Flights Between Habitable Exoplanets

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Introduction

To explore our Galaxy Milky way, it is necessary for developed extra-terrestrial civilizations inhabiting exoplanets to traverse enormous distances that separate them. The exploration of the Galaxy in human lifetimes is possible via Alcubierre's warp drive [1], which deforms space-time so that the starship motion should be superluminal relative to the start point and subluminal relative to the deformed space-time. This work continues our previous paper [2] devoted mainly to the warp drive parameters and the starship geodesics.

Exoplanets

Now more than 4000 exoplanets have been discovered. Their total number in the Galaxy is more than 10^{11}. The exoplanets in the habitable zone are cool or cold (as Earth and Mars), have masses 0.5 to 7 terrestrial ones and are rotating around F, G and K stars located in the Galaxy disc with thickness about 1000 l. y. at the distances 7 to 9 kpc from its centre.

For Earth-like exoplanets a parameter

$$\frac{a_{exo}}{a_{eff}} = \frac{1}{2}\left(\frac{T_{\odot}}{T_{exo}}\right)\frac{R_{\odot}}{a_{\oplus}}\sqrt{1 - A_{\oplus}} \quad (1)$$

is introduced, where a_{exo} is the semi-major axis of the exoplanet orbit, a_{eff} that for the effective terrestrial orbit, T_{exo} the effective exoplanet temperature, $T_{\odot}$ the solar temperature, $R_{\odot}$ the solar radius and $A_{\oplus}$ is the terrestrial albedo. On the effective terrestrial orbit, the exoplanet climat is similar to that on Earth.

$$0.8 < \frac{a_{exo}}{a_{eff}} < 1.3 \qquad (2)$$

for cool exoplanets. If $a_{exo} = a_{eff}$, $T_{exo} = T_{Earth}$ = 247 K.

$$1.2 < \frac{a_{exo}}{a_{eff}} < 3 \qquad (3)$$

for cool ones.

The extraterrestrial civilizations in the habitable zone are separated by the distance

$$L_c = \sqrt[3]{\frac{\pi h\left(R_e^2 - R_i^2\right)}{N}}\,, \qquad (4)$$

where R_e and R_i are the external and internal boundaries of the habitable zone, h is the disc thickness, N the total number of civilizations estimated by Drake's formula [3]

$$N = N_p n_e f_l f_i \frac{L}{T_g}\,, \qquad (5)$$

where N_p is the number of planets in our Galaxy, n_e the fraction of planets in the habitable zone, f_l the fraction of the planets that could support life [4], f_i the fraction of those which develop intelligent life [3], L the lifetime of advanced civilizations, T_g the Galaxy lifetime. Substituting $N_p = 2 \cdot 10^{11}$, $n_e = 0.014$, $f_l = 0.13$, $f_i = 0.01$, $L = 10^5\, y$ and $T_g = 4.6 \cdot 10^9\, y$, we obtain $N = 100$, which is comparable with the recent estimates [5]. Thus, the number of civilizations is estimated as 10^{-7} of the total number of exoplanets in the habitable zone. The average distance between civilizations is estimated from Eq. (4) as 676 pc.

Alcubierre's Warp Drive

Alcubierre's warp drive creates around the starship a bubble of the radius R and the wall of thickness $1/\sigma$, and inside the deforms space-time, which is described by the metric

$$ds^2 = c^2dt^2 - (dx - f v_s dt)^2 - \varrho^2, \tag{6}$$

where $0 \le f \le 1$, $\varrho^2 = y^2 + z^2$, $v_s = \frac{dx_s}{dt}$ is the starship velocity relative to the start point, $r_s^2 = (x - x_s)^2 + y^2 + z^2$.

The restrictions on the starship's bubble sizes and velocity are as follows [2]:

$$\sigma R > 3\,, \frac{c r_s}{v_s \rho} > \frac{\sqrt{3}}{4}, \tag{7}$$

where R is equal to the gravitational radius of the mass $M = \frac{Rc^2}{2G}$.

$M = 0.02M_{\odot}$ for $R = 100\ m$.

Solving the equation of geodesics for metric (6), we obtain the equation as follows:

$$\dot{v}_s\left(\frac{2v_s^2 f^2}{c^2} - 1\right) + \dot{v} + \frac{2\dot{v}_s v_s v f^2}{c^2} = 0\,. \quad (8)$$

Neglecting $\dot{v}$ in this equation, we obtain its solution as follows:

$$v_s = -\frac{v}{2f} + \frac{c}{f\sqrt{2}}\sqrt{1 + \frac{v^2}{2c^2}}\,. \quad (9)$$

Differentiating it with respect to time, we have

$$\dot{v}_s = \frac{1}{2f}\left(\frac{v}{c\sqrt{2+\frac{v^2}{c^2}}} - 1\right)\dot{v}, \tag{10}$$

whence $|\dot{v}| \ll \dot{v}_s$, for $f \ll 1$ and $\dot{v}_s \neq 0$. The local velocity $v_0 = v - f v_s$ has the form:

$$v_0 = \frac{3}{2}v - \frac{c}{\sqrt{2}}\sqrt{1 + \frac{v^2}{2c^2}}\,, \tag{11}$$

where $v_0 = 0, v > 0$ at $v = \frac{c}{2}$ and $v_s = \frac{c}{2f}$. Providing $\dot{v}_s = \dot{v}_{s0} = const$, we obtain:

$$v_s = \dot{v}_{s0}t + v_{s0}\,, \tag{12}$$

where $v_s = v_{s0} = \frac{c}{2f}$ at $t = 0$ and $v_0 = 0$. The law of starship's motion reads:

$$x_s(t) = \frac{ct}{2f} + \frac{\dot{v}_{s0} t^2}{2}\,. \tag{13}$$

From equations of geodesics we obtain the warp drive power:

$$P = \frac{M\left(1-\frac{2v_s^2 f^2}{c^2}\right) f \dot{v}_s v}{\sqrt{1-\frac{v_0^2}{c^2}}}\,, \tag{14}$$

which reduces to

$$P_0 = \frac{Mfgc}{2} \tag{15}$$

at $v_0 = 0$.

Assuming that $f < e^{-6}$, $\dot{v}_s \leq g$, where g is the free fall acceleration on Earth, we obtain that $P_0 \sim 10^{41}\, ergs^{-1}$.

$$T = \frac{Mc^2}{P_0} = \frac{2c}{fg}\,. \qquad (16)$$

Flights between Exoplanets

The maximum distance to be reached in the Galaxy tour

$$D_{max} = \frac{cT}{2f} + \frac{gT^2}{2} = \frac{3c^2}{f^2 g}, \quad (17)$$

is of the order of the Galaxy disk radius, which means that a Galaxy tour with aid of Alcubierre’s warp drive proves to be possible.

If the distance travelled by the starship $d \ll \frac{D}{20}$, then the flight duration $t = \frac{2fd}{c}$ and the energy spent by the starship $E = P_0 t$.

Consider travels between 4 cool exoplanets located at distances 6 to 8 kpc from the Galaxy centre with terrestrial temperatures and masses $1M_{\odot}$ to $6M_{\odot}$, namely

1) Proxima Centauri b, $M = 1M_{\odot}, d_{gc} = 8\ kpc$;
2) Kepler 1638 b, $M = 5\ M_{\odot}, d_{gc} = 7\ kpc$;
3) Kepler 443 b, $M = 6\ M_{\odot}, d_{gc} = 8\ kpc$;
4) Kepler 439 b, $M = 6\ M_{\odot}\ \ , d_{gc} = 8\ kpc$.

The distances between i and k exoplanets d_{ik}, where $i, k = 1, 2, 3, 4$, are

$d_{12} = 878\ pc,\ d_{13} = 778\ pc,\ d_{14} = 692\ pc,$

$d_{23} = 121\ pc,\ d_{24} = 239\ pc,\ d_{34} = 133\ pc.$

The durations of flights between i and k exoplanets t_{ik} are

$t_{12} = 14\,y,\ t_{13} = 13$ y, $t_{14} = 11\,y,\ t_{23} = 2\,y,\ t_{24} = 4\,y,\ t_{34} = 2y$.

The energies E_{ik} in solar mass units spent by the starship in the flights between i and k exoplanets are

$E_{12} = 3 \cdot 10^{-4}, E_{13} = 3 \cdot 10^{-4}, E_{14} = 2 \cdot 10^{-4}, E_{23} = 4 \cdot 10^{-5}$,

$E_{24} = 8 \cdot 10^{-5}, E_{34} = 5 \cdot 10^{-5}$.

Conclusion

The geodesic equations are solvable analytically for starship motion along the x-axis. The difficulties related to the creation of the deformed space-time appear to be overcomable only by a supercivilizations with energy consumption about $10^{44}\ ergs^{-1}$. Even in this case, there arise obstacles seeming insuperable nowadays. The conclusions based on the level of modern science are not ultimate, so much is unknown. Contrary to electromagnetism, we cannot control over gravity. When our knowledge becomes more detailed and extensive, it will be possible for us to succeed in revising many problems of gravity including its modern interpretation in the framework of general relativity.

References

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