{r_0}, \quad r_0 = \frac{2GM}{c^2} \ . \ (10)$$

Let us substitute (10) in (9), we get

$$\frac{\nu}{\nu_0} \approx 1 + \frac{r_0}{r} - \frac{r_0}{r_0}, \quad \text{or} \quad \frac{\nu}{\nu_0} = \frac{\lambda_0}{\lambda} \approx \frac{r_0}{r} \ . \qquad (11)$$

It is known, the energy and mass of photon is

$$E_f = \hbar\gamma, \quad E_f = m_f c^2, \quad m_f = E_f / c^2 \ , \qquad (12)$$

The energy of photon linear depends from its frequency. Reminder: The photon does not have a rest mass.

The relative loss of the photon radiation energy ξ at distance r from BH and the power $P_r$of Hawking radiation at radius r from the BH center is

$$\xi = \frac{r_0}{r}, \quad \nu = \xi\nu_0, \quad P_r = \xi P \ . \qquad (13)$$

The $r_o$is very small and ξ is also very small and $\nu<<\nu_o$.

The result of an energy loss by Hawking photon in the BH gravitational field is very important for AB-Generator. The energy of Hawking radiation is very big; we very need to decrease it in many orders. The initial Hawking photon is gamma radiation that is dangerous for people and matter. In r distance the gamma radiation may be converted in the conventional light or radio radiation, which are not dangerous and may be reflected, focused or a straightforward way converted into electricity by antenna.

10. **Reflection Hawking radiation back to MBH**. For further decreasing the MBH produced energy the part of this energy may be reflected to back in MBH. A conventional mirror may reflect up 0.9 ÷0.99 of radiation (ξ_r= 0.01 ÷ 0.1, ξ_r is a loss of energy in reflecting), the multi layers mirror can reflect up 0.9999 of the monochromatic light radiation (ξ_r= 10^{-3}÷ 10^{-5}), and AB-mirror from cubic corner cells offered by author in [2], p. 226, fig.12.1g , p. 376 allows to reflect non-monochromatic light radiation with efficiency up ξ_r= 10^{-13} strong back to source. In the last case, the loss of reflected energy is ([2] p.377)

$$\xi_r = 0.00023al, \quad l = m\lambda, \quad m \ge 1, \qquad (14)$$

where *l* is size of cube corner cell, m; *m* is number of radiation waves in one sell; λ is wavelength, m; *a* is characteristic of sell material (see [2], fig.A3.3). Minimal value $a = 10^{-2}$ for glass and $a = 10^{-4}$ for KCl crystal.

The reflection of radiation to back in MBH is may be important for MBH stabilization, MBH storage and MBH 'switch off'.

11. **Useful energy of AB- Generator**. The useful energy P_u[J] is taken from AB- Generator is

$$P_u = \xi\xi_r P . \qquad (15)$$

12.Fuel consumptionis

$$\dot{M} = P_u / c^2 , \quad \text{kg.} \qquad (16)$$

The fuel consumption is very small. AB-Generator is the single known method in the World now which allows full converting reasonably practical conversion of (any!) matter into energy according the Einsteinian equation $E = mc^2$.

13. **Specific pressure on AB-Generator cover sphere**p [N/m^2] and on the surface of MBH $p_o$is

$$p = \frac{kP_r}{Sc} = \frac{kP_r}{4\pi r^2 c} = 2.65\cdot 10^{-10}\frac{kP_r}{r^2}, \quad p_0 = \frac{P}{S_0 c} = \frac{\hbar c^9}{15360\cdot 16\pi^2 G^4}\frac{1}{M^4} = 8.57\cdot 10^{76}\frac{1}{M^4} ,(17)$$

where $k = 1$ if the cover sphere absorbs the radiation and $k \approx 2$ if the cover sphere high reflects the radiation, *S* is the internal area of cover sphere, m^2; S_0 is surface of event horizon sphere, m^2; p_o is specific pressure of Hawking radiation on the event horizon surface. Note, the pressure *p* on cover sphere is small (see Project), but pressure p_o on event horizon surface is very high.

14. **Mass particles produced on event surface**. On event horizon surface may be also produced the mass particles with speed $V<c$. Let us take the best case (for leaving the BH) when their speed is radially vertical. They cannot leave the BH because their speed *V* is less than light speed *c*. The maximal radius of lifting r_m [m] is

$$dV = -gdt, \quad dV = -\frac{g}{V}dr = -\frac{GM}{V}\frac{dr}{r^2}, \quad r_m = \frac{2GM}{c^2 - V_0^2} = \frac{r_0}{1-(V/c)^2}, \qquad (18)$$

where *g* is gravitational acceleration of BH, m/s^2; *t* is time, sec.; r_o is BH radius, m; V_0 is particle speed on event surface, m/s^2. If the r_m is less than radius of the cover sphere, the mass particles return to BH and do not influence the heat flow from BH to cover sphere. That is in the majority of cases.

15.Explosion of MBH. The MBH explosion produces the radiation energy

$$E_e = Mc^2 . \qquad (19)$$

MBH has a small mass. The explosion of MBH having $M = 10^{-5}$ kg produces 9×10^{11} J. That is energy of about 10 tons of good conventional explosive (10^7 J/kg). But there is a vacuum into the cover sphere and this energy is presented in radiation form. But in reality only very small part of explosion energy reaches the cover sphere, because the very strong MBH gravitation field brakes the photons and any mass particles. Find the energy which reaches the cover sphere via:

$$dE = \xi c^2 dM, \quad \xi = \frac{r_0}{r}, \quad r_0 = \frac{2G}{c^2}M, \quad dE = \frac{2G}{r}MdM, \quad E = \frac{G}{r}M^2 = 6{,}674\cdot 10^{-11}\frac{M^2}{r} . \quad (20)$$

The specific exposure radiation pressure of MBH pressure p_e[N/m^2] on the cover sphere of radius *r* <r_o may be computed by the way:

$$p_e = \frac{E}{V} = \frac{3G}{4\pi}\frac{M^2}{r^3} = 1.6\cdot 10^{-11}\frac{M^2}{r^3}, \quad r > r_0 \ , \qquad (21)$$

where $V=3/4\ \pi r^3$ is volume of the cover sphere.

That way the exposure radiation pressure on sphere has very small value and presses very short time. Conventional gas balloon keeps pressure up 10^7 N/m^2 (100 atm). However, the heat impact may be high and AB- Generator design may have the reflectivity cover and automatically open windows for radiation.

Your attention is requested toward the next important result following from equations (20)-(21). Many astronomers try to find (detect) the MBH by a MBH exposure radiation. But this radiation is small, may be detected but for a short distance, does not have a specific frequency and has a variably long wavelength. This may be why during more than 30 years nobody has successfully observed MBH events in Earth environment though the theoretical estimation predicts about 100 of MBH events annually. Observers take note!

16. Supporting the MBH in suspended (levitated) state. The fuel injector can support the MBH in suspended state (no contact the MBH with any material surface).

The maximal suspended force equals

$$F = qV_f\,, \quad q = \frac{P_u}{c^2}, \quad F = \frac{P_u V_f}{c^2}, \qquad (22)$$

where q is fuel consumption, kg; $V_f$is a fuel speed, m/s. The fuel (plasma) speed 0.01$c$is conventionally enough for supporting the MBH in suspended state.

17. AB-Generator as electric generator. When the Hawking radiation reaches the cover as radio microwaves they may be straightforwardly converted to electricity because they create a different voltage between different isolated parts of the cover sphere as in an antenna. Maximal voltage which can produces the radiation wave is

$$w = \frac{\varepsilon\varepsilon_0 E^2}{2} + \frac{\mu\mu_0 H^2}{2}, \quad w = \frac{P_r}{c}, \qquad (23)$$

where w is density of radiation energy, J/m^3; E is electric intensity, V/m; H is magnetic intensity, T; $\varepsilon_0 = 8.85\times10^{-12}$ F/m is the coefficient of the electric permeability; $\mu_0 = 4\pi\times10^{-7}$ N/A^2 is the coefficient of the magnetic permeability; $\varepsilon = \mu = 1$ for vacuum.

Let us take moment when $H = 0$, then

$$E = \sqrt{\frac{2w}{\varepsilon_0}} = \sqrt{\frac{2P_r}{\varepsilon_0 c}} = 2.73\sqrt{P_r} \quad U \approx b\pi DE, \quad b = \frac{\pi D}{0.5\lambda} \le 1,$$
$$P_e \approx bP_r\,, \quad \lambda = \lambda_0\frac{r}{r_0} = 16r, \quad b = \frac{4\pi r}{16r} = \frac{\pi}{4}, \qquad (24)$$

where E is electric intensity, V/m; U is voltage of AB-generator, V; b is relative size of antenna, D is diameter of the cover sphere if the cover sphere is used as a full antenna, m; P_e is power of the electric station, W.

As you see about π/4 of total energy produced by AB-Generator we can receive in the form of electricity and (1-π/4) reflects back to MBH; we may tap heat energy which convert to any form of energy by conventional (heat engine) methods. If we reflect the most part of the heat energy back into the MBH, we can have only electricity and do not have heat flux.

If we will use the super strong and super high temperature material AB-material offered in [3] the conversion coefficient of heat machine may be very high.

18. Critical mass of MBH located in matter environment. Many people are afraid the MBH experiments because BH can absorb the Earth. Let us find the critical mass of MBH which can begin uncontrollably to grow into the Earth environment. That will happen when BH begins to have more mass than mass of Hawking radiation. Below is the equation for the critical mass of initial BH. The educated reader will understand the equations below without detailed explanations.

$$dV = gdt, \quad g = \frac{GM}{r^2}, \quad dt = \frac{dr}{V}, \quad VdV = gdr, \quad \int_V^c VdV = \int_r^{r_o} \frac{GM}{r^2} dr, \quad r_0 = \frac{2G}{c^2} M, \quad V^2 = c^2 \frac{r_0}{r},$$

$$V = c\sqrt{\frac{r_0}{r}}, \quad dt = \frac{\sqrt{r}dr}{c\sqrt{r_0}}, \quad \int_t^0 dt = \frac{1}{c\sqrt{r_0}} \int_r^{r_o} \sqrt{r}dr, \quad t = \frac{2}{3c\sqrt{r_0}}\left(r^{3/2} - r_0^{3/2}\right) \approx \frac{2r^{3/2}}{3cr_0^{1/2}}, \quad r = \left(\frac{3c\sqrt{r_0}}{2}t\right)^{3/2}, \quad (25)$$

$$r = 1.65 G^{1/2} M^{1/3} t^{2/3}, \quad \dot{M} = \frac{P}{c^2} = \frac{\hbar c^4}{15360\pi G^2} \frac{1}{M^2} = 4 \cdot 10^{15} \frac{1}{M^2}, \quad \text{for} \quad t = 1 \ s,$$

$$\dot{M}_c = \frac{4}{3}\pi r^3 \gamma = 6\pi\gamma G^{3/2} M \approx 10^{-4}\gamma M, \quad M = M_c e^{6\pi\gamma G^{3/2} t} \approx M_c e^{10^{-4}\gamma t}, \quad t = \frac{1}{6\pi\gamma G^{3/2}} \ln\frac{M}{M_c} \approx \frac{10^4}{\gamma} \ln\frac{M}{M_c},$$

where V is speed of environment matter absorbed by MBH, m/s; g is gravity acceleration of MBH, m/s; r is distance environment matter to MBH center, m; t is time, sec; $\dot{M}$ is mass loss by MBH, kg; $\dot{M}_c$ is mass taken from Earth environment by MBH, kg; γ is density of Earth environment, kg/m3; Mc is critical mass of MBH when one begin uncontrollable grows, kg; t is time, sec.

Let us to equate the mass $\dot{M}$ radiated by MBH to mass $\dot{M}_c$ absorbed by MBH from Earth environment, we obtain the critical mass Mc of MBH for any environment:

$$M_c^3 = \frac{\hbar c^4}{92160\pi^2 G^3} \frac{1}{\gamma} = 3.17 \cdot 10^{24} \frac{1}{\gamma}, \quad \text{or} \quad \gamma = 3.17 \cdot 10^{24} \frac{1}{M_c^3}, \quad (26)$$

If MBH having mass $M = 10^7$ kg (10 thousands tons) is put in water (γ = 1000 kg/m^3), this MBH can begin uncontrollable runaway growth and in short time (~74 sec) can consume the Earth into a black hole having diameter ~ 9 mm. If this MBH is located in the sea level atmosphere (γ = 1.29 kg/m^3), the initial MBH must has critical mass $M = 10^8$ kg (100 thousand tons). The critical radius of MBH is very small. In the first case ($M = 10^7$ kg) $r_o = 1.48\times 10^{-20}$ m, in the second case ($M = 10^8$ kg) $r_o = 1.48\times 10^{-19}$ m. Our MBH into AB-Generator is not dangerous for Earth because it is located in vacuum and has mass thousands to millions times less than the critical mass.

However, in a moment of extreme speculation, if far future artificial intelligence (or super-small reasoning) beings will be created from nuclear matter [3] they can convert the Earth into a black hole to attempt to access quick travel to other stars (Solar systems), past and future Universes and even possibly past and future times.

19. General note. We got our equations in assumption $\lambda/\lambda_o = r/r_o$. If $\lambda/\lambda_o = (r/r_o)^{0.5}$ or other relation, the all above equations may be easy modified.

AB-Generator as Photon Rocket

The offered AB- Generator may be usedas the most efficient photon propulsion system (photon rocket). The photon rocket is the dream of all astronauts and space engineers, a unique vehicle, which would make practical interstellar travel. But a functioning photon rocket would require gigantic energy. The AB- Generator can convert any matter in energy (radiation) and gives the maximum theoretical efficiency.

The some possible photon propulsion system used the AB –Generator is shown in Fig.7. In simplest version (***a***) the cover of AB generator has window 3, the radiation goes out through window and produces the thrust. More complex version (***c***) has the parabolic reflector, which sends all radiation in one direction and increases the efficiency. If an insert in the AB- Generator covers the lens 6 which will focuses the radiation in a given direction, at the given point the temperature will be a billions degree (see Equation (2)) and AB- Generator may be used as a photon weapon.

The maximal thrust T of the photon engine having AB- Generator may be computed (estimated) by equation:

$T = \dot{M}c$, N,

For example, the AB-generator, which spends only 1 gram of matter per second, will produce a thrust 3×10^5 N or 30 tons.

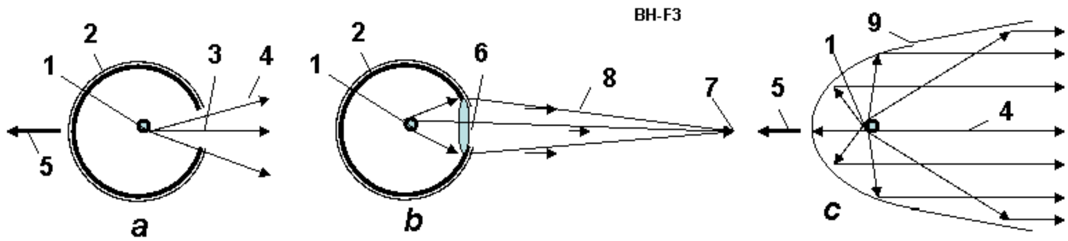

Fig.7. AB- Generator as Photon Rocket and Radiation (Photon) Weapon. (***a***) AB- Generator as a Simplest Photon Rocket; (***b***) AB- Generator as focused Radiation (photon, light or laser) weapon; (***c***) Photon Rocket with Micro-Black Hole of AB-Generator. *Notations*: 1 – control MBH; 2 – spherical cover of AB-Generator; 3 – window in spherical cover; 4 – radiation of BH; 5 – thrust; 6 – lens in window of cover; 7 – aim; 8 - focused radiation; 9 – parabolic reflector.

Short information of Photon Rockets and relativistic flight.

A photon rocket is a hypothetical rocket that uses thrust from emitted photons (radiation pressure by emission) for its propulsion [2].

Photons could be generated by onboard generators, as in the nuclear photonic rocket.

The speed an ideal photon rocket will reach, in the absence of external forces, depends on the ratio of its initial and final mass:

$$v = c\frac{(m_i/m_f)^2 - 1}{(m_i/m_f)^2 + 1}, \qquad (27)$$

where $m_i$is the initial mass and $m_f$is the final mass: $c = 3\cdot10^8$ m/s is light speed

The gamma factorcorresponding to this speed has the simple expression:

$$\gamma = 0.5(m_i/m_f + m_f/m_i) \qquad (28)$$

The **Lorentz factor** or **Lorentz term** is the factor by which time, length, and relativistic mass change for an object while that object is moving. The expression appears in several equations in special relativity, and it arises in derivations of the Lorentz transformations.

The Lorentz factor is defined as [2]

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}} = \frac{1}{\sqrt{1-\beta^2}} = \frac{dt}{d\tau} \qquad (29)$$

where: v is the relative velocity between inertial reference frames, β is the ratio of v to the speed of light c, τ is the proper time for an observer (measuring time intervals in the observer's own frame), t is coordinate time,$c = 3\cdot10^8$ m/s is the *speed of light in a vacuum*.

The Lorentz transformation**:** The simplest case is a boost in the x-direction, which describes how space-time coordinates change from one inertial frame using coordinates (x, y, z, t) to another (x' , y' , z' , t') with relative velocity v:

$$t' = \gamma\left(t - \frac{vx}{c^2}\right), \quad x' = \gamma\left(x - vt\right) \qquad (30)$$

Corollaries of the above transformations are the results:

Time dilation: The time ($\Delta t'$) between two ticks as measured in the frame in which the clock is moving, is longer than the time (Δt) between these ticks as measured in the rest frame of the clock:

$$\Delta t' = \gamma \Delta t. \quad (31)$$

Length contraction: The length ($\Delta x'$) of an object as measured in the frame in which it is moving, is shorter than its length (Δx) in its own rest frame:

$$\Delta x' = \Delta x / \gamma. \quad (32)$$

Applying conservation of momentum and energy leads to these results:

Relativistic mass: The mass of an object m in motion is dependent on $\gamma$and the rest massm_0:

$$m = \gamma m_0. \quad (33)$$

Relativistic momentum: The relativistic momentum relation takes the same form as for classical momentum, but using the above relativistic mass:

$$\vec{p} = m\vec{v} = \gamma m_0 \vec{v}. \quad (34)$$

Relativistic kinetic energy: The relativistic kinetic energy relation takes the slightly modified form:

$$E_k = E - E_0 = (\gamma - 1) m_0 c^2 \quad (35)$$

Speed (units of c)	**Lorentz factor**	**Reciprocal**
$\beta = v/c$	γ	$1/\gamma$
0.100	1.005	0.995
0.150	1.011	0.989
0.200	1.021	0.980
0.900	2.294	0.436
0.990	7.089	0.141
0.999	22.366	0.045

The Lorentz factor has the Maclaurin series:

$$\gamma = \frac{1}{\sqrt{1-\beta^2}} \approx 1 + \frac{1}{2}\beta^2 + ... \quad (36)$$

which is a special case of a binomial series.

The approximation $\gamma \approx 1 + {}^1/_2\beta^2$ may be used to calculate relativistic effects at low speeds. It holds to within 1% error for $v< 0.4$ c ($v< 120{,}000$ km/s), and to within 0.1% error for $v< 0.22\ c$ ($v<$ 66,000 km/s).

The truncated versions of this series also allow physicists to prove that special relativity reduces to Newtonian mechanics at low speeds. For example, in special relativity, the following two equations hold:

$$\vec{p} = \gamma m \vec{v},\ E = \gamma m c^2 \quad (37)$$

For $\gamma \approx 1$ and $\gamma \approx 1 + {}^1/_2\beta^2$, respectively, these reduce to their Newtonian equivalents:

$$\vec{p} = m\vec{v}\ .\ E = mc^2 + \tfrac{1}{2}mv^2. \quad (38)$$

The Lorentz factor equation can also be inverted to yield:

$$\beta = \sqrt{1 - \frac{1}{\gamma^2}} \quad (39)$$

This has an asymptotic form of:

$$\beta = 1 - \tfrac{1}{2}\gamma^{-2} - \tfrac{1}{8}\gamma^{-4} - \tfrac{1}{16}\gamma^{-6} - \tfrac{5}{128}\gamma^{-8} + \cdots \quad (40)$$

The first two terms are occasionally used to quickly calculate velocities from large γ values. The approximation $\beta \approx 1 - {}^1/_2\gamma^{-2}$ holds to within 1% tolerance for $\gamma> 2$, and to within 0.1% tolerance for $\gamma>$ 3.5.

Project of AB-Generator for Photon Rocket

Let us to estimate the possible energy production of an AB-Generator. That is not optimal, that is example of computation and possible parameters. Let us take the MBH mass $M = 10^{-5}$ kg and radius of the cover sphere r = 5m. No reflection. Using the equations (1)-(24) we receive:

$$
\begin{aligned}
&P = 3.56\cdot 10^{32}/M^2 = 3{,}56\cdot 10^{42} \quad \text{W},\\
&r_0 = 1.48\cdot 10^{-27}M = 1.48\cdot 10^{-32} \quad \text{m},\\
&\xi = r_0/r = 2.96\cdot 10^{-33},\\
&P_r = \xi P = 1.05\cdot 10^{10}, \quad P_u = \xi\xi_r P = P_r, \quad \text{W}, \quad \xi_r = 1.\\
&\lambda_0 = 3{,}73\cdot 10^{-26}M = 3.73\cdot 10^{-31} \quad \text{m}. \qquad\qquad (41)\\
&\lambda = 16\cdot r = 80 \quad \text{m}.\\
&p = \frac{P_r}{4\pi c r^2} = 0.111 \quad \frac{N}{m^2}, \quad c = 3\cdot 10^8 \quad \text{m/s},\\
&\dot{M} = P_u/c^2 = 1.17\cdot 10^{-7} \quad \text{kg/s},\\
&p_e = 1.6\cdot 10^{-11}\frac{M^2}{r^3} = 1.28\cdot 10^{-23} \quad \text{N/m}^2
\end{aligned}
$$

Remain the main notations in equations (27): $P_r = P_u = 1.05\times 10^{10}$ W is the useful energy (π/4 of this energy may be taken as electric energy by cover antenna, the rest is taken as heat); λ = 80 m is wavelength of radiation at cover sphere (that is not dangerous for people); $\dot{M} = 1.17\times 10^{-7}$ kg/s is fuel consumption; $r_o = 1.48\times 10^{-32}$ m is radius of MBH; $p_e = 1.28\times 10^{-23}$ N/m^2 is explosion pressure of MBH.

Look your attention - the explode pressure is very small. That is less in billions of time then radiation pressure on the cover surface p = 0.111 N/m^2. That is no wonder because BH takes back the energy with that spent for acceleration the matter in eating the matter. No dangerous from explosion of MBH.

Heat transfer and internal electric power are

$$
\begin{aligned}
&q = \frac{P_u}{S} = \frac{P_u}{4\pi r^2} = 3.34\cdot 10^7 \quad \frac{\text{W}}{\text{m}^2},\\
&\text{For} \quad \delta = 2\cdot 10^{-3}\ \text{m}, \quad \lambda_h = 100, \quad \Delta T \approx q\delta/\lambda_h = 668^o\text{K}, \qquad\qquad (42)\\
&E = 2.73\sqrt{P_r} = 2.8\cdot 10^5 \quad \text{V/m}, \quad U = E\cdot 2r = 2.8\cdot 10^6 \quad \text{V}, \quad P_e = P_r/8 = 1.31\cdot 10^9 \quad \text{W},
\end{aligned}
$$

where q is specific heat transfer through the cover sphere, S is internal surface of the cover sphere, m^2; δ is thickness of the cover sphere wall, m; λ_h is heat transfer coefficient for steel; ΔT is difference temperature between internal and external walls of the cover sphere; E is electric intensity from radiation on cover sphere surface, V/m; U is maximal electric voltage, V; P_e is electric power, W.

We get the power heat and electric output of a AB-Generator as similar to a very large complex of present day Earth's electric power stations ($P_r = 10^{10}$ W, ten billion of watts). The AB-Generator is cheaper by a hundred times than a conventional electric station, especially since, we may reflect a heat energy back to the MBH and not built a heat engine with all the problems of conventional power conversion equipment (using only electricity from spherical cover as antenna).

We hope the Large Hadron Collider at CERN can get the initial MBH needed for AB-Generator. The other way to obtain one is to find the Planck MBH (remaining from the time of the Big Bang and former MBH) and grow them to target MBH size.

Results

1. Author has offered the method and installation for converting any conventional matter to energy

according the Einstein's equation $E = mc^2$, where m is mass of matter, kg; $c = 3 \cdot 10^8$ is light speed, m/s.

2. The Micro Black Hole (MBH) is offered for this conversion.
3. Also is offered the control fuel guns and radiation reflector for explosion prevention of MBH.
4. Also is offered the control fuel guns and radiation reflector for the MBH control.
5. Also is offered the control fuel guns and radiation reflector for non-contact suspension (levitation) of the MBH.
6. For non-contact levitation of MBH the author also offers:
   a) Controlled charging of MBH and of ends of the fuel guns.
   b) Control charging of rotating MBH and control of electric magnets located on the ends of the fuel guns or out of the reflector-heater sphere.
7. The author researches show the very important fact: A strong gamma radiation produced by Hawking radiation loses energy after passing through the very strong gravitational MBH field. The MBH radiation can reach the reflector-heater as the light or short-wave radio radiation.
   That is very important for safety of the operating crew of the AB- Generator.
8. The author researches show: The matter particles produced by the MBH cannot escape from MBH and cannot influence the Hawking radiation.
9. The author researches show another very important fact: The MBH explosion (hundreds and thousands of TNT tons) in radiation form produces a small pressure on the reflector-heater (cover sphere) and does not destroys the AB-generator (in a correct design of AB-generator!). That is very important for safety of the operating crew of the AB-generator.
10. The author researches show another very important fact: the MBH cannot capture by oneself the surrounding matter and cannot automatically grow to consume the planet.
11. As the initial MBH can be used the Planck's (quantum) MBH which *may* be everywhere. The offered fuel gun may to grow them (or decrease them) to needed size or the initial MBH may be used the MBH produce Large Hadron Collider (LHC) at CERN. Some scientists assume LHC will produce one MBH every second (86,400 MBH in day). The cosmic radiation also produces about 100 MBH every year.
12. The spherical dome of MBH may convert part of the radiation energy to electricity.
13. A correct design of MBH generator does not produce the radioactive waste of environment.
14. The attempts of many astronomers find (detect) the MBH by a MBH exposure radiation will not be successful without knowing the following: The MBH radiation is small, may be detected only over a short distance, does not have specific frequency and has a variable long wavelength.

Discussion

We got our equations in assumption $\lambda/\lambda_o = r/r_o$. If $\lambda/\lambda_o = (r/r_o)^{0.5}$ or other relation, the all above equations may be easy modified.

The Hawking article was published 34 years ago (1974)[1]. After this time the hundreds of scientific works based in Hawking work appears. No facts are known which creates doubts in the possibility of Hawking radiation but it is not proven either. The Hawking radiation may not exist. The Large Hadron Collider has the main purpose to create the MBHs and detect the Hawking radiation.

Conclusion

TheAB-Generator could create a revolution in many industries (electricity, car, ship, transportation, etc.). That allows designing photon rockets and flight to other star systems. The maximum possible efficiency is obtained and a full solution possible for the energy problem of humanity. These overwhelming prospects urge us to research and develop this achievement of science [1]-[5].

General Discussing Parts 1- 4

Interstellar flight is impossible at current time. It is in some orders more difficult than trip to Mars. The sending of small probe to the nearest star systems “Alfa-Centauri”requests gigantic energy (about 100 powerful electric station), expensive equipment (hundreds of billions dollars) and large trip time (30 ÷ 40 years). The conventional nuclear and thermonuclear on-board reactors cannot also solve this problem. Weare hoping to find an advanced civilization that will move our technology leap. But we do not know: there is platens at nearest star systems having conditions closed to our Earth? Is there a life on these planets? What is leveltheir development? If they are above us, why do not they came to us, or at least do not send signals to us?

There are many sceptic questions. But we do not must wait, we must develop our science and technology. Early or later we reach a level when human/robot civilization colonize not only our galactic but all Universe and will create the new Universe and new intelligent civilization , higher mind [1-2].

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