N91-22181

ANTIMATTER APPLIED FOR EARTH PROTECTION FROM ASTEROID COLLISION

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ABSTRACT

An earth protection system against asteroids and meteorites in colliding orbit is proposed. The system consists of detection and deorbiting systems. The analyses are given for the resolution of microwave optics, the detectability of radar, the orbital plan of intercepting operation, and the antimatter mass required for total or partially blasting the asteroid. Antimatter of 1kg is required for deorbiting asteroid of 200 m in diameter. An experimental simulation of antimatter cooling and storage is planned. The facility under construction is introduced.

INTRODUCTION

The space activities of mankind have been supported by

1) curiosity in sense to find new laws of universe and in exploration to find new world,

and will be so in future. Another motivation of space activities especially in future is

2) desire to preserve the human race, i.e. instructive move for survival.

The second motivation may take the form of Solar Power Satellite (SPS) and human resource exploitation, i.e. helium 3. These are counter action against the energy crisis coming in future. The energy crisis is related to the expansion of human activities. On the other hand, there is another type of crisis, the natural disaster caused by asteroid collision with the earth.

Asteroids approaching to the earth have so high relative velocities about 30 km/s that the kinetic energy is extremely large even if it is much smaller than the earth. Asteroids collision with the earth result in not only the craters formation and tidal waves but also the earth environment modification. The Hiroshima atomic bomb has an energy of 10^{15}J, which corresponds to the estimated kinetic energy of a meteorite, 10 m in diameter and 5 in specific gravity. Celestial body in 10 m class crashes on the earth once every several hundreds years. It is reported that a collision with a meteorite in the Cretaceous period changed the climate and exterminated the dinosaur in the mass. The collision corresponds to 5 billion Hiroshima bombs. The asteroid collision equivalent to the dinosaur extinction happens once per 100 million years[1]. Asteroids very frequently near-miss the earth [2] as shown in Fig.1. Figure 1 is not a complete list since the asteroids in Fig.1 were accidentally observed by voluntary observers. The 1989 FC passing by the earth on March 22 in 1989, had several times as large kinetic energy as the asteroid which formed the Arizona's famous 1.2km-meteo-crater.

Antimatter annihilation propulsion for interstellar and deep space missions has been recently studied because of high energy density of antimatter-matter reactions. Most of the studies emphasize the mission analyses and the conceptual designs of antimatter engines. On the other hand, we have been studying the storage of the antimatter and considering the application of the earth protection system against asteroid collisions.

The asteroids of 10-100 m size, which had impinged in the ocean and caused global weather impact, may not be recorded in the history books.

The earth protection system presented here not only actively detects the celestial bodies approaching to the earth but also modifies their orbit. The objectives of this paper are:

1) to estimate distance to detect asteroids from the earth and remaining time before collision,
2) to estimate requirements for radar system characteristics using Very Long Base Line Interferometry (VLBI),
3) to estimate the amount of antihydrogen for the orbital modification of meteorites,
4) to examine antimatter storage,
5) to design the antimatter factory and base.

REMAINING TIME BEFORE ENCOUNTER

In order to make the analysis simple, three dimensional effects such as the inclination of the asteroid orbit are ignored. Meteorites are either comets or minor planets. Based on orbital data of comets[3], the eccentricities are found around 0.8 and the distance of perihelion ranges from 0.13 to 0.98 a.u.. Figure 2 shows the relation between the remaining time and the distance. The asteroid is assumed to move from the aphelion toward the orbit of the earth in the calculation. While the orbital radius distributes from 2 to 3 a.u. in the case of meteorites which are categorized as minor planets. It is concluded from these results that the distance to have to detect the asteroid is 1 a.u. and the remaining time before encounter is from 2 to 3 months.

RADAR SYSTEM BY VLBI

The radar system is required to detect and track an object approaching to the earth as soon as possible. Suppose the asteroid of 100 m in diameter is detected at 1 a.u. distance from the earth. A great number of celestial bodies are observed by the photographic method with large telescopes. Asteroids approaching to the earth are discovered and tracked by the radar. The precision for the tracking radar requires 0.1 nrad in angular resolution. Such a resolution can be achieved by VLBI in radio astronomy such as VSOP (VLBI Space Observatory Program) in Institute of Space and Astronautical Science (ISAS). For the purpose of determination of transmission power of microwave, wave length, diameter of antennas and baseline distance, it is assumed:

1: Antenna for microwave transmission are the same size as receptive one.
2: Receptive sensitivity is 10^{-20} W.
3: Microwave is scattered at the asteroid's surface uniformly and isotropically.
4: Reflectivity of asteroids is 0.1.

The first assumption is made only for convenience. The second precision corresponds to an observation of a radio galaxy with 1 mJy ($1\mathrm{Jy}=10^{-26}\mathrm{Wm}^{-2}\mathrm{Hz}^{-1}$) by a radio telescope which is 100 m in diameter and 100 kHz in band width[4]. The third assumption is very natural since the surface unevenness is larger than the wave length. The reflectivity of Apollo objects is assumed to be 0.1.

Now we derive the relation between the transmitted and the received power. Microwave beam diverges with transmitting distance. The theoretical minimum for beam collimation is given by [5]

$$A=\frac{4}{\pi}L^2\left(\frac{\lambda}{d}\right)^2 \qquad (1)$$

A : cross sectional area of microwave beam
L : distance between asteroid and the earth
d : diameter of transmit and receptive antenna
λ : wavelength of microwave.

The power received by the receptive antenna is given by the equation,

$$P_r=\frac{\frac{\pi}{4}D^2}{A}\cdot\frac{\delta\Omega}{4\pi}\,P_t$$

$$=\frac{\pi^2 D^2 d^4}{4^3 L^4 \lambda^2}P_t \qquad (2)$$

P_a : received microwave power
P_t : transmitted microwave power
$\delta\Omega$: solid angle of receptive antenna measured from asteroid
D : asteroid diameter

The angular resolution of VLBI can be estimated to be the order of λ/L. The power required for each satellite is about 10 kW if the millimeter wave is transmitted at 10 Hz repetition with the pulse width of 10 μs. The required characteristics of the radar system are summarized in Table 1.

Table 1: Specifications of the Radar System

diameter of asteroid	: 100 m
diameter of antennas	: 25 m
received power	: 10^{-20} W
wave length	: 0.1 mm
peak power of microwave	: 100 MW
number of transmission satellites	: 10
baseline distance	: 1000 km

As exhibited in Table 1, these satellites are only 2.5 times larger than that of the VSOP in size. The surface accuracy of the receptive antenna, however, will be required at least 2 order of magnitude higher than that in VSOP since the parabolic surface of the VSOP is controlled to maintain within the small displacement of 0.1mm. It is indicated that additional difficulties are found by the VLBI of millimeter range at present[6].

ANTIMATTER REQUIRED FOR MODIFICATION OF ASTEROID ORBIT

For small asteroids, the interceptors loaded with the antihydrogen can destroy them completely. If the asteroid is too large to be entirely exploded, it is necessary to penetrate into the celestial body and blast off the surface materials effectively. It is estimated in the case of orbital change using explosion that the energy utilization efficiency is less than 1% i.e. the ratio of the exploded mass to the remaining mass of the asteroid.

The antimatter-matter annihilation generates shock wave and produces high energy plasma at the center of the explosion. If the plasma dissipates its energy to surrounding materials efficiently lava with high energy will be blasted off. The reaction against the asteroid produces the thrust. The energy E generated by the annihilation is related :

$$E = \frac{4}{3}\pi r^3 \rho \left(\frac{\Delta V^2_{melt}}{2} + \frac{U^2}{2} \right) \qquad (3)$$

ρ : asteroid density
r : diameter of lava region (depth of penetration)
M : asteroid mass
ΔV_{melt}: effective velocity corresponding to melting energy
U : mean velocity of lava

The first term of the right hand side of Eq.(3) represents the internal energy and the second one does the kinetic energy of the lava. It is assumed that a half of the lava blasts and contributes to the orbital modification, and the rest half merely heats up surroundings. The velocity change V and the efficiency η are calculated:

$$V = \frac{E\,U}{2M\,(\,\Delta V^2_{melt} + U^2\,)} \tag{4}$$

$$\eta = \frac{E\,U^2}{8M\,(\,\Delta V^2_{melt} + U^2\,)^2} \tag{5}$$

The radius r is a control parameter of the explosion (or thrust generation). Choosing r so as to maximize the efficiency:

$$V_{opt} = \frac{E}{4M\Delta V_{melt}} \tag{6}$$

$$r_{opt} = \left(\frac{3\,E}{4\,\rho\,\Delta V^2_{melt}}\right)^{1/3} \tag{7}$$

are obtained as the optimum velocity change and penetrating depth. For example, the optimum depth is estimated to be 240 m from Eq.(7) for the antihydrogen of 1 kg.

Figure 3 shows the relation between the mass of the antihydrogen and the delta-V calculated from Eq.(4). A value of 1m/s is the minimum delta-V required for the orbital change if the orbit is modified at 1.3 a.u. distance from the sun. Generally, the minimum delta-V is a function of the orbital elements, the direction of the thrust and the distance from the earth. The closest distance between the earth and the asteroid is plotted in Fig.4 with thrusting directions as parameters. The optimum direction is either parallel or anti-parallel to the orbiting direction of the asteroid. The delta-V at $\vartheta = \pi/3$ is ten times as high as that at $\vartheta = 0$ for given distance. Figure 5 shows the closest distance as a function of delta-V on deorbiting position as parameter. The delta-V required for 1.55×10^8km is ten times as large as that for 2×10^8km. As the farther distance the orbit is modified, the smaller the delta-V is required. This means the importance of the early detection and the orbital modification as soon as possible.

ANTIHYDROGEN STORAGE

At present, antiprotons are generated by the method of a collision between a heavy metal target and a proton beam which is accelerated up to several tens of GeV or more. Reference 7 reports that 10^{11} antiprotons (~pg) are obtained per hour in Fermilab. The productive amount of the antiprotons has been increased at the rate of 10 times per 3.5 years ever since the discovery by Segre and Chamberlain so that the antiproton will be available industrially in 2020's if it monotonically increases. It is necessary that the antimatter is stored as solid antihydrogen at cryogenic temperature since the antimatter required for the orbital modification amounts to the order of kg or more as seen in Fig.3.

The storage processes are shown in Fig.6. At first, the produced antiparticles are cooled by stochastic and electron coolings[7] because antiprotons are tremendously hot just after they are generated by an accelerator. They are decelerated as slow as several keV and are turned into the antihydrogen by three body recombination with cold positrons. The unrecombined particles are cycled in the antiproton and positron rings being collimated with accelerator and electrostatic lens. The resultant antihydrogen beam is decelerated and trapped by means of laser cooling. A vacuum ultraviolet CW laser for the hydrogen cooling have not been accomplished yet, but will be put to practical use in near future with stable multi-ionized ion sources recently accomplished. Solid antihydrogen is produced from the trapped antihydrogen, and is stored electrostatically.

Experimental demonstration is in progress with respect to the recombination and the deceleration of the antihydrogen. The antihydrogen is simulated by ordinary matter argon in the experiment, since antiparticle can be regarded as particle with opposite charge without annihilation. Except for the differences in the mass and the energy level for the laser cooling, the argon in a metastable state has the advantage of being incorporated with laser diode, which has energy level related to near infrared range. The photograph of the experimental apparatus is shown in Fig.7. It consists of a plasma source which simulates a low energy antiproton beam, a recombination chamber, a cooling and trapping chamber.

ANTIMATTER FACTORY AND INTERCEPTOR BASE

Necessary conditions for establishing the antimatter factory and the interceptor base comprises[1];

1: Sufficient solar power can be easily obtained,
2: Energy to launch the interceptor is small,
3: The earth's safety is assured at an accident.

The construction of the factory farther than the Mars orbit from the sun is not beneficial since the SPS (Solar Power Satellite) collects solar energy to produce antimatter. Lagrange points of L4 and L5 between the sun and the earth have the advantage of the minimum launching energy since they are the points of the gravitational equilibrium. It is also convenient from following standpoints to construct the plant on the back side of the SPS. First, the plant is cooled down as cryogenically as the space back ground temperature of 3 K because of isolation from the solar energy flux. Second, the high vacuum environment keeps the loss rate of the stored antimatter low because of low background density, a few particles per cm^3. Even if the disaster by the annihilation occurs in the plant, the irradiation from the antimatter factory remains as low as several times of natural level at the earth with 150 million km (1 a.u.) distance between the earth and the plant[1].

Next we estimate the antimatter fuel to be changed in the interceptor. Suppose the interceptor encounters the asteroid at 200 million km from the sun in 30 days after launch. The necessary delta-V is about 30 km/s when the interceptor is launched in the same direction as the earth evolution, and about 90 km/s in the opposite direction. As for the latter mission, it is impossible for chemical rockets because of large payload mass ratio of 10^5. However, antimatter engine enables such a mission since the specific impulse can be chosen just like electric propulsion and the thrust density is as high as that of the chemical rocket. Forward[8] indicates that the payload mass ratio of the antimatter rocket do not exceed 5.

The mass of the vehicle, m_v is assumed as 1 ton including an apparatus for the antimatter storage. Energy utilization efficiency ε by the antimatter-matter reactions is assumed as 0.32. The necessary antimatter is given by[8]

$$m_a = \frac{0.39}{\varepsilon} \frac{\Delta V^2}{C^2} m_v \qquad (8)$$

m_v : mass of vehicle included an apparatus for antimatter storage
m_a : mass of antimatter propellant
ε : energy utilization efficiency by annihilation
ΔV : mission delta-V
c : speed of light

Substituting ΔV=90km/s into Eq.(8), the required amount of the antimatter is 0.1g at most, which is negligible compared with that for the orbital modification of the asteroid. The mass of the reaction fluid is 4 ton. Consequently, the launching from the antimatter base located on the Lagrange points is possible. The earth protection system is schematically shown in Fig.8.

CONCLUSION

First, necessity of the earth protection system against the meteorite collisions is investigated. The designed system consists of the VLBI radar tracking system, the antimatter plant and the interceptor to modify asteroid orbits. The radar tracking an asteroid by means of VLBI is feasible considering the state of arts of required technology. Some issues of millimeter wave remains open. An experimental simulation for the antimatter storage is introduced. It is desirable to construct the antimatter plant and the interceptor base combining the SPS at the Lagrange point. Destruction or orbital change of asteroids is concluded to be impossible without use of the annihilation energy.

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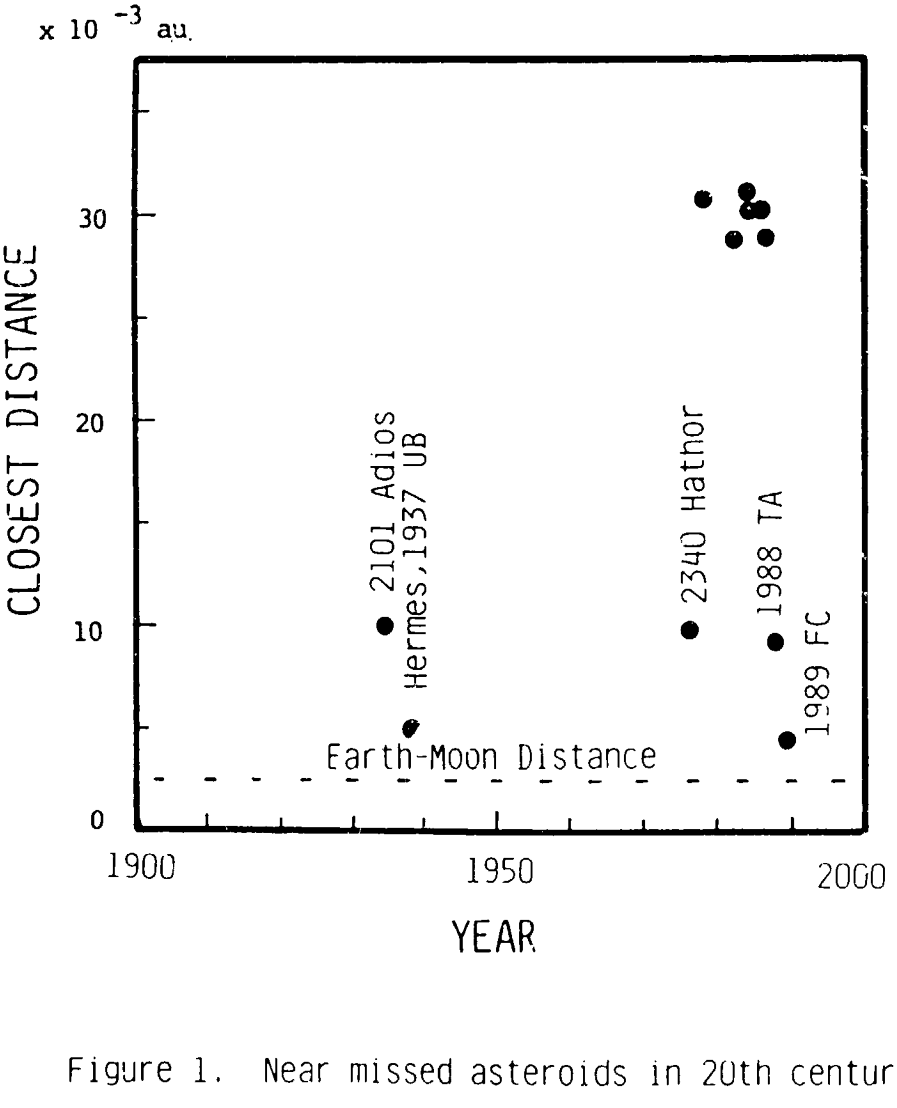

Figure 1. Near missed asteroids in 20th century

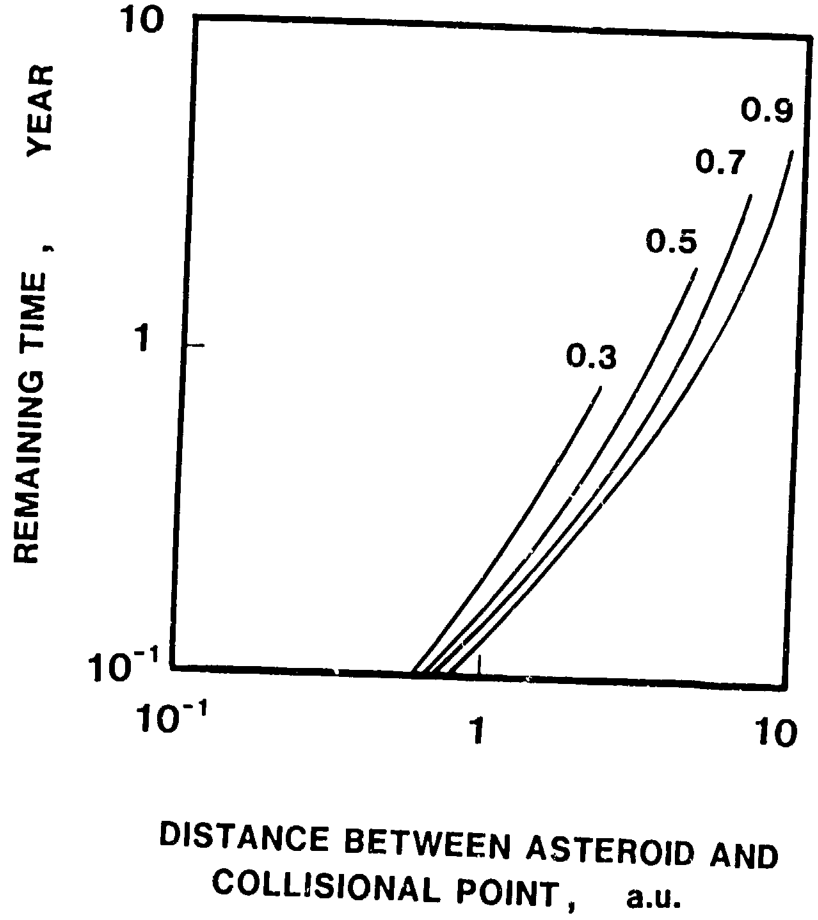

Figure 2. Remaining time before collision and periherions. The asteroid orbit with eccentricity of 0.8 is assumed.

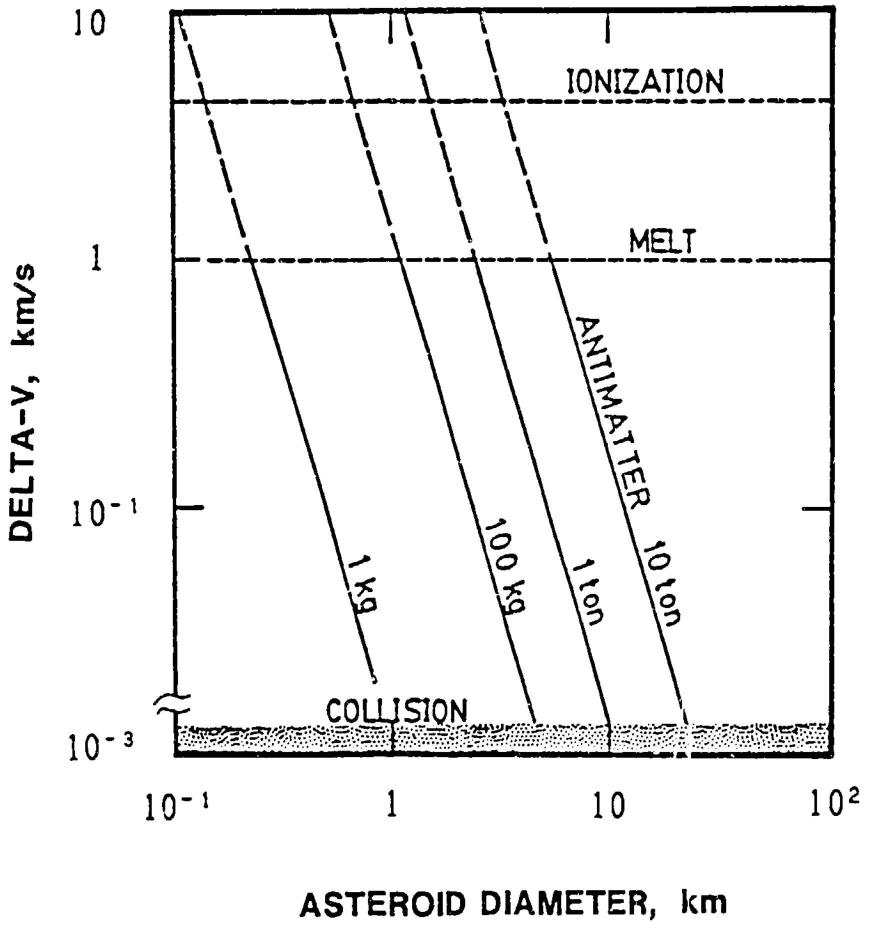

Figure 3. Delta-V and amount of antimatter. Asteroid orbit with eccentricity of 0.9 and periherion of $5x10^7$ km is modified at $2x10^8$ km distance from the sun.

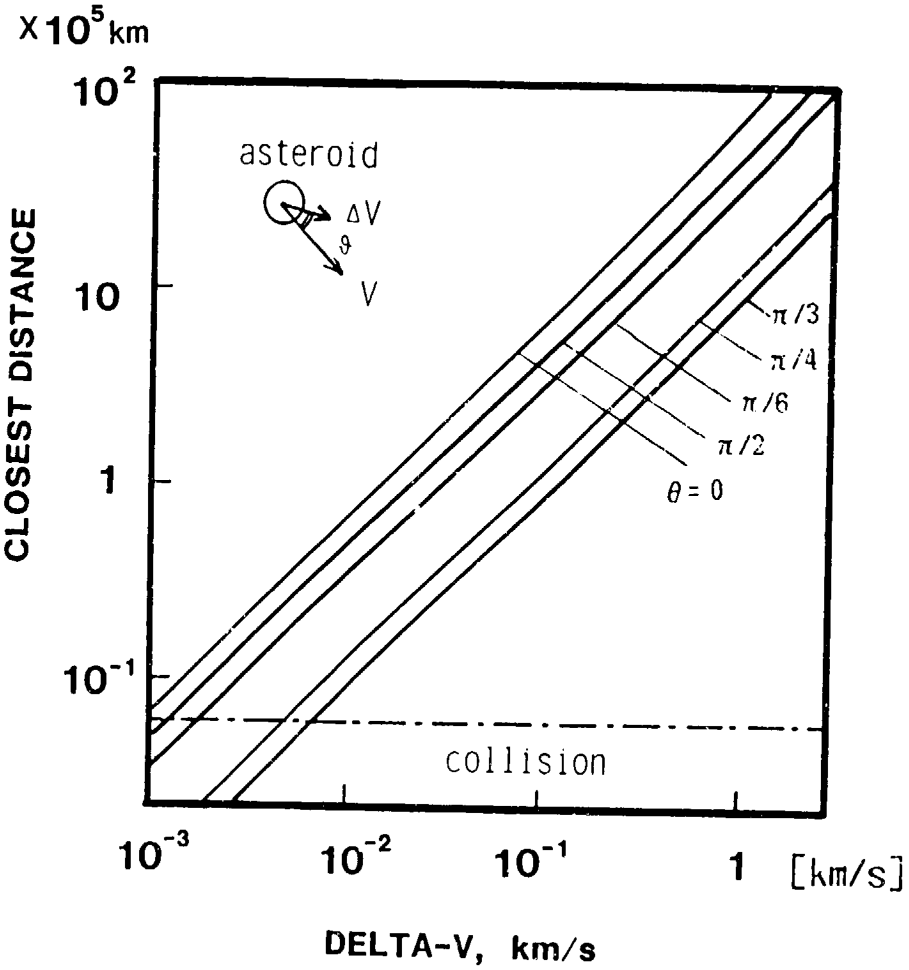

Figure 4. Closest distance from the earth and ΔV. Thrusting an asteroid is the parameter. .Eccentricity of 0.9 and periherion of 5x10^7 km, and orbital modification at 2x10^8 km distance from the sun are assumed.

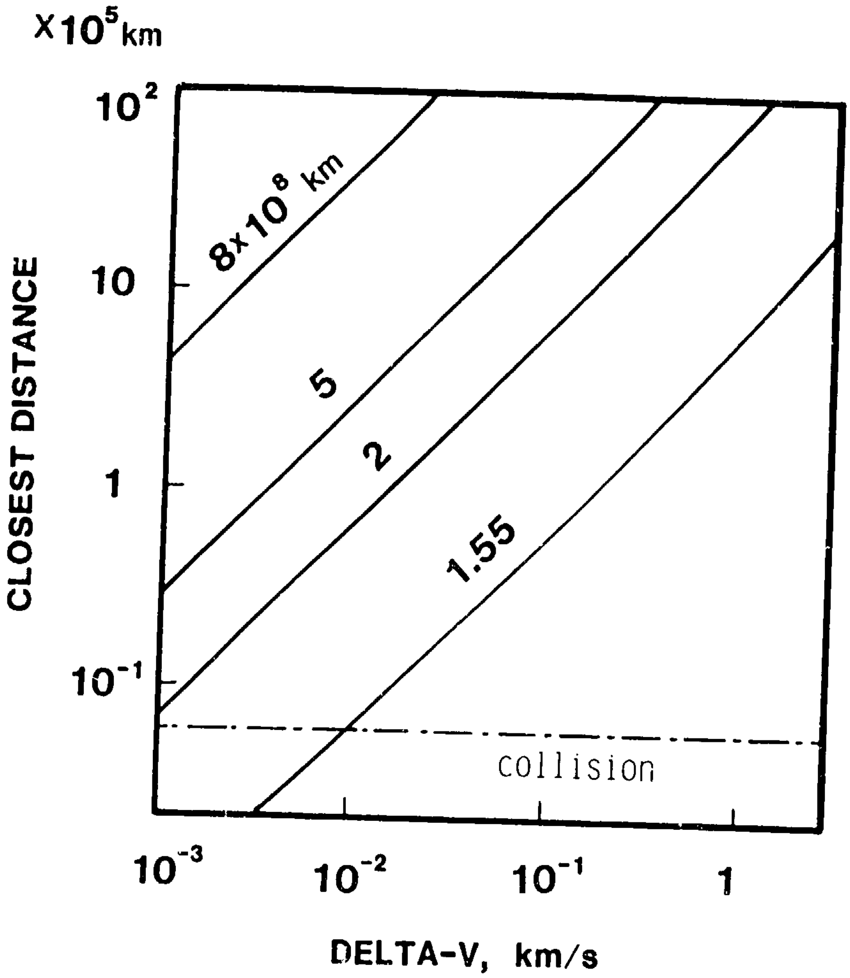

Figure 5. Closest distance from the earth and Delta-V. Position from the sun is the parameter. Asteroid orbit with eccentricity of 0.9 and perihelion of 5×10^7 km, the delta-V parallel to the proceeding direction are assumed.

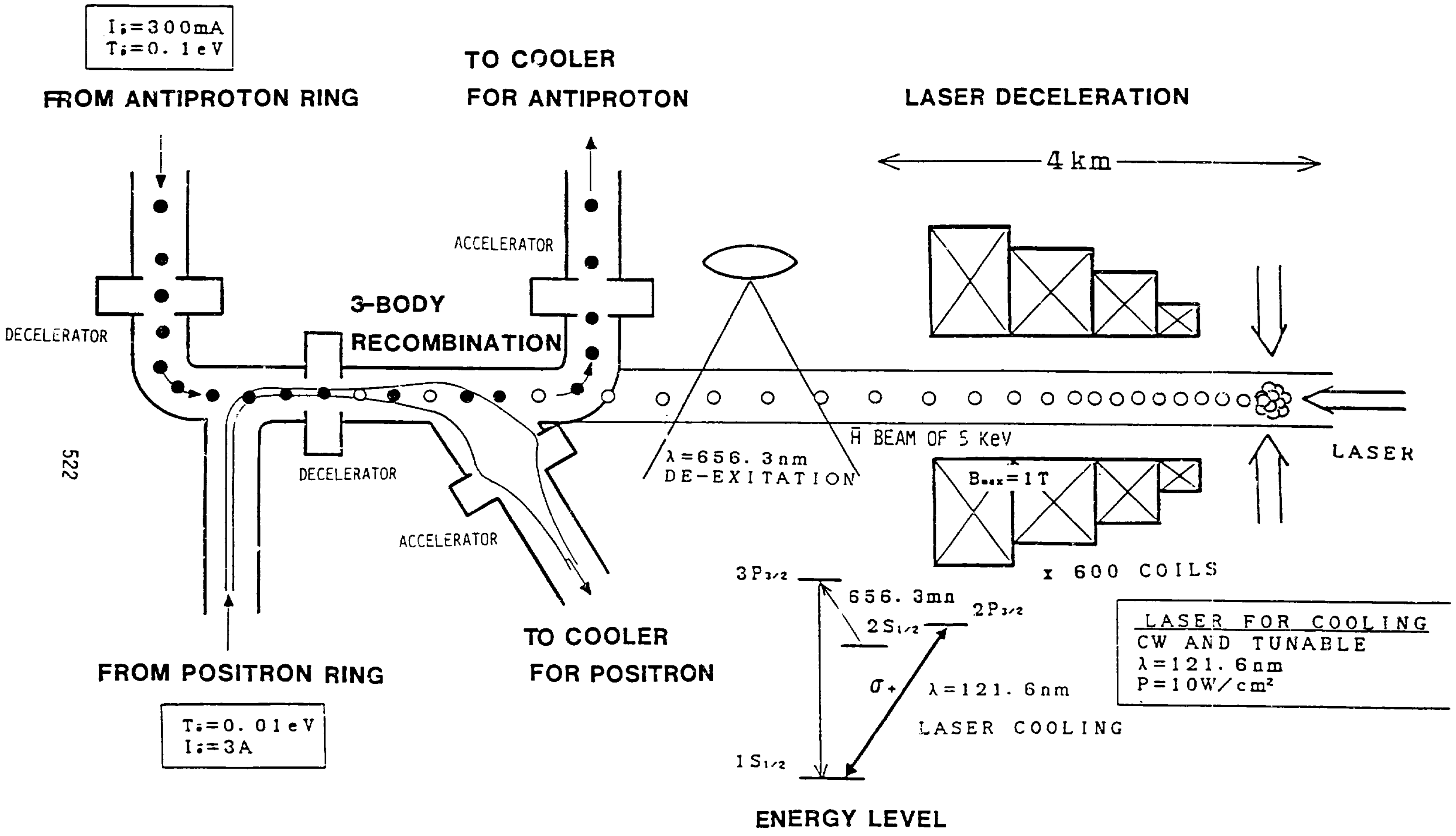

Figure 6. Antihydrogen breeder

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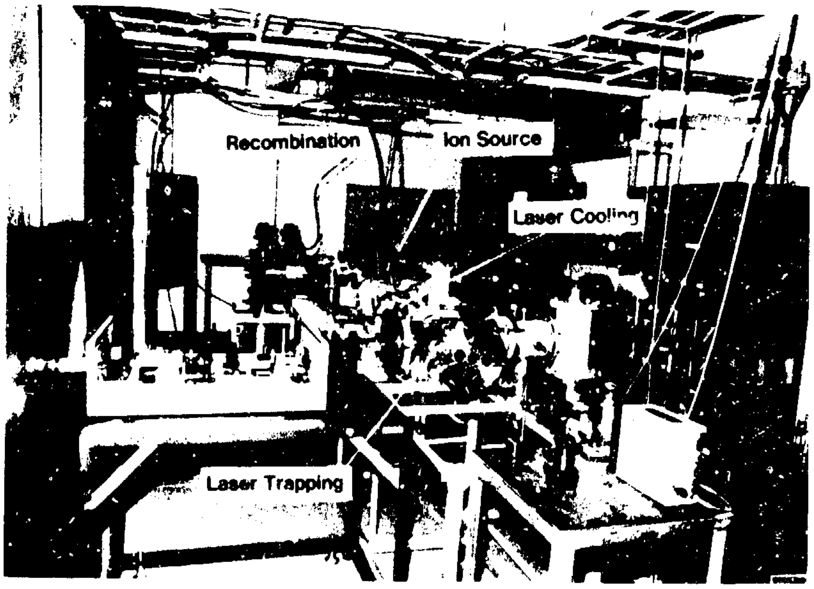

Figure 7. Experimental apparatus

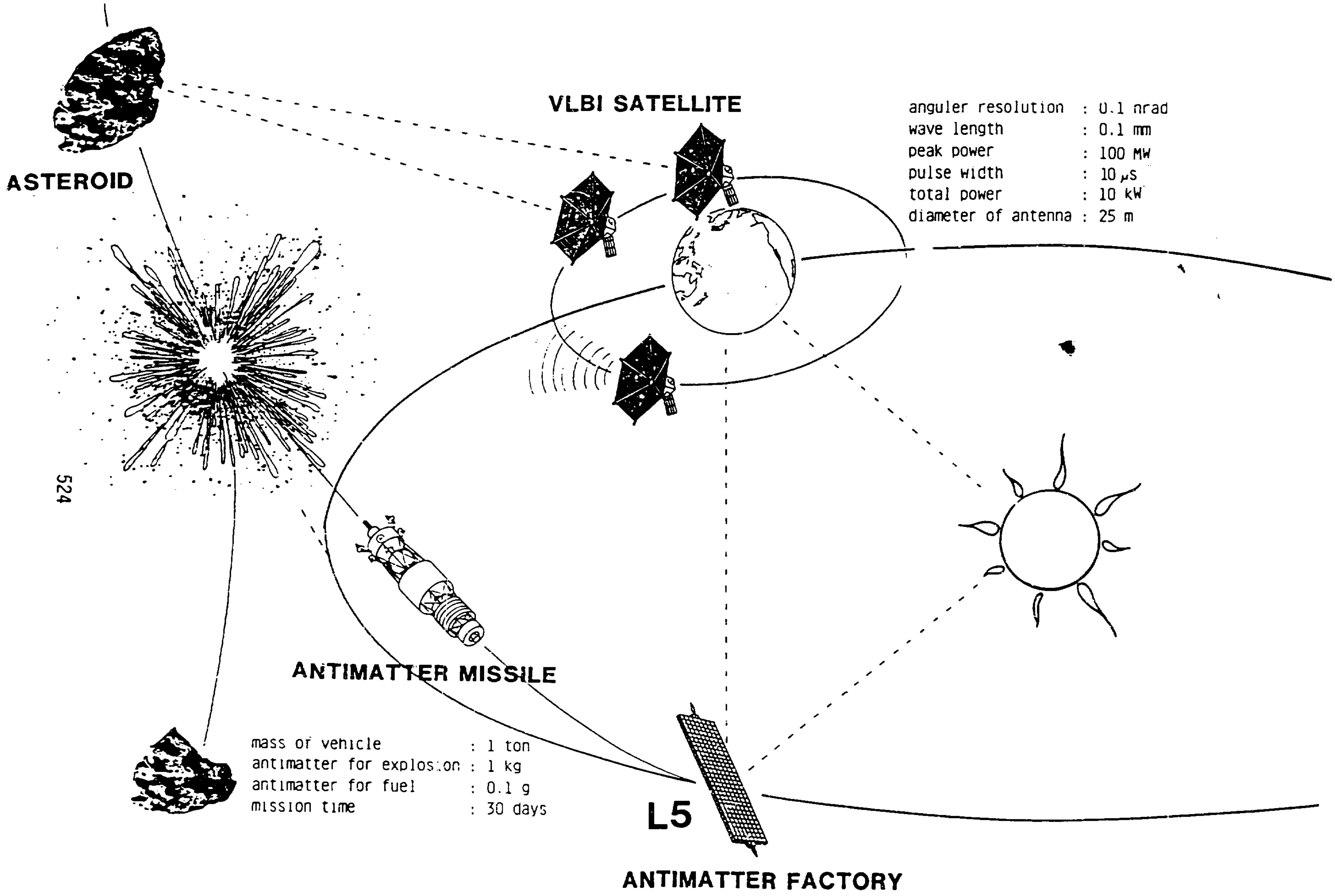

Figure 8. Earth protection system