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P3_1 On the feasibility of neutrino sails

R.H. Peck, H.W. Buttery, C.D.Y. Moore, C.J. Middleton

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

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Abstract

In this paper we consider whether a neutrino sail, a sheet of material absorbing neutrinos and gaining thrust from their momentum change, is a viable method of spacecraft propulsion. We calculate an upper bound for the thrust that could be achieved per unit area and compare this to that possible using a photon solar sail. We also calculate the thickness of sail necessary assuming that there are no special conditions under which the cross section for neutrino interactions with nuclei can be increased. We find that a thickness of 34000 light years would be necessary if a sheet of Osmium were used, whereas neutron star matter could achieve this at 189 km thickness. We conclude that a neutrino sail is not a practical method of propulsion.

Introduction

Solar sails are a means of spacecraft propulsion which rely on radiation pressure from photons reflecting off a large surface to generate thrust. In this paper we consider whether it would be possible to devise a similar system using the pressure of absorbed neutrinos, and whether such a system would give any advantages over a photon solar sail. We use as a model a neutrino sail capable of absorbing 90% of the neutrino flux upon it.

Neutrino flux

Inside the Sun the fusion reactions responsible for generating the Sun's power output also generate neutrinos, which quickly escape the Sun. The proton-proton (p-p) chain, responsible for the majority of fusion reactions in Sun-like stars, emits two neutrinos for each helium nucleus created. Other fusion cycles, such as p-e-p, are very rare and can be neglected[1]. The overall reaction liberates 27 MeV of energy[2]. Given the Sun's total power output of 3.83×10^{26} W[3] this results in the release of 1.8×10^{38} neutrinos s^{-1}. At the radius of Earth's orbit this gives a flux of 6.4×10^{14} neutrinos $m^{-2}s^{-1}$.

Neutrino pressure

By assuming that all the neutrinos produced by the p-p chain are at their peak energy of 400 keV[4] we can put an upper bound on the sail's thrust per unit area. 400 keV is the total energy including both the rest mass energy and kinetic contributions. For relativistic particles momentum p and energy E are related by Eq. (1).

$$E^2 = (pc)^2 + (m_0 c^2)^2 [3] \quad (1)$$

The rest mass m_0 of a neutrino is a topic of ongoing research. However, for the purposes of this calculation it makes little difference whether the rest mass is zero or merely very small. In either circumstance the 400 keV energy is great enough that the equation tends towards $E = pc$. Thus the momentum of such a neutrino is $\sim$

2×10^{-22} kg ms^{-1}. The pressure P_n upon a sheet of material absorbing 90% of incident neutrinos per unit area n, each with momentum p in time t is given by Eq. (2). n/t is the neutrino flux, and was calculated previously.

$$P_n = \frac{0.9np}{t} \tag{2}$$

We find that neutrino absorption generates $P_n = 1.3 \times 10^{-7}$ Pa at Earth orbit.

Sail thickness

Estimates of the mass per unit area of the sail can also be made. The cross section for neutrino interactions, σ, is $\sim 10^{-49}$ m^2 [5]. To model the absorption in the sail we use Eq. (3)

$$I = I_0 e^{-n\sigma x}[6] \tag{3}$$

where I is the neutrino flux at depth x into the sail and I_0 is the neutrino flux at the Sun facing surface of the sail. Table 1 gives the thicknesses x and masses per unit area M/A required for $I = 0.1\, I_0$, 90% absorption, in materials of different number density n as determined using Eq. (3).

Material	n **(m^{-3})**	x**(m)**	M/A**(kg m^{-2})**
Osmium	7.15×10^{28}[3]	3.22×10^{20}	7.27×10^{24}
Nuclear matter	1.22×10^{44}[3]	1.89×10^{5}	4.37×10^{22}

Table 1: The required thicknesses of sails made of Osmium and Nuclear matter (density of a neutron, e.g. Neutron Star material). x is dependent on the number density of the material but M/A can only be decreased by having less mass per scattering centre. x data and M/A data were found by calculation.

It can be seen in Table 1 that for Osmium, a thickness of around 34000 LY is required, whereas for nuclear matter, a thickness of 189km is required. In the Osmium case the inverse square law will significantly further reduce the neutrino flux. For the context of this paper it is suffice to say that the sail required if this extra loss is accounted for will be even thicker.

Comparison with a photon solar sail

For radiation pressure on a reflecting surface we use Eq. (4)

$$P_s = \frac{2I_s}{c}[3] \tag{4}$$

with P_s as the pressure, I_s the flux and c the speed of light. The flux of Sunlight at Earth's orbit is 1370 W m^{-2} [3], hence the pressure on a photon sail will be 9.13×10^{-6} Pa.

Conclusion

We have shown that a photon sail gives 70 times the thrust per unit area than the upper bound of what a neutrino sail could reach, and that if using nuclear matter, a neutrino sail will need a mass per unit area of 4.37×10^{22} kg m^{-2}, whereas using Osmium 7.27×10^{24} kg m^{-2} is needed. Compared to the mass per unit area of 7×10^{-3} kg m^{-2}[7], which is proposed for mylar solar sails, the neutrino sail appears absurdly massive as well as lacking in thrust. It is concluded that as it gives less thrust per unit area than a solar photon sail and would require an utterly prohibitive mass to absorb the neutrinos, the neutrino sail concept does not seem to merit any further study as a means of spacecraft propulsion.

References

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