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Acta Astronautica 57 (2005) 59–64
ACTA ASTRONAUTICA
www.elsevier.com/locate/actaastro

Academy transactions note

Radioactive decay to propel relativistic interstellar probes along a rectilinear hyperbolic motion (Rindler spacetime)

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Received 2 October 2003; accepted 1 February 2005
Available online 21 April 2005

Abstract

In this academy transactions note, we study a type of relativistic interstellar flight that would enable an unmanned space probe to reach the nearest stars in a few decades' time. "Time" here means "proper time", that is the time aboard the probe, a little shorter than the time elapsed on Earth for the same flight.

We consider what in special relativity is called "hyperbolic motion", that is a rectilinear, accelerated motion with a constant acceleration a in the probe's reference frame.

The overall mission to any nearby star is thus subdivided into two equal halves:

(1) from the Sun to half way the distance to the target star, the probe undergoes a uniform proper acceleration a;
(2) at mid-point the probe is turned by an angle of 180°, so that the propulsion system becomes a braking system;
(3) the probe then undergoes a uniform proper deceleration a, until it reaches the target star with zero speed.

The probe's top speed is thus achieved at mid-point between the Sun and the target star, and it may equal a significant fraction of the speed of light (20% or higher).

An equation is then derived expressing the hyperbolic motion's uniform acceleration a as a function of the overall mission time and of the distance of the target star from the Sun. This is the first key equation for a realistic mission plan.

We next prove, by resorting to the Ackeret equation for a relativistic rocket, that, for the hyperbolic motion, the mass of the "propellant" decreases *exponentially*.

The important point then comes: *this exponential decrease of the propellant mass formally has just the same equation as the radioactive decay equation. The way thus is paved to exploit the radioactive decay as a propulsion system to achieve the uniformly accelerated mission profile of the hyperbolic motion*.

Finally, from this "perfect match" between hyperbolic motion and radioactive decay, one more basic equation is derived. This equation expresses the radioactive decay constant λ as the ratio between the hyperbolic uniform proper acceleration a

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doi:10.1016/j.actaastro.2005.02.003

and the proper speed w of the ejected radioactive fragments "propelling" the probe in the opposite direction. This equation is vital inasmuch as it enables one to *select the appropriate radioactive material* as the "propellant" capable of achieving the requested constant proper acceleration a for a given target star.

In conclusion, the logical sequence of steps to design an interstellar probe based on the radioactive decay of a certain material has now been made clear:

(1) First determine the uniform proper acceleration a in terms of the assumed overall flight proper time, T_{overall}, and of the distance of the target star, D_{star}.
(2) Then select the appropriate radioactive material by selecting its radioactive decay constant λ, expressed as the ratio of the previously selected constant proper acceleration a to the (constant) proper speed of the ejected radioactive fragments w.
(3) For different target stars, select different radioactive materials according to the equation $\lambda = a/w$.

1. Introduction

This paper looks forward to the far future.

How far exactly, this author does not know. But if one looks back into the last 100 years of scientific progress, one landmark stands out: just a century ago, an obscure clerk of the Bern Patent Office, by the name of Albert Einstein, came along and taught the world that "reality" is the theory of relativity, not classical Newtonian mechanics.

It then took one more century for even a few among the most illuminated scientists to realize that relativity, despite wonderful success in astrophysics, still has to make humankind its most precious offer: the relativistic interstellar flight enabling humans to reach the nearest stars and the planets revolving around them.

NASA took notice of the changing times in 1996, when the Breakthrough Propulsion Physics (BPP) Program was established (the relevant web site is http://www.grc.nasa.gov/WWW/bpp/). This program, however, had such a small budget (zero dollars as of January 31, 2003) and dealt with topics so mathematically difficult to be understood even by the experts (for instance "wormholes" in general relativity and the zero-point field (ZPF) in quantum field theory) that no wonder it failed to convince many about the feasibility of interstellar flight.

In this paper, we try to follow an alternative, much simpler route. First, we confine ourselves to "easy" special relativity, thus automatically disposing of "too advanced topics" like wormholes, Casimir-like "negative energy", and the like. Second, we prove mathematically that the simple exponential law of radioactive decay is a perfect match with the special-relativistic type of motion called "hyperbolic motion" by physicists (the relevant spacetime is also called "Rindler space" by today's astrophysicists and cosmologists). The result is that the relativistic hyperbolic motion could become the ideal mission profile to send probes *to the nearest stars in a time of decades*, *if propelled by radioactive decay*.

Finally, the Ackeret equation for the (special)-relativistic rocket will be the mathematical tool to pave the way for the most important result proved in this paper: the relationship between

(1) the radioactive decay constant, λ,
(2) the "exhaust" speed (with respect to the spacecraft) of the decaying radioactive material, w,
(3) and the (proper) constant acceleration a of the hyperbolic motion.

This result, the most important result in this academy transactions note, reads then

$$\lambda = \frac{a}{w}. \tag{1}$$

2. Relativistic hyperbolic motion: a "simple minded" summary

This section is an attempt to summarize "by easy terms" what is the hyperbolic motion in special relativity.