Gram-scale Nano-spacecraft Entry into Star Systems

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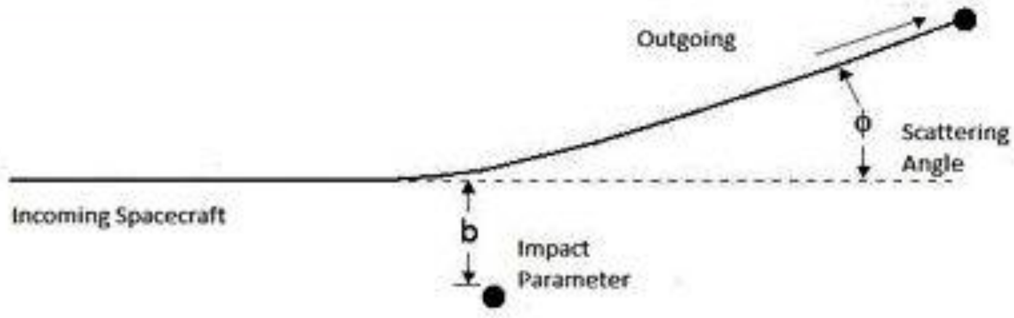
Objectives

1) Arrive at the Centauri system with 20% the speed of light.
   (Such that there is an encounter with a star.)[1]
1) Decelerate or curve the trajectory using the local stellar environment.
2) Which can be by using:
a) Radiation Pressure
b) Poynting Robertson Effect (drag)
c) Lorentz Forces …. Charge …. Magnetic forces
d) Electro motive force
e) Corpuscular Drag
f) Alfven Wings
g) Magnetic Sail
h) Electric Sail

(1)[Heller, René; Hippke, Michael, Deceleration of High-velocity Interstellar Photon Sails into Bound Orbits at α Centauri, The Astrophysical Journal Letters, Volume 835, Issue 2, article id. L32, 6 pp. (2017)]

Trajectory

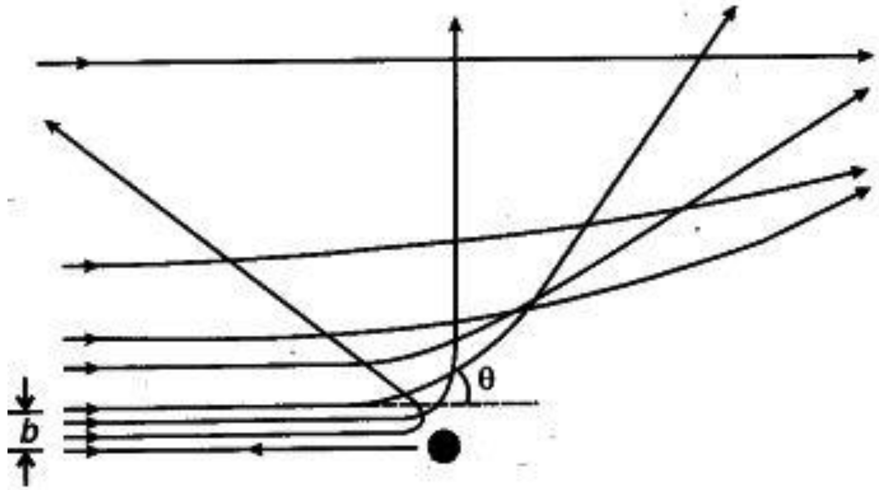


$$\mathbf{F}_{\mathrm{gr}} = -\frac{(1-\beta)GM\mathbf{r}}{r^3}$$

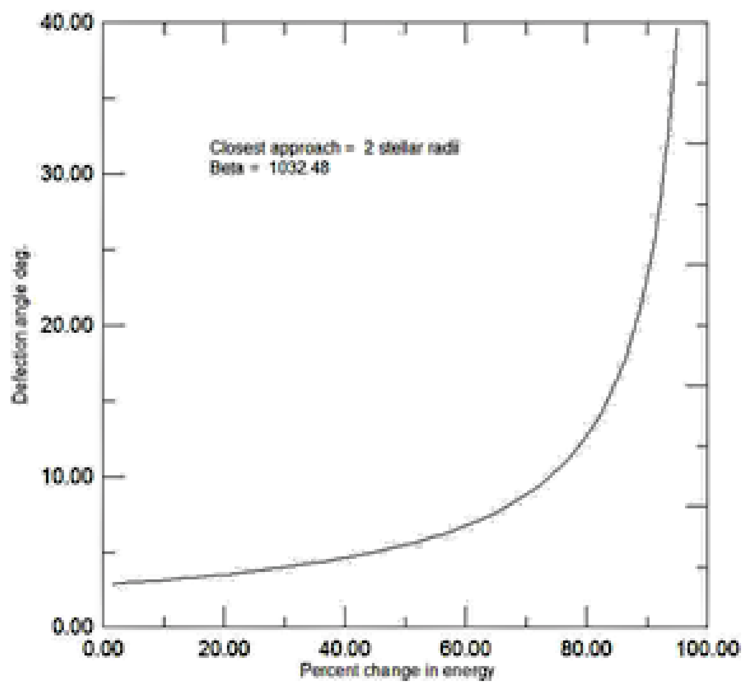
$$r = \frac{\mathrm{p}}{1-e\cos(\theta)}$$

$$b = r_p\sqrt{1+\frac{2GM(1-\beta)}{r_p \mathrm{v}_\infty^2}}$$

$$e^2 = 1+\frac{b^2 {\mathrm{v}_\infty}^4}{\mathrm{G}^2 M^2 (1-\beta)^2}$$



Essentially Rutherford Scattering from a repulsive potential.



Deflection angle as a function of change In energy due to Dissipation.

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Radiation Forces

mass = $\pi\sigma s^2$

σ= surface density = 8.6×10^{-4} gm/m^2

(s = size of ship, G = gravitational constant, M=mass of star,r=distance)

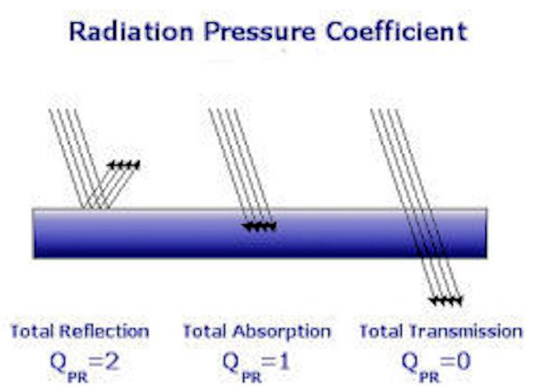
$$F_{gr} = -\frac{\pi s^2 \sigma G M}{r^2}$$

$$F_r = \left(\frac{SA}{c}\right) Q_{pr}$$

$$\beta = \frac{F_r}{F_g} = \left(\frac{L}{4\pi G M c}\right)\left(\frac{Q_{pr}}{\sigma}\right).$$

Q_{pr} = radiation pressure coefficient.

For Graphene, an absorber, $Q_{pr} \cong 1$

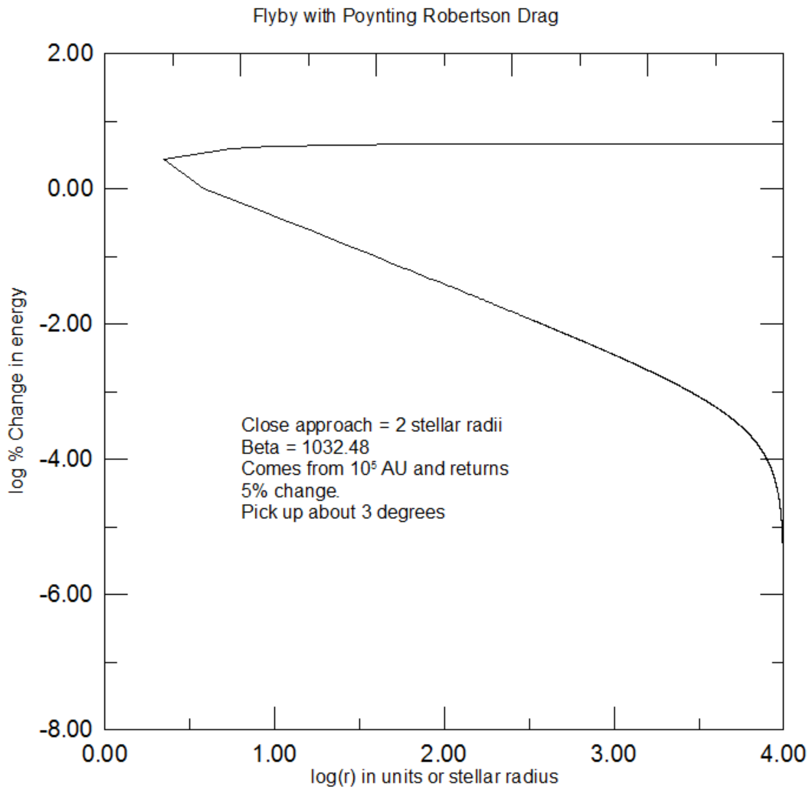


Radiation Pressure and the Poynting Robertson Effect

Numerical integration of the equations of motion with radiation Pressure and Poynting- Robertson Drag. With the $\boldsymbol{\beta}$ and closest approach Specified.

$$\mathbf{F}_{\mathrm{gr}} = -\frac{(1-\beta)GM\mathbf{r}}{r^3}$$

$$\mathbf{F}_{pr} = -\frac{GM\beta}{r^2}\left[\frac{\dot{r}}{\mathrm{c}}\frac{\mathbf{r}}{\mathrm{r}} + \frac{\mathbf{v}}{\mathrm{c}}\right]$$



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Lorentz Force

$$F_{Lorentz} = Q\boldsymbol{v} \times \mathbf{B}$$

$$B_r = B_{r0}\left(\frac{r_0}{r}\right)^2$$

$$B_\theta = B_{\theta 0}\left(\frac{r_0}{r}\right)\cos\theta$$

$$B_\phi = 0$$

Using Lorentz force to
Decelerate in the magnetic
Field of the target stellarsphere.
B is about 5 nT at 1 AU

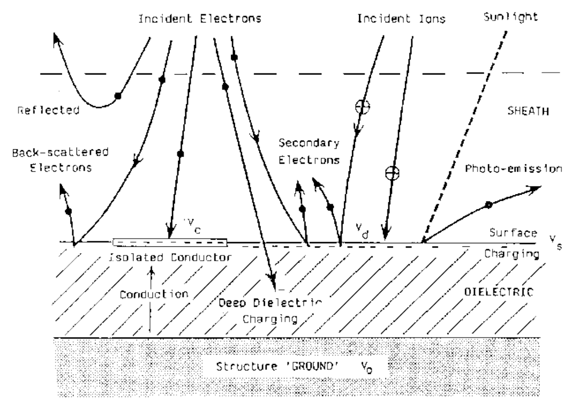
$$S = \left(\frac{\Phi}{a}\right)^2 / 4\pi$$

$$\Phi = \frac{Ze}{a}$$

S= Tensile Strength (Graphene) ~ 10^{11} Pascals

10^4 Coulombs could be put on a 10 cm Graphene sphere!

Chagrining in the natural
Environment. Does not
Seem possible.



Make similar calculation
For a sphere with a dipole
Moment. Hard to make work.

-> $\mathbf{F} = \boldsymbol{\mu} \cdot \nabla\mathbf{B}$

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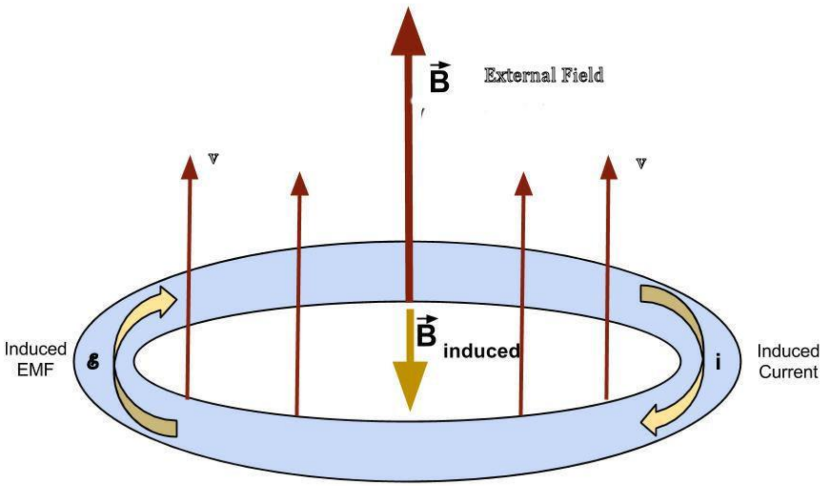
Induced Force

$$emf = vaB_a$$

$$I = \frac{emf}{\Omega}.$$

$$F = IaB_a$$

A super conducting ring ,Graphene, thrust into the Stellarsphere magnetic field At 20% c. Hard to make work.



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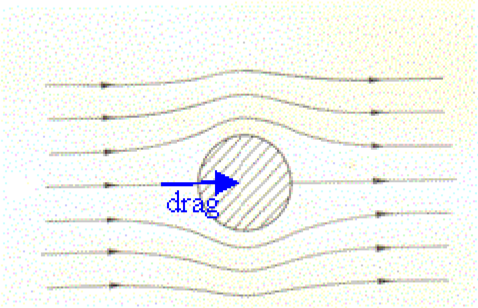
Corpuscular Drag

$$F_d = -C_d n m_p v^2 \pi a^2$$

Space craft 'gas' drag
At 20% speed of light.
Might work if the ship is
Not destroyed!

$$n = n_0 \left(\frac{r_0}{r}\right)^2$$

r_0 is 1 AU, $n_0 = 7.3 \times 10^6$



At 2 stellar radii drag can be substantial

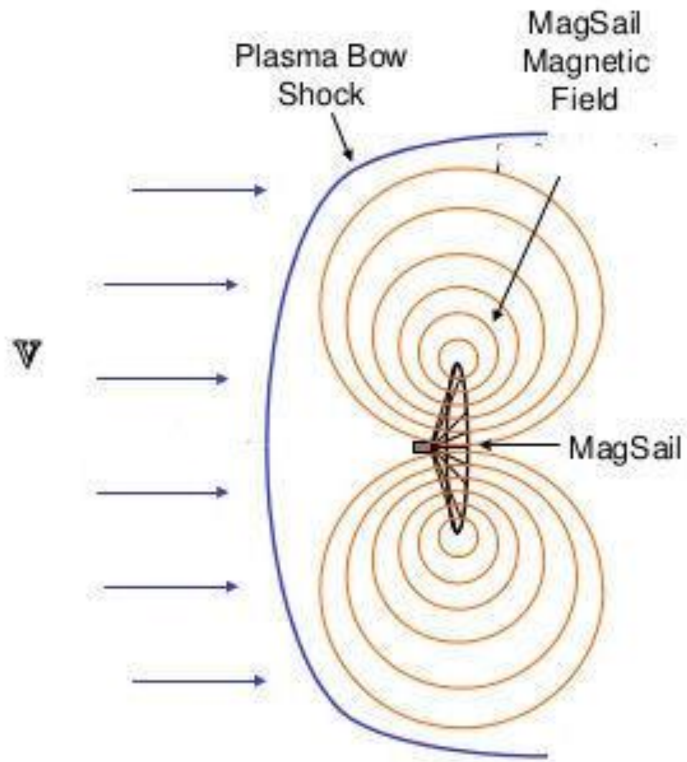
Mag sail

The no free lunch drag approach.
Carry or generate onboard power
To run a Magsail. Lots of power
Required for such a small ship.

$$F_d = \rho v^2 \pi R_s^2$$

$$\rho = m_p n$$

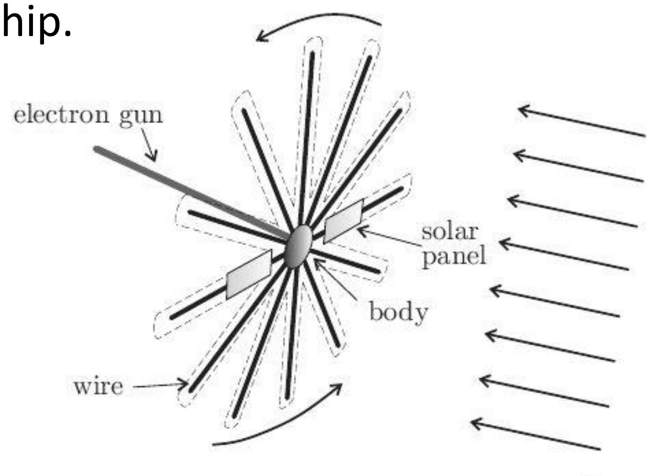
$$R_s = \left[\frac{2B^2}{\mu_0 \rho v^2}\right]^{\frac{1}{6}}$$



Zubrin and Andrews

Esail

Another no free lunch drag approach.
Carry or generate onboard power
To run a Esail (Electric Sail).
Lots of power
Required for such a small ship.



P. Janhunen

Alfvén Wings

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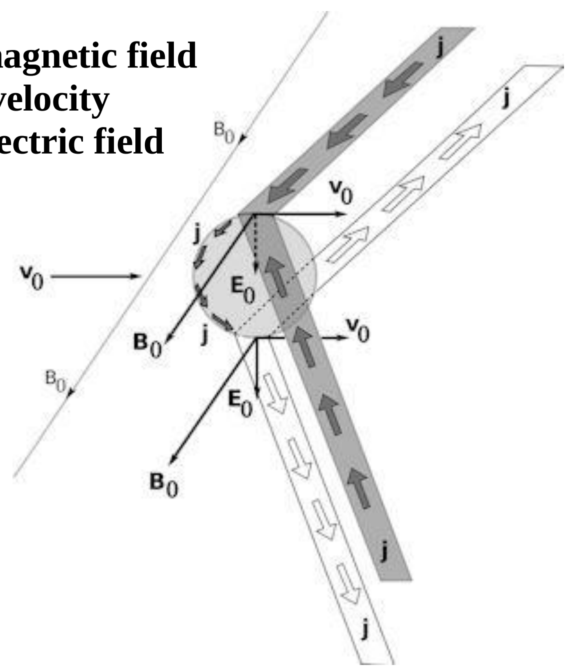
A conductor moving in a magnetic field will produce a charge separation and an electric field. Currents can flow using conduction in the presence of plasma there can be a coupling and a flow of current. These kinds of disturbances are called Alfven waves. The waves carry away energy and cause drag. Unfortunately the entry speed of 20% c the flow is faster than the Alfvén velocity V_a, the ship is preceded by a shock wave and 'wings' do not form.

B_0 = ambient magnetic field
V_0 = incoming velocity
E_0 = induced electric field
j = current



Conclusions

1)Stopping and curving is hard when doing 20% c.

2) Radiation forces can help one if pre-entry energy can be bled from the trajectory.

3) A plain charged generic space craft might use the Lorentz force but how to get/keep enough charge?

4) A free lunch dissipation from motional emf drag does not seem to work.

5) Straight up gas drag gives fair numbers, but is it dangerous? How to make it work?

6) The Magnetic and Electric sails as 'active' dissipators seem to require too much energy?

This is a work in progress and a challenge

to researchers.