Extraterrestrial Life: Lecture #25

Course questionnaires at end of class today

Final homework due Thursday

Answer keys to all homeworks will be on the web by the end of the week

Today: practical (or at least conceivable) approaches to interstellar travel…

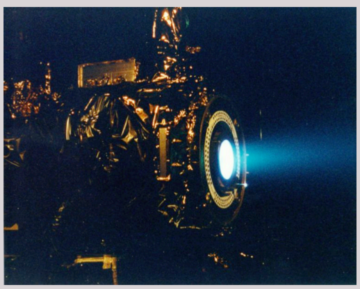
Difficulty with accelerating to velocities significant (~0.1c) for interstellar travel is the **mass of the fuel**.

Quantified via the *rocket equation* (see textbook p. 442):

$$M_{ship+fuel} = M_{ship} e^{v/v_{exhaust}}$$

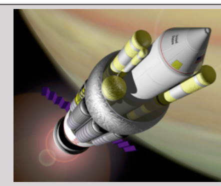
launch mass — final mass — velocity of the exhaust gas

High exhaust velocities are best, but it is hopeless to reach 0.1 c using either chemical rockets ($v_{exhaust}$ ~ 5 km/s) or ion drives (50 km /s)



Ion thrusters - will be used on future interplanetary missions

Project Orion

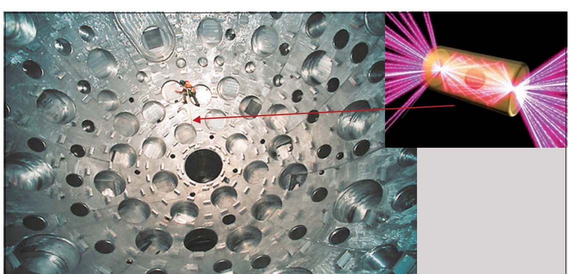


1950s / 60s era concept for a spacecraft powered by exploding a few thousand nuclear bombs behind a shock-absorbing plate

Debris velocity can be ~1000 km/s or more

Abandoned after the test-ban treaty in 1963

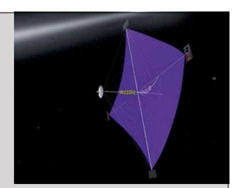
More modern versions might use laser fusion of smaller deuterium / tritium pellets



Technology is being developed for the National Ignition Facility / "inertial confinement fusion"

Only interstellar probe design that could be built with relatively near-term technology development

Laser sails



Alternate approach: leave the power source (fuel) on Earth and beam light at a large sail - radiation pressure of the reflected light accelerates the probe

Advantage: rocket equation limitations do not apply - the fuel can be as heavy and inefficient as you want

Can also be used with sunlight in the Solar System - but this doesn't work for interstellar travel as the Solar flux falls off too fast

Engineering challenge is in the mass needed for the sail material and achieving enough laser power…

Suppose we want to accelerate to 0.1 c in one year:

$$v = at$$

$$a = \frac{3 \times 10^7 \text{ m/s}}{3.16 \times 10^7 \text{ s}} = 1 \text{ m/s}^2$$

Need one tenth of a g acceleration

Force exerted by a laser beam of luminosity L reflecting off a sail is: $F = \frac{2L}{c}$

Using Newton's 3rd law: F = ma, $L = \frac{1}{2} mca$

This is the laser power needed to accelerate a probe of mass m at acceleration a.

Example: for a 100kg probe (including the mass of the sail and supporting structure), need:

$$L = \frac{1}{2} \times 100 \text{ kg} \times 3 \times 10^8 \text{ m/s} \times 1 \text{ m/s}^2$$
$$= 15 \text{ GW}$$

Again, not unreasonable power requirement (Grand Coulee dam on the Columbia has ~7 GW capacity)

However, *currently*, efficiency of high power lasers is very low - highest power continuous lasers are only "megawatt class"

No physics reason why higher efficiencies could not be achieved in the future…

Another consideration is that it would be hard to focus the laser power onto the sail

After 1 year of acceleration, probe will be at a distance from Earth:

$$d = \frac{1}{2} at^2 = 5 \times 10^{14} \text{ m (3000 AU)}$$

Remember that to focus a beam of light of wavelength λ into an angle θ we need a dish of size $D \sim \lambda / \theta$

If the sail were 100km across, we would need a mirror of 2km size to focus the laser power onto the sail

A more powerful laser with a smaller mirror might be more feasible…

Antimatter as a fuel

All elementary particles have *anti-particles* - e.g. electron's antiparticle is the **positron**, proton's is **antiproton**

When particles meet their (distinct) antimatter counterpart, annihilate into pure radiation:

$$E = mc^2$$

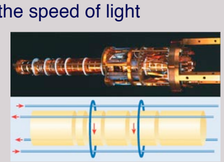
E is the energy yield, m is the mass of the particles that annihilate

Antimatter fuel has the highest possible energy density

e.g. one year's output from the Grand Coulee dam could be matched by annihilating 1.2 kg of antimatter with same amount of normal matter

If antimatter could be created in ~kg quantities, and if it could be stored safely, could be used as a fuel to accelerate to reasonable fraction of the speed of light

Antiparticles (positrons, antiprotons) are routinely made and accelerated in particle accelerators



Harder to make neutral antimatter atoms - perhaps a few million have been created in experiments

1 million antihydrogen atoms = 1.7×10^{-21} kg…

Know of no lightweight way to store large quantities…

Fermi paradox

Difficulties in interstellar travel are formidable - but not impossible given known laws of physics.

Engineering might be possible with today's technology given enough investment - certainly seems feasible in the far future.

At one tenth the speed of light, probes could cross the Galaxy in ~one million years.

Fermi paradox: if there are civilizations 100s of millions of years older than ours in the Galaxy, why have they not spread out through the Galaxy already?