Chin. J. Astron. Astrophys. Vol. 8 (2008), **Supplement**, 399–411
(*http://www.chjaa.org*)

Chinese Journal of
Astronomy and
Astrophysics

Asteroid Deflection: How, Where and When?

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Abstract To deflect impact-trajectory of massive and spinning km^3 asteroid by a few terrestrial radiuses one need a large momentum exchange. The dragging of huge spinning bodies in space by external engine seems difficult or impossible. Our solution is based on the landing of multi screw-rockets, powered by mini-nuclear engines, on the body, that dig a small fraction of the soil surface to use as an exhaust propeller, ejecting it vertically in phase among themselves. Such a mass ejection increases the momentum exchange, their number redundancy guarantees the stability of the system. The slow landing (below $\simeq 40\,\mathrm{cm\,s^{-1}}$) of each engine-unity at those very low gravity field, may be achieved by safe rolling and bouncing along the surface. The engine array tuned activity, overcomes the asteroid angular velocity. Coherent turning of the jet heads increases the deflection efficiency. A procession along its surface may compensate at best the asteroid spin. A small skin-mass (about 2×10^4 tons) may be ejected by mini-nuclear engines. Such prototypes may also build first safe galleries for humans on the Moon. Conclusive deflecting tests might be performed on remote asteroids. The incoming asteroid 99942 Apophis (just 2% of km^3) may be deflected safely a few Earth radiuses. Its encounter maybe not just a hazard but an opportunity, learning how to land, to dig, to build and also to nest safe human station inside. Asteroids amplified deflections by gravity swing may be driven into longest planetary journeys, beginning i.e. with the preliminary landing of future missions on Mars' moon-asteroid Phobos or Deimos.

Key words: asteroids: deflection — spin — gravity swing — nuclear energy

1 INTRODUCTION: THE ASTEROID SAFE DEFLECTION

On late December 2004 an asteroid labeled 2004 MN4, now named 99942 Apophis, has been noted as being in possible future collision trajectory with Earth on 2029 and 2037. The 2029 nearer encounter will be as near as 5 terrestrial radiuses. Therefore we shall inquire the need to divert in a decade time by the same distance an incoming spinning asteroid.

The case is now less pressing because a better trajectory knowledge reduced the future impact probability. Nevertheless the subject revived the simple question on how and when it is possible to deflect an asteroid. The possibility of an asteroid collision with Earth is usually small but, as in the past, in any near or far future it may be faced as a real threat to human life or in general to life. Here we re-derived the simplest basic law ruling the asteroid deflection, keeping in mind its very possible spinning nature, in a quite general way.

The landing of a screw-rockets array on a spinning asteroid to dig the soil, to fuel engine and to deflect its trajectory in phase, possibly while contra-rotating, is the proposal of the present paper.

In next Section 2 we show in parametric form the general deflection laws, linking energy budget, asteroid mass, jet velocity and mass to eject in a unique system. In next Section 3 we discuss why mass propulsion is much better than radiation pressure, taking into account the prompt nuclear options. In the

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main Section 4 we compare the spin energy versus the deflection one, showing the difficulty to deal with the asteroid angular momentum. We also consider the landing of the screw-engine unities and their co-operative deflecting role on the whole asteroid surface by three main processes: Array in phase, Turning Jets, Contra-rotating procession. In Section 5 we conclude that deflecting asteroids by array is possible: this effect can be amplified by gravity swing. These large deviation may drive them in space, offering a safe housing, from cosmic ray radiation flare, for human travels in far planetary spaces. Some applications to near future 99942 Apophis event are considered in conclusions section, where we present a surprising note on the key role of Phobos and Deimos (being asteroid-moons of Mars): these moons are in fact ideal guest place before Mars landing.

In late appendix (A, B, C, D, E, F) we answer to six related questions: How many Nukes for a deflection? Why Neutron Bombs are better in impulse transfer? May Asteroid be charged and deflected by Solar Lorentz Forces? Are hypothetical Anti-Asteroids deflections, by gas annihilation, observable? May fast Spinning Asteroid be break down and split in pairs? The last question is puzzling also considering the relevant spinning effect made by tidal forces while Apophis will approach at a few radius impact distance the Earth on 2029 encounter. The final and actual question is how to tag successfully Aphofis trajectory on 2017.

2 THE BASIC PARAMETRIC LAWS

We shall first summarize the equation of motion for an asteroid deflection. In the large mass limit $M_{\rm A} \gg m$ of the asteroid $M_{\rm A}$ respect the ejected fuel one m and in a non relativistic approximation for propeller velocity ($v_1 \ll c$), the main equation of motion are ruled by the needed deviation distance d (let's scale it by $5R_\oplus$), the mass of the flying object $M_{\rm A}$ (let's scale it by a km^3 water like mass or giga-ton unity) in the given time t that may be considered in a characteristic decade duration length, and also by a given total engine energy budget $E_{\rm t}$ (we compare it also with Hiroshima bomb energy unit $\simeq 10^{21}$ erg). The consequent needed asteroid acceleration ($a_{\rm Asteroid}$) is:

$$a_{\rm Asteroid} = \frac{2d}{t^2} = 6.4 \times 10^{-8}\,{\rm cm\,s^{-2}}\left(\frac{d}{5R_\oplus}\right)\left(\frac{t}{10\,{\rm y}}\right)^{-2}. \tag{1}$$

The required asteroid final velocity is:

$$v_{\rm f} = \frac{2d}{t} = 20.2\,{\rm cm\,s^{-1}}\left(\frac{d}{5R_\oplus}\right)\left(\frac{t}{10\,{\rm y}}\right)^{-1}. \tag{2}$$

The consequent required thrust (force) is:

$$\begin{aligned} F_{\rm Asteroid} &= M \cdot a_{\rm Asteroid} = \dot{m}_{\rm ejected} \cdot v_1 = 2Md \cdot t^{-2} \\ &= 640.5\,{\rm N}\left(\frac{M}{10^{15}\,{\rm g}}\right)\cdot\left(\frac{d}{5R_\oplus}\right)\cdot\left(\frac{t}{10\,{\rm y}}\right)^{-2}. \end{aligned} \tag{3}$$

This small force is comparable with a terrestrial person weight. Just to compare the above force with the one due to the radiation pressure of solar light at 1 AU over a rock sphere whose mass does correspond to a km^3 water one with a typical radius of $R = 4.51 \times 10^4$ cm, and whose disk area is $A = 0.64\,{\rm km}^2$ or more simply on an ice-like sphere asteroid whose radius is now $R = 6.2 \times 10^4$ cm, and whose disk area is $A = 1.2\,{\rm km}^2$, one finds for the latter 4.66 or 9.3 Newton, respectively for total absorption or complete retro-reflection. A possible large mirror-sail may mildly deflect the body asteroid, but the needed deflection force considered above (Eq. (3)) is at least two or three order of magnitude above the radiation one, without any consideration on the problematic about the safe holding of a sail on a spinning body. It is nevertheless worth full to consider the possible mild deflection (hundreds km size in a decade) achieved by a complete albedo change. There are at least three very different changes: *black spray painting*, *mirror layer painting* or *retro-reflector painting*. The total paint mass may reach a few tons (for few micron thickness). The eventual painting deflection, mass and operative cost maybe comparable or competitive with the Kinetic Impactor deflection Rizzo et al. (2006), but the final deflection do not reach the needed few Earth radiuses desired. Most the final kinetic energy $E_{\rm k}$, (of the total initial energy $E_{\rm t}$ stored in the rocket engines, partially dissipated in heat) resides in the fast exhausted gas mass (m), E_{k1}, ejected at velocity (v_1), while only a tiny fraction of the total kinetic energy lay in the slow asteroid, at final velocity v_f, whose final deflected momentum is $\Delta P_{Ast} = 2.018 \times 10^{16}\,\mathrm{g \cdot cm\,s^{-1}} (\frac{d}{5R_\oplus})(\frac{M}{10^{15}\,\mathrm{g}})(\frac{t}{10\mathrm{y}})^{-1}$,

$$E_{kAst} = 2.035 \times 10^{17}\mathrm{erg} \cdot \Big(\frac{d}{5R_\oplus}\Big)^2 \Big(\frac{t}{10\,\mathrm{y}}\Big)^{-2} \Big(\frac{M}{10^{15}\,\mathrm{g}}\Big). \quad (4)$$

To be more precise the exact final velocity $v_{Asteroid-final}$ derived by equation of motion for a rocket at a final mass M_f and initial one M_i ($M_f - M_i = m$) is: $v_{Asteroid-final} = v_1 \cdot \ln[\frac{M_i}{M_f}] = v_1 \cdot \ln[\frac{M_f + m}{M_f}]$, where v_1 is the emission velocity of the propeller mass m respect to the asteroid. However because $M_f \gg m$ the above linear approximation holds.

In general $\frac{E_{kAst}}{E_{k1}} = \frac{m}{M}$; for present characteristic km^3 events $\frac{E_{kAst}}{E_{k1}} = 2 \times 10^{-5}(\frac{m}{2 \times 10^{10}\,\mathrm{g}})(\frac{M}{10^{15}\,\mathrm{g}})^{-1}$. Because of momentum conservation, for any given engine efficiency η in converting into kinetic thrust the total rockets energy E_t, we have $\eta \equiv \frac{E_k}{E_t} \leq 1$ and the needed engine-jet velocity v_1 for any asteroid mass, deflection time, displacement and total energy, are bounded at once in the expression:

$$v_1 = \frac{E_t \cdot \eta \cdot t}{M \cdot d} = 9.9 \times 10^5 \mathrm{cm\,s^{-1}} \eta \cdot \Big(\frac{E_t}{10^{22}\,\mathrm{erg}}\Big)\Big(\frac{t}{10\,\mathrm{y}}\Big)\Big(\frac{M}{10^{15}\,\mathrm{g}}\Big)^{-1}\Big(\frac{d}{10\,\mathrm{y}}\Big)^{-1}. \quad (5)$$

Here we imagined a characteristic reserve energy for all the engine, of the order of $E_t = 10^{22}$ erg= 10^{15} joule unity, corresponding to nearly ten Hiroshima bomb energy which is a typical value for small size nuclear engines. The nuclear fuel engine, spread in a dozen of unities, should not exceed a few tenths of kilos each one while the nuclear core, the robotic screw engines, the tractor wheels, the thruster rockets, might be well within a half a ton mass per unit. We remind the absence of any radiative protection in these robotic unities, allowing a light unit reactor mass. The smaller and the lighter, the better. The relation between the exhaust soil kinetic and total energy conversion $E_{k_1} = 1/2 \cdot m v_1^2 = E_t \cdot \eta = 10^{22}$ erg$\cdot\eta$ and the above equation, defines the needed total propelled mass:

$$m_{ejected} = \frac{2 \cdot M^2 d^2}{E_t \cdot \eta \cdot t^2} = 2.037 \times 10^{10}\,\mathrm{g}\,\Big(\frac{M}{10^{15}\,\mathrm{g}}\Big)^2\Big(\frac{d}{5R_\oplus}\Big)^2\Big(\frac{E_t}{10^{22}\,\mathrm{erg}}\Big)^{-1}\Big(\frac{\eta}{1}\Big)^{-1}\Big(\frac{t}{10\,\mathrm{y}}\Big)^{-2}. \quad (6)$$

$$\dot{E}_{k1ejected} = \frac{E_{k_1}}{t} = 3.17 \cdot MW\Big(\frac{E_t}{10^{17}\mathrm{joule}}\Big) \cdot \Big(\frac{\eta}{1}\Big) \cdot \Big(\frac{t}{10\,\mathrm{y}}\Big)^{-1}. \quad (7)$$

By geometry, we know that the fraction of radius of the asteroid skin eroded by mass expulsion, is on average $\frac{r}{R} = \frac{1}{3}\frac{m}{M} = 0.66 \times 10^{-5} \cdot (\frac{M}{10^{15}\,\mathrm{g}})(\frac{d}{5R_\oplus})^2(\frac{E_t}{10^{22}\,\mathrm{erg}})^{-1}(\frac{\eta}{1})^{-1}(\frac{t}{10\,\mathrm{y}})^{-2}$.

Each one of the, let's say a dozen, screw-engine may eject a smaller fraction $\simeq 10\% - 20\%$ of the power above. The usually huge amount of expelled mass (assuming to be delivered to the asteroid by a chemical rockets) is too large (tens of thousands tons) and too risky (also for mini-meteorites impact) to be, in our opinion, seriously considered (nevertheless, see a different opinion in Schweickart et al. 2003). Nuclear engines may provide the main energy at a much small weight (a total few tons range) and the asteroid mass soil the main propeller thrust (at tens thousand of tons range). The wide spread in unities components and moreover their different places, guarantee the stability and the redundance of the mission.

The total consequent ejected mass rate is :

$$\dot{m}_{ejected} = \frac{2 \cdot M^2 d^2}{E_t \cdot \eta \cdot t^3} = 64.54\,\mathrm{g\,s^{-1}}\Big(\frac{M}{10^{15}\,\mathrm{g}}\Big)^2\Big(\frac{d}{5R_\oplus}\Big)^2\Big(\frac{E_t}{10^{22}\,\mathrm{erg}}\Big)^{-1}\Big(\frac{\eta}{1}\Big)^{-1}\Big(\frac{t}{10\,\mathrm{y}}\Big)^{-3}. \quad (8)$$

It should be noted the *inverse cubic dependence* with time: the faster is the needed deflection, the higher is the mass rate ejection (as well as, *inverse quadratically* total mass needed).

One may wish to reverse the above formula to derive a needed time for a deflection of a km^3 asteroid. Its characteristic value is, obviously, already calibrated to a decade. For the same power and energy in case of "light" Apophis the result becomes:

$$t = 0.737\,\mathrm{y}\sqrt[3]{\Big(\frac{\dot{m}_{eject}}{64.5\,\mathrm{g\,s^{-1}}}\Big)^{-1}\Big(\frac{M_{Apoph}}{2 \times 10^{13}\,\mathrm{g}}\Big)^2\Big(\frac{d}{5R_\oplus}\Big)^2\Big(\frac{E_t}{10^{22}\,\mathrm{erg}}\Big)^{-1}\Big(\frac{\eta}{1}\Big)^{-1}}. \quad (9)$$

The needed time to reach the object in its periodic trajectory and to land the array and to make it active should be around few years.

3 MASS PROPULSION VS RADIATION PRESSURE.

To better appreciate the efficiency of the mass ejection over *massless* explosive radiation (at same energy budget, see also Appendix A, B), it is worth-full to remind that the momentum exchange ΔP for a mass m ejected at velocity v_1 is

$$\Delta P = \sqrt{2E_{\rm t} m\eta}$$

where $\eta = \frac{E_{\rm k1}}{E_{\rm t}}$ is the total energy conversion into propeller kinetic one. Note that the above expression may be derived from both non relativistic and ultra-relativistic regime. Therefore the adimensional ratio R between the momentum exchange for the present screw model, with the help of a mass m ejected over an analogous due to radiation pressure (external nuclear explosions) with albedo $\hat{\eta}$ at same energy budget, is:

$$R = \sqrt{\frac{2mc^2\eta}{E\hat{\eta}}} = 6.32 \times 10^4 \sqrt{\left(\frac{m}{2\times 10^{10}\,\mathrm{g}}\right)} \sqrt{\frac{10^{22}\,\mathrm{erg}}{E_{\rm t}}} \cdot \sqrt{\frac{\eta}{\hat{\eta}}}. \tag{10}$$

Therefore, contrary to much written in popular science, to eject matter is much more effective (nearly five order of magnitude, as in example above) in deflecting a km^3 asteroid than any radiating propeller (Fargion 1998). External radiating atomic bomb are uneffective (see Appendix A and B). The prompt explosion of nuclear bombs on the asteroid *interior* may be as good as the screw array, but this prompt event, even if it is well projected, may lead to uncontrolled breaking into undesired asteroid fragments (Fargion 1998).

Moreover we would reconsider the screw-engine landing and mining the asteroid. Because of this low gravity the vertical propeller engine has two role: first is to eject mass and to thrust the asteroid, second is to force the engine-screw tank toward the asteroid surface. Indeed while digging or mining the surface there would be a very problematic impulse reaction back from the asteroid to the screw engine. For instance, an astronaut hitting with a fist of few joules on the asteroid ground could be sent in orbit or at infinity. Consequently we like to have a persistent engine pressure on the ground that guarantes a permanent adherence on surface, even while the screw is digging the soil (within limited pressure). Once again this force might be spread on each active engine all over the surface, leading to a tiny $\simeq 64\,\mathrm{N}$ force, corresponding about to a terrestrial $6.4\,\mathrm{kg}$ weight and (over a $\simeq m^2$ engine base area) a pressure as small as 6.4×10^2 Pa (0.6% of terrestrial atmospheric one). This thrust is well above the YORP (Yarkovsky-O'Keefe-Radzievskii-Paddack) effect phenomenon and a solar light net force (at 1 AU) on a km^2 asteroid surface, which exert a force (even for maximal albedo) higher of a few Newton. Therefore this Jet activity may rule all the predictable disturbances by nearly three order of magnitude. It should be noted that, if the asteroid is made off of pile or pieces as in a rubble pile model, than such a unit force may accelerate any smallest finite zone (let us imagine $\sim 0.001\%$ of the whole km^3 asteroid, an island block of 10^{10}g) transferring by gravity the thrust pull, as in the gravity tractor proposal Lu et al. (2005). Such a tiniest 10^{10}g fragment (let say a sphere) attracts indeed the other asteroid masses by gravity with an acceleration

$$\tilde{g} = G \cdot \left(\frac{4\cdot\pi\rho}{3}\right)^{\frac{2}{3}} \cdot m^{\frac{1}{3}} \simeq 7.06 \times 10^{-4}\,\mathrm{cm\,s^{-2}} \cdot \left(\frac{m}{10^{10}\,\mathrm{g}}\right)^{\frac{1}{3}} \cdot \left(\frac{\rho}{2.6}\right)^{\frac{2}{3}}. \tag{11}$$

Thousands of times larger that the one produced on the whole body by the desired deflection (see Eq. (1)). The body will move as a unique object. The eventual but extremely improbable deformation of a fragile asteroid surface under such a tiny pressure, can be just overcome by driving the screw-tractor elsewhere or by a physical linking the screw-engine array into a self-dragging spread web-net or wide area wheel extension. Indeed, elastic wheels should be inflated into a tubular cylinders array (long and extended), possibly linked in a tractor (like an armored tank) structure. The wheel area will spread the force and lower the pressure successfully. Anyway the free-fall or collapse on such a small gravity body is so slow (hours long) that the engines will have time to move safely. A preventive soil structure study may avoid such a surprise by the help of mini-test impact hit.

3.1 Binary Asteroid Companion: will it be Lost?

The large presence of multiple or binary companion along asteroids may lead to a question abou a safe acceleration in such binary case. As in the previous case, the slow acceleration considered for safe deflection $a_{\rm Asteroid} = \frac{2d}{t^2} = 6.4 \times 10^{-8}\,\mathrm{cm\,s^{-2}}(\frac{d}{5R_\oplus})(\frac{t}{10\,\mathrm{y}})^{-2}$, is well below the characteristic gravity on the surface (for sake of simplicity let us imagine a spherical km^3 body): $g_{\mathrm{Asteroid}} = G(\frac{4\pi\rho}{3})^{\frac{2}{3}} \cdot M^{\frac{1}{3}} = 3.28 \times 10^{-2}\,\mathrm{cm\,s^{-2}} \cdot (\frac{M}{10^{15}\,\mathrm{g}})^{\frac{1}{3}}$. It comes out that the dragging of the heaviest primary asteroid will smoothly and safely drive also the second companion as a unique object.

4 THE ASTEROID SPIN ROLE

A km^3 asteroid is in general an irregular shaped body. Because of it the sun light pressure acts a net torque on the asteroid. Because of such a YORP phenomena (Yarkovsky-O'Keefe-Radzievskii-Paddack effect) it has been early estimated (and also recently observed on 1862 Apollo spin rate Mikko 2007) that the asteroid rotation may be propelled and accelerated to the maximal angular velocity (just before to break apart). In general the angular velocity is non zero. Let us consider as first estimate a spherical prototype whose own gravity and inertial momentum is well predictable: we may estimate its own kinetic rotational energy (at critical break angular velocity or even just at a smaller Keplerian one) and compare it with the desired asteroid center of mass kinetic displacement. It is easy to show that for such critical (orbital) spinning asteroid, its rotational energy $E_{\mathrm{Ast-Rot}}$ is:

$$E_{\mathrm{Ast-Rot}} = \frac{1}{5} \cdot M^{\frac{5}{3}} \cdot \left(\frac{4\pi\rho}{3}\right)^{\frac{1}{3}} \cdot G = 2.96 \times 10^{17}\,\mathrm{erg} \cdot \left(\frac{M}{10^{15}\,\mathrm{g}}\right)^{\frac{5}{3}} \cdot \left(\frac{\rho}{2.6}\right)^{\frac{1}{3}}. \tag{12}$$

This value is comparable to the asteroid kinetic deflection energy shown before

$$E_{\mathrm{kAst}} = 2.04 \times 10^{17}\,\mathrm{erg} \cdot \left(\frac{d}{5R_{\oplus}}\right)^{2}\left(\frac{t}{10\,\mathrm{y}}\right)^{-2}\left(\frac{M}{10^{15}\,\mathrm{g}}\right),$$

and it implies an additional (at least a $\frac{5}{2}$ larger factor) energy cost and a more difficult control as in any one unique tug (Schweickart et al. 2003) engine project. Moreover because $E_{\mathrm{Ast-Rot}} \propto M^{\frac{5}{3}}$ while $E_{\mathrm{Ast-c.m.}} \propto M$ it is obvious that for large mass asteroids $\geq 1.5 - 2\,\mathrm{km}^3$ the de-spin energy request will largely exceed the deflection one. In a different and popular scenario where the deflection is due to the pulling by a sail (many square km^2 area) one faces the unavoidable problem for almost all spinning bodies, on how and where to held the thrust on such turning massive body. If we do not have stability along the principal axis it will turn out to be an almost impossible mission: there is not in general any fixed tracking point where to hang the cable to the sail (or external jet engine). We suggest to overcome the asteroid rotation disturbance by a cooperative engine action on the asteroid surface, mainly in three different (but complementary) procedures that we summarize here as: *A tuned Phase Array activity, Contra-Rotating Procession Array* and *a turning Sunflower or Earth-flower array*.

Let us first briefly describe the unity engine, the preliminary test, its parental missile structure and the individual engine landing procedure on the asteroid.

4.1 Deflecting a Spinning Asteroid: Preliminary Test

Any landing on asteroids of the main rocket array, must be preceded by precursor mini-stationary satellites whose role is to be on orbit and to inspect the soil nature, composition and structure. Assuming a few AU distances of the asteroid position, the whole preparation (first test landing, final array landing, deflection) for a km^3 size, might take a decade. Different tracking exploration will guarantee the success. The first landing of mini acoustical, radio, gamma and optical devices might better characterize the asteroid inner cohesion, as well as its exact morphological map, gravity potential and spinning behavior. An array of light retro-reflectors, mirrors and antennas may offer at best echoes tracking. Piezoelectric acoustic emitters and detectors may offer a 3D physical test of the asteroid. This preliminary study will leave an independent radio array to better communicate and a gyroscope array on the surface and on nearby asteroid-stationary orbit to track the spinning details of the body. This may be the case of Apophis, discussed also in Section 4.9 and in Appendix F.

4.2 In Flight from the Earth to an Incoming Asteroid

The flight and the landing might take place, if possible, either in one of the eventual nearby asteroid periodic Earth encounter, or viceversa for any one-way incoming impact event, by a fast reaching to the asteroid in flight, possibly accelerated by other planet's gravity bending and swinging as well as by a rapid slowing down into stationary orbit and on the soil, at lowest Kepler orbital velocities (a fraction of m s $^{-1}$); for a spherical ideal case (that maybe simply estimated) this Kepler orbital velocity is:

$$v_{\mathrm{Ast-Kepl}} = G^{\frac{1}{2}} \cdot M^{\frac{1}{3}} \cdot \rho^{\frac{1}{6}} \cdot \left(\frac{3}{4\pi}\right)^{(-\frac{1}{6})} = 38.45\,\mathrm{cm\,s^{-1}} \cdot \left(\frac{M}{10^{15}\,\mathrm{g}}\right)^{\frac{1}{3}} \cdot \left(\frac{\rho}{2.6}\right)^{\frac{1}{6}}. \quad (13)$$

4.3 The Landing of Unit Screw-Rocket Engine in a Safe Oval Airbag

We suggest to build a robotic unit (of the whole array) made as a mini "screw" tank of a few hundred kg mass or less, based on a screw-rocket structure, whose mini-nuclear engine is digging and drilling downward the soil while being ejecting it at high speed (ten km s $^{-1}$), upward into a (nearly vertical) jet beam. Such a mini nuclear engine should not be confused with much larger and heavier nuclear thermal rocket considered elsewhere for self-sustained lunch or longest planetary voyages. The center of mass of the oval airbag, guarantees a soft rolling and a vertical standing (because of low gravity $g_{\mathrm{Asteroid}} = (G\frac{4\pi\rho}{3})^{\frac{2}{3}} \cdot M^{\frac{1}{3}} = 3.277 \times 10^{-2}\,\mathrm{cm\,s^{-2}} \cdot (\frac{M}{10^{15}\,\mathrm{g}})^{\frac{1}{3}} \cdot \frac{\rho}{2.6}^{\frac{2}{3}}$) in a very slow oscillatory period (assuming a three meter oval height):

$$P = 601.1\,\mathrm{s} \cdot \left(\frac{M}{10^{15}\,\mathrm{g}}\right)^{(-\frac{1}{6})} \left(\frac{\rho}{2.6}\right)^{(-\frac{1}{3})} \left(\frac{h}{3\,\mathrm{m}}\right)^{\frac{1}{2}}.$$

Therefore the relaxation time is long and the vertical engine propulsion may increase the apparent gravity and the speed up relaxation time. The common chemical boosters might be the main carrier rocket (containing the payload of a dozen of screw-rocket unities, possibly located in two or three independent landing rocket heads). The whole parental missile will depart from the Earth surface by the usual chemical thrust engines, while in outer spaces it will be partially accelerated to high speed and decelerated by additional (few tons) power-full engines (this one using on board chemical propeller and eventual nuclear thruster).

The whole array and the parental courier engines (that will remain for control and communication in asteroid orbit) may reach a mass of nearly ten tons. Just to compare the lunar payload for the various past missions, it varied between 48 and 75 tons. The asteroid landing will occur at very low spiralling orbital speed, as small as a fraction of m s $^{-1}$. Because of it there is not need of any delicate landing procedure but just a few safe air-bags or twin halves of egg-like inflated airbags: they may allow a smooth rolling and bouncing and landing along the asteroid, leaving the engine standing vertically on asteroid surface. The expulsion of such mini-airbag, or the undressing of the egg-like landing envelope may take place once at rest at vertical position. The procedure is simple and testable on Earth (see Fig. 1).

The screw and dig procedure occurs while the engine is moving along its surface. Because of the asteroid extremely low gravity and the risk of inclined escape from the surface, we imagine a cooperative ejection (of the rocket) orthogonally to the ground, whose reaction and thrust guarantee downward pressure and complete adhesion on its asteroid surface. The landing at extremely low gravity is offered by a slow (a fraction of m s $^{-1}$) rolling of the engine inside an inflated spherical multi-layer, possibly a transparent air-bag envelope, as suggest by figure above.

4.4 The Simplest, Anrealistic, Non Rotating Asteroid

In a very rare case the asteroid is not rotating respect to the Earth; in such an ideal situation, the engines location may face (respect to us) always the same side. In this peculiar case there is a point or a slow moving region on the surface (defined by the intersection Earth-Asteroid) where to locate the propeller engines. This eventuality could be faced by an ideal array configuration clustered in a very narrow area as described, for instance, in Figure 3. There is also a very tiny, though non zero, probability that the asteroid principle inertial momentum axis and spin is located at the main symmetry axis and mostly collimated toward (or opposite to) the Earth. As before, in this very fortuitous case, the deflection maybe offered also by a few well located engines. But there are good reasons not to relay on this unprobable case.

4.5 To Compensate the Asteroid Spin: *a Tuned Phase Array Activity*

A wide and wild spinning of the asteroid, may need a random spread of screw rocket engines on the asteroid surface; these rockets will switch their engines at given synchronous times in analogy of our Earth human

Fig. 1 The multi-layer oval envelope that will be inflated around the screw-engine at the landing time, offering a safe bouncing, rolling and a final standing up on the asteroid soil. The egg-like bag, possibly made by twin-vertical slice component, will be safely abandoned on the ground or deflated on the engine sides.

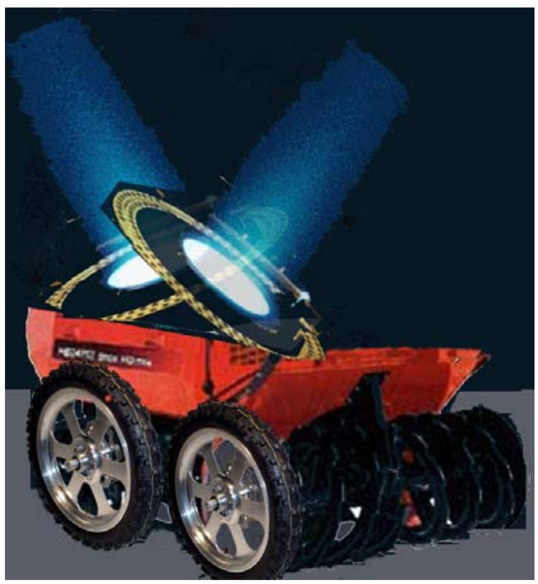

Fig. 2 The screw-engine tractor might bend partially its jet directions, leading to a wide angle sky coverture. This angle (related to the friction coefficient μ) is: $\theta \leq \arctan \mu$). It may guarantee the inclined emission within a narrow or wide solid angle $\Omega = \pi\theta^2$).

cities, that switch on the lights while in the night time: so the rocket-screw engines will act every time is facing, for instance, the Earth (as in the simplest case).

The multi jet action at synchronous phase will cope with the asteroid rotation and it will push coherently to a needed direction. This procedure imply dead time for most of the engines and it may reduce the whole thrust efficiency. However, the engines reside within their nearby landing places and do not move much far away on the asteroid surface. Moreover, the estimated energy of thrust engines may be considered as an average one: therefore the whole mass and energy output in above equations remain the same ones. The eventual need of contemporaneous ejection of a number inclined engines-jet at different angle α may reduce by a factor $\cos(\alpha)$ the whole output efficiency. For a maximal spread of $\Delta\alpha = 60^\circ$ the efficiency will be within a factor of a half. Figure 4 describes the possible set up of a large array distributed either at will or in a random way. The possible turning of the engine beam jet pointing (as Sun-flower or better as an *Earth-Flower*) makes the efficiency larger while a partial engine array procession, discussed below, might also increase the efficiency back to the unit (see Fig. 2).

4.6 A *Contra-rotating Procession Array*

In the case of a safe mobility on the asteroid, the mini-screw-engines may follow or trace a *road-map* on the asteroid surface whose trajectory is defined by the intersection of the line from the Earth to the Asteroid center of mass, with the asteroid surface. This *road-map* might be a point (or a small circle) on the body tip if the asteroid is spinning along a principal axis who is, at the same time, pointing toward the Earth, as discussed above. In general it may be a ring or arrays of rings defining a *road-map* possibly never returning at the same starting points. A slow procession of the screw engines may always stand in the optimal place in axis with Earth-C.M. (Center of Mass of the Asteroid, see Fig. 5).

4.7 *A turning Sunflower or Earth-flower jet array*.

If the surface of the asteroid with the screw engines, and its tires, offer a large friction coefficient (as on terrestrial soil), $\mu \simeq 0.5 - 1$, than the jet propulsion may be turned not just vertically to the surface, but also at moderate inclined zenith angle: $\theta \leq \arctan\mu$. For the values $\mu = 0.5 - 1$ the consequent sky coverture by jet bending becomes: $\frac{\Delta\Omega}{\Omega} = \frac{\pi(\arctan\mu)^2}{4\pi} \simeq 5.4\%$ and 15.5% of all the sky or at least $\Omega \geq 0.679\,\mathrm{sr}$. The inverse of these fractions (respectively 18.5 and 6.45 defines the number of unities to complete 4π sky coverture. In general a dozen of engines may be a quite reasonable number. It is the jet bending (for instance as an Earth flower mode) that may thrust the asteroid leading to the persistency of the array unity all over the flight; an additional slow contra-rotating procession (as prescribed above) may better optimize the cooperative action of the array (see Fig. 2).

4.8 The First Useful Mining on the Moon

The test of robotic screw-tractors on the Moon is a first goal: such a robotic array on lunar soil may mine and provide first galleries and tunnels for human station and shielding for permanent biophysical and human scientific laboratories. The eventual small nuclear pollution on empty moon will not induce relevant problems; the quality test for the automated system will be a very important step for a permanent landing and stay on our natural satellite.

4.9 A pro-po of 99942 Apophis and Swing Gravity: a Hazard or an Opportunity?

(99942) Apophis (previously known by its provisional designation 2004 MN4) is a near-Earth asteroid; in future is expected to reach an impact Earth distance on 2029 of 0.0002318 Astronomic Unit ($34.700\,\mathrm{km}$) forcing to a question of hazard and urgency, calling for the feasibility of needed deflection. The above formulas have been advocated for a km^3 rarest masses, while the Apophis one is much smaller, nearly 2×10^{13}g, or 50 times less the considered unite mass. Therefore the deflection ability considered for km^3 case is nearly 2500 the needed one for Apophis and the mass request may be reduced to a smaller fraction (just a few tens tons). This mass maybe evacuated by micro nuclear screw-engines, whose weight may be extremely light. A few terrestrial radius deflection means a great opportunity: to use the Earth (or Venus or any planet) gravity swing at our will. Indeed the gravity swing (even its General Relativity extension) may amplify the future trajectory by wide spreading angle (Fargion 1981):

$$\Delta\varphi = 2 \cdot \frac{GM_\oplus}{c^2}\frac{1+\beta^2}{b\beta^2},$$

where β is the incoming-out-coming asteroid velocity at infinity in c unite, b is the impact distance, M is the bending body. For the Apophis visit this angle value is:

$$\Delta\varphi \simeq 15.2^\circ \cdot \Big(\frac{v}{10\,\mathrm{km\,s^{-1}}}\Big)^{-2}\Big(\frac{5R_\otimes}{b}\Big).$$

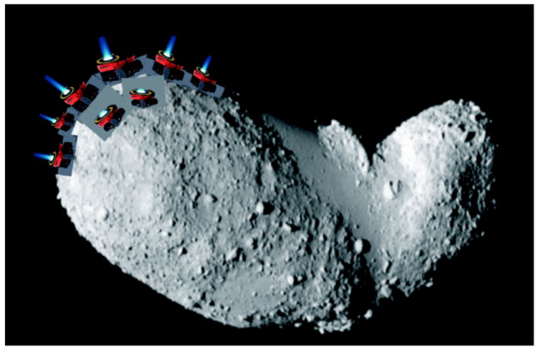

Fig. 3 A non rotating or a spinning asteroid in axis toward the Earth, may offer the simplest solution of a clustering of a few screw-engine in a well defined area, as described in figure. In principle it may exist just a point on the surface, connecting a line from the Earth toward the asteroid center of mass intersecting the body surface; however, even in the most optimistic configuration, this point by slow orbital spin will define at best a small area where to locate the engines.

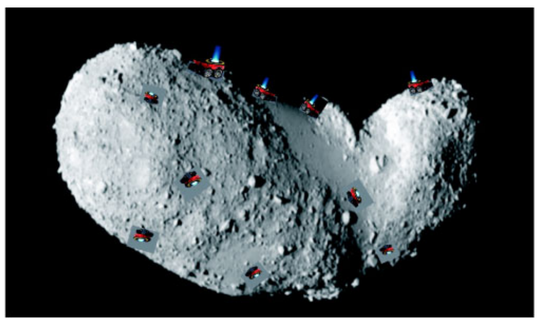

Fig. 4 A number of screw-engine tractor might activate the jet in phase compensating its rotation; an additional bending of its directions is leading to a better coherent thrust. The total number required is related to complete sky coverture. The bending angle (related to the friction coefficient μ) is: $\theta \leq \arctan \mu$ and it depends on the screw-engine material over the asteroid one). It may guarantee the inclined emission within a solid angle ($\Omega = \pi\theta^2$).

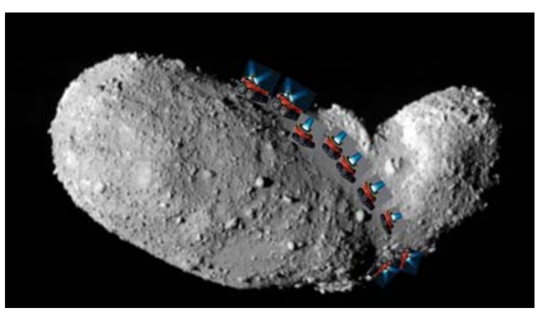

Fig. 5 A procession of the screw-engine jet leading to a coherent thrust contra-rotating and vanishing the asteroid spin.

Because of the large deflection b may be changed by a factor 2–3 leading to a wide solid angle where the asteroid might be driven. Assuming a general maximal deflection (at 2.5 terrestrial radius) the whole solid angle is 7% of the whole sky. A large window of opportunity into space.

5 CONCLUSIONS: AMPLIFIED ASTEROIDS DEFLECTION BY GRAVITY SWING TO DRIVE THEM IN SPACE

A safe and successful asteroid deflection (a few Earth radius) finds a solution by the landing of an array of screw-robotic engines (at best of nuclear nature) able to co-work in phase, keeping care of the body rotation. Such an array maybe used to create a first gallery net inside the Moon to guest permanent human laboratories. Exploiting mini asteroids, driving them by array engines at highest speed (also aided by planetary gravitational swing) may offer a novel safe shielding for future human interplanetary flight. Indeed the proliferous presence of incoming smaller asteroids NEO (at 20 meter size) may allow fastest deflections. Indeed for the lighter the body (not billions, like km^3 but few tens thousands tons) the larger is the final velocity achieved. $v_{\mathrm{Asteroid-final}} = 10\,\mathrm{km\,s}^{-1}\frac{v_1}{10\,\mathrm{km\ s}^{-1}}\ln[\frac{M_\mathrm{i}}{M_\mathrm{f}}]$; if the final mass is , for an example, half of the initial one, than the final velocity maybe $v_{\mathrm{Asteroid-final}} = 6.93\,\mathrm{km\,s}^{-1}\frac{v_1}{10\,\mathrm{km\ s}^{-1}}$; therefore it could be possible to drive the asteroid to a planet gravity swing able to deflect and accelerate the asteroid to highest velocities in solar system. It maybe possible to project a *hijack* of nearby small asteroid deflectable toward Mars. The inner (few meters under-ground) spaces of the asteroids may offer a safe container for biological eco-system and even human room able to survive longest trip screened by most dangerous cosmic rays radiations. Indeed the largest solar flare threat (often taking place in a few years duration) may lead to a lethal radiation dose to astronauts. The procedure maybe experienced on nearby Earth Object (NEO) or on far Jove (a few km^3) captured asteroids: S/2003 J12 19002480; S/2003 J9 22441680.

The Apophis near encounter at few terrestrial radius deflection means a great opportunity: to use the Earth gravity swing at our will. It is not yet clear if the deflection may point to Mars, but probably it maybe forced to Venus. Indeed the gravity swing may amplify the future trajectory by wide spreading angle and the asteroid mass may be the novel niche where life may travel into inter-planetary spaces. Or at least asteroid mass is a reserve where to pick up propeller (dust) to feed and fuel spacecraft jet engines. In this view and because of the low gravity and a low cost docking on asteroids, it is preferable to first land on a large asteroids (tens of thousand km^3) like Phobos or on Deimos, than on Mars itself. There are very good reasons why these asteroids, may guest in the inner core the first human station in martian space, from where to visit, time to time, the main planet. Therefore small and large asteroids may be the courier, the shielding, the refueling station and the host for new human steps into deep space.

Acknowledgements The author wish to thank Dr. Aiello that suggested the subject in Appendix B, as well as Drs. O. Lanciano, P. Oliva, F. La Monaca for useful discussions and M. Farina, for a mathematical control. The paper is devoted to the memory of Margherita Habbib Fargion, born on 12 May 1923, and Yakov Evron Abudi, lost on 1 May 2007.

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Appendix A: HOW MANY NUKES FOR AN ASTEROID DEFLECTION?

One would like to compare the needed Screw-engine output

$$\dot{E}_{\text{k1ejected}} = \frac{E_{\text{k}_1}}{t} = 3.17 \cdot MW\left(\frac{E_{\text{t}}}{10^{17}\,\text{joule}}\right) \cdot \left(\frac{\eta}{1}\right) \cdot \left(\frac{t}{10\,\text{y}}\right)^{-1}, \tag{A.1}$$

as well as its total energy $E_{\text{t}} = 10^{22}\text{erg}/\eta$ (ten Hiroshima bomb energy or a week of large nuclear, GW power activity) versus a competitive *external* nuclear blast prompt deflection.

One should note that radiation being massless, for a same energy content, offer much less momentum than a mass with same kinetic energy. Moreover the spherical atomic blast momentum, to be captured at most, might explode nearby the asteroid: its huge consequent thermal inhomogeneity and corresponding momentum impulse $E_{\text{HiroshimaBomb}}/c = 3.33 \times 10^{10}\,\text{g cm s}^{-1}$ might break down the body integrity. Anyway the total needed momentum $\Delta P_{\text{Ast}} = 2.018 \times 10^{16}\,\text{g cm s}^{-1}(\frac{d}{5R_\oplus})(\frac{t}{10\,\text{y}})^{-1} \cdot (\frac{M}{10^{15}\,\text{g}})$, might be reached by

$$N_{\text{HiroshimaBomb}} = 6 \times 10^5.$$

Such a huge explosion might be occurring coherently or might be beamed as a plane wave, possibly each one, by an ad hoc paraboloid $\simeq$ km^2 sail-mirror, whose structure, nevertheless will be immediately evaporated by the explosion. Otherwise nearly a million coherent bombs in half a sphere should explode in phase and time on the desired asteroid side. This configurations seem unrealistic and nevertheless very risky because of very probable fragmentation.

Appendix B: WHY NEUTRON BOMBS TRANSFER LARGE IMPULSE?

Neutron bombs, also called enhanced radiation bombs (ER weapons), are small nuclear or thermonuclear weapons in which the burst of neutrons generated by the fusion reaction is intentionally not absorbed inside the weapon, but allowed to escape. Because a large fraction of the explosion is focused into baryons of mass m (and not in radiation) the courier momentum is higher than in radiating nukes (the effect grows with the square root of the mass). The exchanged momentum is: $\Delta P = \sqrt[2]{2mE}$. For instance for a neutron bomb mass m as large as 20 kg, at a smaller energy (nearly two k-ton TNT) will eject almost 2×10^{12} g cm s^{-1} momentum, nearly a hundred times larger than the previous case. Moreover the same result maybe enhanced by an order of magnitude if the ER loaded mass is as large as 2 ton. Such a deflection may lead to a prompt deflection speed for incoming Apophis asteroid (2% of km^3 mass) as large as 1 cm s^{-1}, corresponding to a deflection in a decade scale of nearly 3000 km distance. Therefore even if quite dangerous because of possible asteroid fracture, the mass loaded nuclear bombs (ER) are an interesting options for fast deflections. However the neutron-bomb lifetime is limited because they are composed by tritium, which has a half-life of 12.3 years. In such a long journey it maybe a problem or an handicap. However to make the effect larger one may imagine to use larger asteroid skin mass, as indeed in the case of the explosion inside the asteroids (Fargion 1998). However with more danger on the asteroid structure survival. In the same view our present screw-array nuclear engines are doing the same procedure in a longer but much more controlled way : for a nominal asteroid mass ejected $m = 2 \times 10^{10}$ g, and a total energy $E_{\text{t}} = 10^{22}$ erg, comparable to ten Hiroshima bombs, for a km^3 mass asteroid prototype, we recover exactly the same result as for screw array considered in the text.

Appendix C: MAY ASTEROID BE CHARGED AND DEFLECTED BY LORENZ FORCES ?

It is in principle interesting to consider the deflection of an asteroid by charging its surface (by ionic emission) and by bending its trajectory because coherent solar magnetic field. This procedure , while being elegant do not guarantee the needed bending as well as the solar magnetic field coherence. Nevertheless just to have a first estimate we compare the needed Charge for a force with the maximal Lorenz one derived in maximal solar field:

$$Q_{\text{Asteroid}} \cdot B_{\text{Solar}} \cdot \overline{v}_{\text{Asteroid}} = F_{\text{Asteroid}} = M \cdot a_{\text{Asteroid}}$$

$$= 2 \cdot M \cdot d \cdot t^{-2} = 640.5\,\text{N}\left(\frac{M}{10^{15}\,\text{g}}\right) \cdot \left(\frac{d}{5R_\oplus}\right) \cdot \left(\frac{t}{10\,\text{y}}\right)^{-2}$$

From here one derives:

$$Q_{\rm Asteroid} = 6.4\times10^{6} C\Big(\frac{M}{10^{15}\,{\rm g}}\Big)\cdot\Big(\frac{d}{5R_{\oplus}}\Big)\cdot\Big(\frac{t}{10\,{\rm y}}\Big)^{-2}\Big(\frac{B_{\odot}}{10^{-4}\,{\rm Gauss}}\Big)^{-1}\Big(\frac{\overline{v}_{\rm Asteroid}}{10\,{\rm km\,s^{-1}}}\Big)^{-1}. \quad \text{(C.1)}$$

The charge will lead to a highest potential on the Asteroid surface (here assumed spherical) whose capacity is $C = 4\pi\epsilon R_{\rm Asteroid} \simeq 5.17\times10^{-8}\cdot\sqrt[3]{\frac{M}{10^{15}\,{\rm g}}}\big(\frac{\rho}{2.6\times10^{3}\,{\rm kg\cdot m^{-3}}}\big)^{-\frac{1}{3}}$;

$$\Delta V = (\Delta Q)/C \simeq 1.23\times10^{14}\Big(\frac{M}{10^{15}\,{\rm g}}\Big)^{\frac{2}{3}}\cdot\Big(\frac{d}{5R_{\oplus}}\Big)\cdot\Big(\frac{t}{10\,{\rm y}}\Big)^{-2}\Big(\frac{B_{\odot}}{10^{-4}{\rm Gauss}}\Big)^{-1}\Big(\frac{\overline{v}_{\rm Asteroid}}{10\,{\rm km\,s^{-1}}}\Big)^{-1}\cdot V.$$

The needed energy to charge such a huge net charge over the asteroid is prohibitive:

$$E_{\rm Charge-Asteroid} = 3.9\times10^{27}\,{\rm erg}\Big(\frac{M}{10^{15}\,{\rm g}}\Big)^{\frac{5}{3}}\cdot\Big(\frac{d}{5R_{\oplus}}\Big)^{2}\cdot\Big(\frac{t}{10\,{\rm y}}\Big)^{-4}\Big(\frac{B_{\odot}}{10^{-4}\,{\rm Gauss}}\Big)^{-2}\Big(\frac{\overline{v}_{\rm Asteroid}}{10\,{\rm km\,s^{-1}}}\Big)^{-2}. \quad \text{(C.2)}$$

This extreme values is nearly 4×10^{6} Hiroshima bomb energy and it does not guarantee the needed deflection road; indeed one may imagine, in principle, a controlled charge change along the asteroid trip, as well as a verified and controlled solar magnetic field map, at each stages. It is surprising and exciting to imagine the electromagnetism dominance over the gravitational trajectory of a massive body. Because of the energy $E_{\rm Charge-Asteroid}$ dependence on the asteroid mass exponent, $\frac{5}{3}$, versus the linear dependence in screw-array procedure, at lowest masses (a few hundred tons asteroids) the procedure maybe in principle of interest. But such bodies are already safely evaporated in atmosphere. Indeed at lightest edges, charged particles like cosmic rays follows the Lorentz forces more than gravity ones.

Appendix D: ARE ANTI-ASTEROIDS ANOMALOUS DEFLECTIONS OBSERVABLE?

In our Universe and also in our galaxy and solar system there might be present a tiny relic antimatter trace. There are ongoing experiment (AMS) in space looking for primordial anti-nucleolus relic in cosmic rays (AMS Collaboration 2007). The possibility that such larger block, as anti-meteorites, maybe crossing our space and hit Earth, Moon , Sun and planets has been widely investigated (Fargion-Khlopov 2003). This possibility is strongly constrained by the absence of γ mini-burst on Moon, Earth, Jove and Sun. However there are on-going projects to detect eventual anti-helium in cosmic rays. In this view there is an additional argument regarding the eventual rare presence of anti-asteroid (mostly mini-ones) whose trajectory in solar system maybe disturbed by gas matter annihilation on antimatter along their flight trajectory. Even if the amount of energy annihilated at km^2 in ten year period is comparable to the one considered to power the screw-engines the final momentum exchange is negligible: this is because the radiation pressure is much less effective in making force than mass expulsion. Indeed the annihilating nucleons are producing four-five ultra-relativistic pions whose behavior is comparable to massless radiation. Being the effect of annihilation proportional with the surface the total effect is independent on size; however along solar or planet's atmosphere the higher gas density and the anti-matter higher annihilation leads to observable enhanced repulsion or bouncing ruling the antimatter trajectory (Fargion-Khlopov 2003). Therefore one cannot use eventual anomalous asteroid trajectory in solar system to infer or speculate on their eventual anti-matter nature.

Appendix E: MAY FAST SPINNING ASTEROID BROKEN DOWN AND SPLIT IN PAIRS?

The existence of fast spinning asteroids, whose rotational energy may exceed the total kinetic one for a complete deflection, inspire a process that convert this ready spinning energy into a translational kinetic one. The process, eventually aided by a central breaking explosion, may divert two main fragment approximately at their extreme rotational speed (tens of cm s^{-1}), converting part of the present rotational energy into prompt twin kinetic ones (just a few tens of cm s^{-1}). In the most urgent eventuality it is possible to induce such a splitting deflection, by the same screw-engine array thrust and torques, spinning up the body to its maximal angular velocity. In an ideal longitudinal asteroid the break event might be also induced by a central nuclear belt array coherently exploding. Such a twin fragment deflection while being the fastest solution it is still a very risky process: the eventual multi fragment and the uncontrolled fragment size break and velocity may generate undesired consequences. It is nevertheless the fastest deflection that in some extreme case might be taken into consideration. An interesting speed up maybe obtained in slower, but cheaper and coherent way by an asymmetric painting of the body, exploiting the solar radiation pressure (see Lowry et al. 2007) and the YORP phenomena (Yarkovsky-O'Keefe-Radzievskii-Paddack effect).

Appendix F: HOW TO TAG APOPHIS TRAJECTORY ON 2017

One of the simplest and cheapest way to follow the Apophis trajectory with high accuracy is to land or to put in its orbit a precise clock-radio-transmitter: its battery will be fed by solar array, its output will economize by bursting emission (via beamed array) to Earth direction in synchronous coherent radio-wave (nominal duration 100 nanosecond); this timing , like in Pollicino tale story, in a precise correlation with a terrestrial twin clock, will mark the asteroid distance (z depth) from Earth. Every lapse period (hours) will trace the depth distance with necessary accuracy: indeed the present cesium (or even better) atomic clock may tag the time within an error below a second every million years. Such a timing accuracy may guarantee a distance of an error dispersion (for a decade time) of 10 microseconds, corresponding to a distance below 3 km, offering better than three sigma longitudinal distance evaluation (12 km). However the relativistic delay dilution due to radio-clock traveling velocity $\simeq \frac{\beta^2_{\mathrm{Asteroid}-\oplus}}{2} \simeq 8 \times 10^{-8}$ must be estimated, counted out, or emulated and subtracted; for instance by twin clock in peculiar comparable trajectories (for instance in tuned Jove orbit). To obtain a precise angular resolution the signal, for instance at 30 Gigahertz band, might be recorded, by interference, from largest allowable edges. Simultaneous observation of a radio source with the Halca satellite and the ground VLBI network makes possible to obtain images with the same angular resolution as images obtained with a single dish as large as the maximum distance. This distance is about twice the Earth diameter. The consequent angular resolution $\leq 10^{-9}$ rad, makes easy to tracks within one km the Apophis transverse distance $(x - y)$, offering as for the depth z an accurate track of the asteroid position.

A better depth tag z maybe achieved via echoes timing, where the clock radio tag emit an automatic burst message replying to a trigger terrestrial one. Half of the two way time multiplied the velocity of light define the Asteroid distance. No relativistic correction are needed. In this scenario however the radio-clock should be also a very good receiver, making it a much sophisticated and heavier object. Both the system may be applied for a most stable system and a better position evaluation.