How Masers can remove the Geostationary Satellites

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This paper provides a realistic approach to *remove* end of life *geostationary satellites* and GEO orbital debris into geostationary orbit (GEO), using ground-based *masers*. This method can also be used to put spatial probes and spacecrafts in orbit of the Moon, and also in orbit of the planets of the solar system, launching these artifacts from an Earth orbit.

Key words: Removal of Geostationary Satellites, Space debris, Masers, Gravity, Gravitational Shielding.

1. Introduction

The geostationary orbit (GEO) contains a multiplicity of communication satellites, but also military satellites and several new ones are being launched each year. At the end of their operational lives they must be removed in order to reduce the possibility of collisions. Debris from collisions in GEO do not decay from orbit due to atmospheric friction, and therefore present a permanent collision hazard for spacecrafts. The NASA, AFRL, DARPA, and the aerospace community have significant interest in removal inactive GEO satellite and GEO debris. Unfortunately, the capability to remove these debris is limited. Options are costly or not feasible [1, 2].

This paper provides a realistic approach to solving the GEO orbital debris removal problem, using ground-based *masers*.

2. Theory

The outer Van Allen radiation belt is a layer of energetic charged particles (plasma) existing around the Earth. The large outer radiation belt is almost toroidal in shape, extending from an altitude of about 6,600-60,000 km above the surface. The trapped particle population of the outer belt is varied, containing electrons and various ions. *Most of the ions are in the form of energetic protons* (H^+)* . The high-energy of these ions confer to them an extremely high *mobility*.

Mobility μ is defined for any species in the gas phase, encountered mostly in *plasma* physics, as: $\mu = q/m\nu_m$ where q is the charge of the species, ν_m is the momentum transfer collision frequency, and m is the mass.

Mobility is related to the species' *diffusion coefficient* D_E † through an exact (thermodynamically required) equation known as the Einstein relation [4, 5]:

$$\mu = \frac{q}{kT} D_E \qquad (1)$$

where k is Boltzmann's constant; T is the absolute temperature.

In the case of two gases with molecules of the same diameter d and mass m (self-diffusion), the diffusion coefficient is given by [6, 7]

$$D_E = \tfrac{1}{3}\lambda v_T = \frac{2}{3}\sqrt{\frac{k^3}{\pi^3 m}}\frac{T^{3/2}}{Pd^2} \qquad (2)$$

where P is the pressure, λ is the mean free path, and v_T is the mean thermal speed.

By substitution of Eq. (2) into Eq. (1), we get

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* It is generally agreed that the main constituent of the atmosphere at great heights above the Earth (>1,500km) is *hydrogen* (H^+) [3].

† We use the notation D_E for the *diffusion constant* in order to differentiate from the power density D, used in Eq. (1).

$$\mu = \frac{2q}{3Pd^2}\sqrt{\frac{kT}{\pi^3 m}} \qquad (3)$$

It is known that at 36,000 km above the Earth's surface (GEO) the temperature is about 1000ºK, the density is about $10^{-18}\,kg.m^{-3}$ [8, 9] and the pressure is about $10^{-11}\,N/m^2$ ‡. Substitution of these values into Eq. (22) gives $\mu \approx 10^{13}\,m^2.V^{-1}.s^{-1}$.

The conductivity can be expressed by $\sigma = \rho_e\mu_e + \rho_i\mu_i$, where ρ_e and ρ_i express respectively the concentrations (C/m^3) of electrons and ions; μ_e and μ_i are respectively the mobilities of the electrons and the ions.

In the case of the region considered at the exosphere, we get $\rho_e \cong \rho_i = (N_0\rho/A)e \approx 10^{-10}C/m^3$ ($N_0 = 6.02\times10^{26}\,atoms\,/\,kmole$ is the Avogadro's number; $\rho \approx 10^{-18}\,kg.m^{-3}$ is the density; $A \cong 1$ is the molar mass of the hydrogen, and e is the elementary electric charge) and $\mu_e \cong \mu_i = \mu \approx 10^{13}m^2.V^{-1}.s^{-1}$ (Given by Eq. (3)). Thus, we can assume that the conductivity σ of this region is given by

$$\sigma \cong 2\rho_i\mu_i \approx 10^3\,S/m \qquad (4)$$

Therefore, when an electromagnetic radiation with frequency f passes through the mentioned region of the outer Van Allen belt, the gravitational mass, m_g, of this region decreases, according the following expression [10]:

$$m_g = \left\{1 - 2\left[\sqrt{1 + \left(\frac{\mu_0\sigma D}{4\pi\rho\, cf}\right)^2} - 1\right]\right\} m_{i0} \qquad (5)$$

where μ_0, σ and ρ are respectively the magnetic permittivity of free space, the electrical conductivity and the density of the region; D is the electromagnetic energy density in the region produced by the radiation with frequency f.

‡ For $T \approx 1000K$ and $\rho \approx 10^{-18}\,kg.m^{-3}$ the *Equation of State* tells us that the pressure is $\approx 10^{-11}\,N/m^2$.

It was shown that there is an additional effect - *Gravitational Shielding* effect - produced by a substance whose gravitational mass was reduced or made negative [10]. This effect can be expressed in the following form: if the *gravity* upon a particle in a side of the mentioned substance is g then the gravity upon the same particle, in the opposite side of the substance is $g' = \chi g$, where $\chi = m_g/m_{i0}$ (m_g and m_{i0} are respectively, the gravitational mass and the inertial mass of the substance). Only when $\chi = 1$, the gravity is equal in both sides of the substance.

Thus, when the radiation passes through the mentioned region of the outer Van Allen belt, it is transformed into a Gravitational Shielding (See Fig.1) where χ is given by

$$\chi = \frac{m_g}{m_{i0}} = \left\{1 - 2\left[\sqrt{1 + \left(\frac{\mu_0\sigma D}{4\pi\rho\, cf}\right)^2} - 1\right]\right\} \qquad (6)$$

By substitution of the values of $\mu_0 = 4\pi\times10^{-7}\,F/m$, $\sigma \approx 1000\,S/m$ and $\rho \approx 10^{-18}\,kg.m^{-3}$ into the equation above, we get

$$\chi = \left\{1 - 2\left[\sqrt{1 + 10^{11}\left(\frac{D}{f}\right)^2} - 1\right]\right\} \qquad (7)$$

Then, for a radiation flux with $f = 1.4GHz$ and $D \cong 10^4\,W/m^2$, the result is

$$\chi \cong -2 \qquad (8)$$

Thus, if a ground-based maser emits a radiation flux, with the characteristics above, and this flux reaches a satellite in the outer Van Allen belt, then the region below the satellite (See Fig.1) becomes a *gravitational shielding* with $\chi \cong -2$. Consequently, the gravity acceleration upon the satellite (due to the Earth) becomes *repulsive* and given by $g' \cong -2g$. Obviously this acceleration will remove the satellite from its orbit, and it will be launched in the interplanetary space.

Similarly, it will be also possible to put spatial probes and spacecrafts in orbit of the Moon, and also in orbit of the planets of the solar system, launching these artifacts from an Earth orbit. It is easy to see that, in this case, the radiation flux with $f = 1.4GHz$ and $D \cong 10^4 W/m^2$ can be optionally emitted from the own spatial probe or spacecraft. In addition, a plasma cloud can also be emitted, in order to interact with the radiation flux, producing an "artificial" gravitational shielding similar to that produced in the outer Van Allen belt (See Fig.2).

Masers with the characteristics above ($f = 1.4GHz$ and $D \cong 10^4 W/m^2$) already can be produced with today's technology [11]. Thus, this is a feasible method that can be used to solve the GEO orbital debris removal problem, having moreover several others applications.

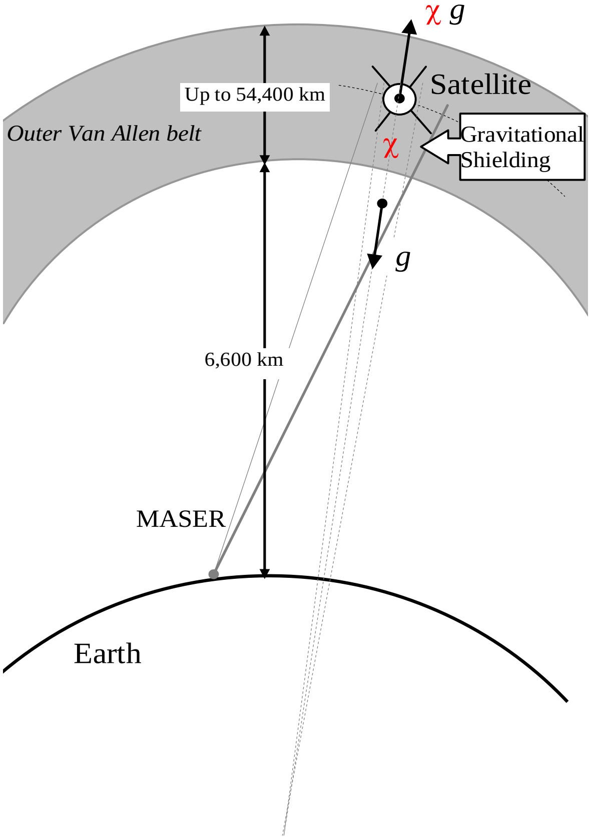

Fig. 1 - A realistic approach to *remove* end of life *geostationary satellites* and GEO orbital debris into geostationary orbit (GEO), using ground-based MASERS.

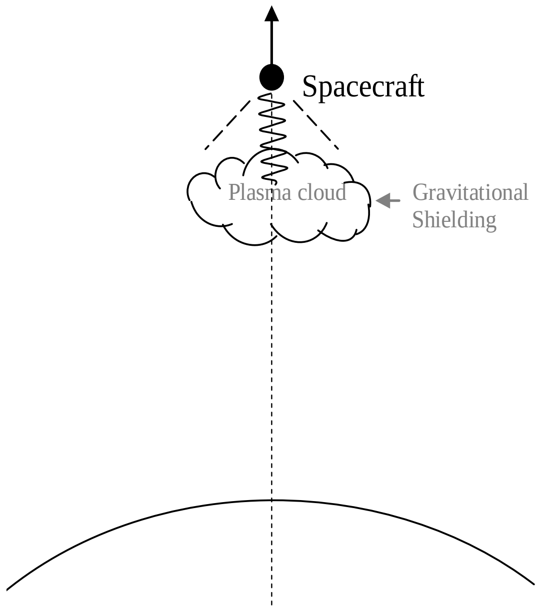

Fig.2 - A plasma cloud can also be emitted, in order to interact with the radiation flux emitted from the spacecraft, producing an "artificial" gravitational shielding similar to that produced in the outer Van Allen belt.

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