Outline of lecture notes
(Handed out Tuesday Dec.2)
Star Travel + The Fermi Paradox

This is the material in sections 13.1,2,3 in your textbook. You don't have to read sec. 13.4.

If you are interested in reading further on these topics, do not go to the textbook links (mostly extinct). As usual, Wiki has a good discussion and many links. David Darling's "encyclopedia" also has good discussions; see http://www.daviddarling.info/encyclopedia/I/istravel.html. Full-length books on interstellar travel are: The Starflight Handbook, by Eugene F. Mallove (1989, probably the best treatment, but with necessary physics), and Interstellar Travel and Multi-Generational Starships, by Yoji Kondo.

There will be only one page of lecture notes on "The Fermi Paradox" – they are meant to make it clear that the authors have not read the papers on the Fermi paradox, especially by Michael Hart, whose argument is much more iron-clad than the textbook, sec. 13.3. We will discuss briefly if time.

The primary problem: The speed of light "c"

This is the extreme upper limit for starship speeds, *and* there is no foreseeable way to approach anything larger than about 10% of the speed of light (0.1c).

Anything faster has ridiculous energy requirements, simply a result of Einstein's theory of special relativity—the upper limit of the speed of light and effects when approaching it. Textbook has excellent discussion of details. Online, one of the few textbook links that aren't extinct or useless is a link to this tutorial on special relativity:

http://www.howstuffworks.com/relativity.htm

You can find better at Wiki or in David Darling's encyclopedia. The main effect that keeps us from star travel is:

→ Mass increases very rapidly (well-verified, e.g. particle accelerators), so need much more fuel (energy).

In addition:

→ Clocks slow down (also well-verified, clocks in orbit,…): "Time dilation" and the "twin paradox."

After numerous and challenging tests, there is not even a hint that special relativity is in error. (The question of *why* there is an upper limit that has the value it does is a mystery, but no more so than the values of the other fundamental constants of physics.)

Exotica: Textbook mentions "Wormholes and Hyperspace", etc., or you may encounter internet claims about "tachyon power," "vacuum energy," using dark energy, other space-time bridges, Miguel Alcubierre's "warp drive" that requires more energy than contained in observable universe, etc. These have no basis—at least according to present-day physics—or have engineering requirements that are unimaginable; e.g. how will you get that crew and ship into that wormhole without destroying them? How much "vacuum" would you need to harness that "vacuum energy?" (You can buy it online, along with "tachyonated water" and more.)

We will not cover this, nor will it be on the exam.

Wormhole Induction Propelled Spacecraft,

Most proposed designs still rely on "rocket" principle: Momentum flow in one direction requires momentum change, and hence acceleration, in the opposite direction. (Newton's laws of motion—see textbook)

Possible fuels:

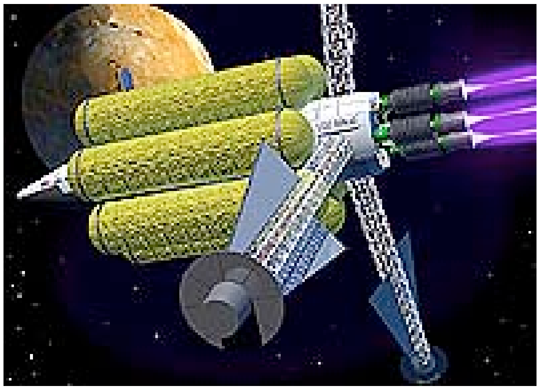
- Chemical – Like present day rockets, or a fireplace. Energy yield far too small, for same reason you can't power the Sun with coal)
- Fission - better, but still small yield; radioactive isotopes for fission are rare, so can't see where to get enough. Also radiation damage and contamination.
- Fusion – approach **a percent of mc^2**. But how to contain fusion? (We assume it will happen in foreseeable future.) How about that mass-to-fuel ratio problem?
- Matter-antimatter – When matter and antimatter interact, they are converted entirely into photons (gamma rays). Example is the positron (positive electron).

Can get mc^2, so ~ 100 times more efficient than fusion, but where to get the antimatter? How to contain it?

[Our universe has the mysterious property that a slight asymmetry, which must have arisen when the universe was very young, resulted in a universe that had a slight excess (about one part in 100 million) of matter over antimatter. After the matter and antimatter annihilated each other, only this excess matter (the matter we see today) remained. That is why we would have to produce the antimatter ourselves, but that requires an enormous amount of energy (as you might expect!).]

"Robotic interstellar vessel with Matter-Antimatter propulsion"

Some workable suggestions (mentioned in textbook) can get ship to no more than 1-2% of the speed of light:



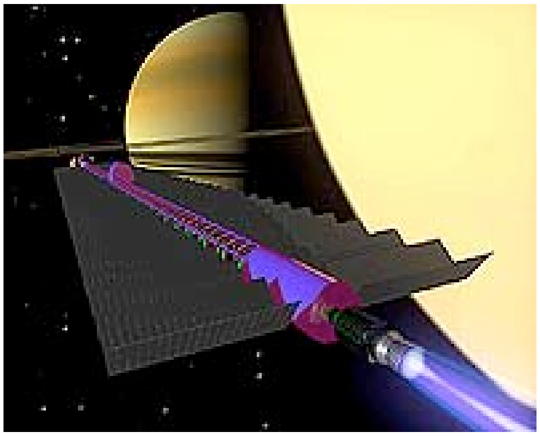
Ion engine – accelerate charged particles in an electric or magnetic field. Designs are mostly for travel around our solar system.

"Advanced plasma engines that produce high-power jets of ionized gas are another option for travel to the planets."

Solar sails – inverse square law of light means you have to accelerate very close to the sun and then coast the rest of the way. Again, 0.02c is maximum possible. (*Laser* sails are discussed below.) See http://www.ugcs.caltech.edu/~diedrich/solarsails/

→ All serious proposed vehicles that might be viable for star travel presume some form of nuclear fusion and can just get to an average speed of 0.1c; this is *if* nuclear fusion could be controlled/contained. The rest of this discussion is restricted to that case.

"A fusion-powered spaceship starts braking into orbit around Titan, Saturn's methane-shrouded moon and a possible harbor for extraterrestrial life. Basic research on fusion rocket technology is one of several topics for this week's workshop."



Considerations for ~ 0.1c star travel

● Distances to nearby stars

Recall that speed of light requires decades-to-centuries for two-way messages to the ~ 100 nearest stars.

Alpha Centauri (4 LY distant) requires average speed of about 0.1c to arrive within a human lifetime of 40 years.

More likely (more distant) destinations require either >> human lifetime or speeds > 0.1c (very unlikely, see below). e.g. tau Ceti is about 12 LY distant.

Potential solutions do not seem feasible:

→ **Suspended animation** - Stymied by property of water that we claimed was so useful for life earlier in course—what happens to the density of water upon freezing? Bye-bye cell walls…

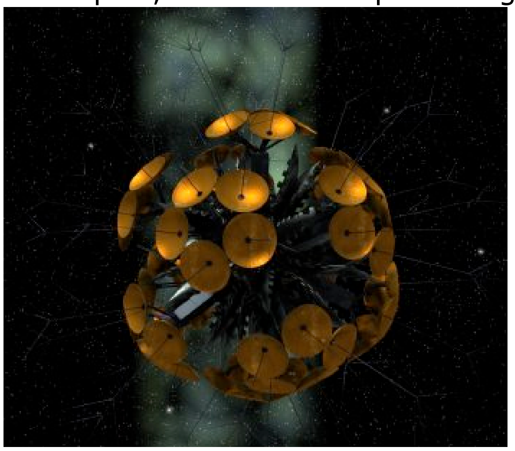
→ **Multigenerational crews** - Where to find crew who are qualified *and* would sign up? Unforeseen SF novel consequences too risky.

→ **Lifetime >> present human** – This is presently not on the horizon for humans, but it will be important for thinking about alien colonization of the Galaxy and the Fermi paradox. Why couldn't other life forms have lifetimes of 1000 years? (Complex question that we skip here.)

→ **Embryo space colonization** – keep zygotes ready to develop just as habitable planet is detected.

Another solution: Robotic probes (assumes we on Earth will be willing to wait the centuries required until the robots report home)

Von Neumann probes - starships that make copies of themselves and launch the copies, which then replicate again and launch further copies, etc. A good tactic to colonize the Galaxy!



Bracewell probes – "Messenger probe." if robotic probe finds life, it remains dormant, observes, and eventually makes contact (or destroys—"Berserker"). Could there be one, waiting, in our Solar System? Variations in echo delay times of radio transmitters claimed as evidence for this in early SETI projects. Bracewell, R. N. (1960). "Communications from Superior Galactic Communities". *Nature* **186**: 670–671

The irony of Galactic architecture:

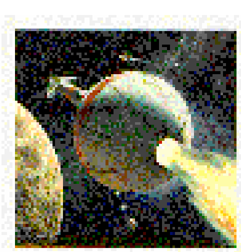
Recall how distances between stars was a problem even for SETI-type two-way communication, and that was at the speed of light! In present case, can only approach 0.1c, and at extreme expense with optimistic future controlled fusion device. Galaxy does not appear designed for human star travel or communication.

Consider situation in a globular cluster, where the distance between stars might be only ~ 0.01 light years. *Then planetary systems would be unstable due to gravity of the passing nearby stars!*

● Serious problem: **Mass-to-fuel ratio**. Sometimes just "mass ratio." Remember, you need to have a large "payload" consisting of supplies and equipment needed during the trip, materials for a settlement or colony upon landing, ***and enough fuel to return*** with a payload consisting of supplies and equipment needed during the trip.

A single-stage rocket would need at least 99 percent of its total mass comprised as fuel to achieve 0.1c. So need 100 times as much fuel as payload. That is a lot, but you also need that much for the return, so need to start with 10,000 times as much fuel mass as payload mass. Better pack light!

Multi-stage fusion and matter-antimatter rockets (if you could somehow collect and store them) require relative mass ratios between stages that exceed 1,000.



All proposed rocket designs that carry their own fuel encounter this problem, which seems insurmountable. This was the problem for the first serious starship proposal, begun in the 1950s: **Project Orion** – would have used energy from nuclear bombs released from the rear, use energy of explosion to "push" ship. This is called **"nuclear pulse propulsion."** But mass in bombs would be huge because of the mass-to-fuel problem. See links at http://www.islandone.org/Propulsion/

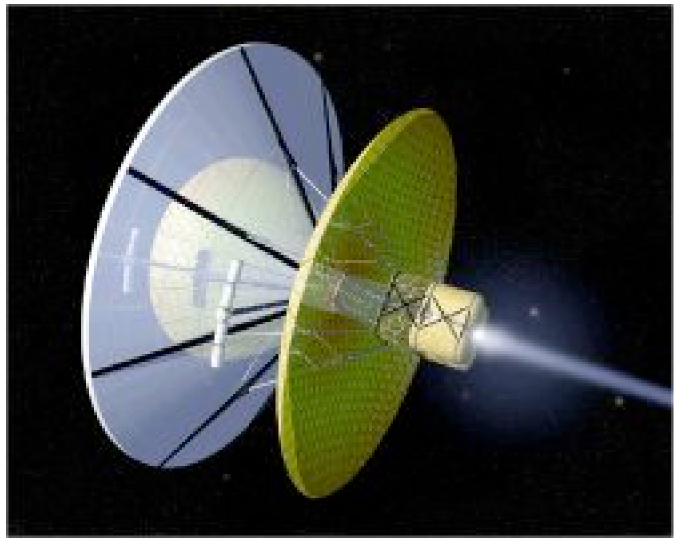
A later design in the 1970s, called **Project Daedalus**, was designed assuming near-future fusion technology. A self-replicating version was designed in 1980. It constructs its own automated industrial complex, weighed in at over 10 million tons, mostly fuel needed for deceleration. But the same mass-to-payload problem occurs.

How about not taking fuel with you?

● **Bussard fusion ramjets** – Scoop up interstellar hydrogen along the way, to feed the nuclear reactor.

Don't have to carry along fuel, and in principle could accelerate to nearly speed of light. But even to get to ~ 0.1c, scoop area would need to be ~ size of U.S. *The density of gas in our Galaxy is too small, by orders of magnitude, to make this possible.*

Magnetic scooping would relieve the scoop size problem, but how to generate such a magnetic field?



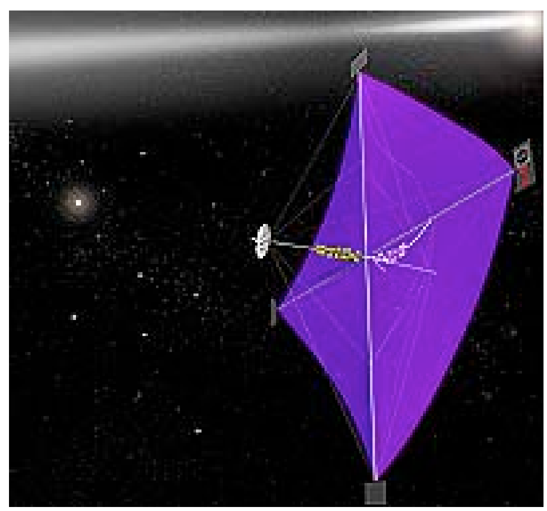
"Bussard ramjet fusion propulsion systems still lack workable engineering solutions to provide magnetic scooping and fusion of interstellar hydrogen" (The miles-wide electromagnetic field is not shown.)

● **Laser-powered sails** - Use laser-beam power from the Earth instead of carrying fuel. Light pressure on "sail" gives the ship momentum, so accelerates it. In principle could get to about 0.1c. But some big ifs:

→ How to make a laser powerful enough? Text estimates 1000 times current total human power consumption.

→ Assumes beam could be so narrow (well-collimated) that it could pinpoint a sail light years from Earth. But even a perfectly collimated beam is spread by interaction with interstellar gas.

→ Requires *very* large and low density sails that are difficult to deploy and control.



→ *How to slow down upon approaching destination? If no landing, how to turn around?* See caption next to illustration—someone thinks they can decelerate!

"Space sail with detached inner sail in deceleration mode"

THE FERMI PARADOX

Textbook, Chapter 13.3. Only one point made here.

It is important to understand how the argument has been misrepresented in nearly all sources. Michael Hart's paper is the definitive version, but the premise is that, in order for SETI searches to have the slightest hope of being successful, the Galaxy must contain a very large number of civilizations, or else the nearest one could not be only ~ 100 light years away. Then he says: If there are so many civilizations, why aren't they here, now?

The usual version is simply the latter statement, "Where are they?" This is so simple it is no paradox at all. However Hart's version has never been cracked, as far as I know, because you if you offer a sociological, or psychological, or any reason why a civilization might not be interested in colonizing, it would have to apply to all the millions of civilizations that inhabit the Galaxy (millions because you need to be able to find intelligence on stars ~ 100 pc away).

Here is a typical list of possible ways around the "Fermi paradox."

First, the valid typical questions that come up negative:

1. *It is too difficult to attain speeds of 0.1c, in which case no civilizations could have colonized or even gone far from home.* But we are already working on it.

2. *The time for a civilization to colonize the Galaxy is so long that they haven't arrived here yet.* This is an interesting one, because several people have shown how easy it is to colonize the Galaxy in only ~ 20 million years. (See the "coral strategy" in your book). This is such a short time compared to the Galactic age of ~ 10 billion years, that we are sure it should have occurred.

The next "explanation" is not valid:

3. *Maybe the civilization is not interested in colonization, or they spend all their waking hours painting, or they transcended technological civilization, or….*

Note that none of these (3) are valid in Hart's version, because they would have to apply to millions of civilizations. If you say, "But maybe there is only one," then you are saying that SETI searches are a waste of time, because then the only other civilization would on average be many kiloparsecs away.

This list is from David Darling's web encyclopedia.

Various explanations have been put forward [to explain the Fermi paradox], including that extraterrestrials are:

● Interested in us but do not want us (yet) to be aware of their presence (see sentinel hypothesis; zoo hypothesis).

● Not interested in us because they are by nature xenophobic or not curious (see extraterrestrial intelligence, character of).

● Not interested in us because they are so much further ahead of us (see extraterrestrial intelligence, more advanced than us).

● Prone to annihilation before they achieve a significant level of interstellar colonization, because:

(a) They self-destruct.

(b) They are destroyed by external effects, such as:

(i) The collision of an asteroid or comet with their home world.
(ii) A galaxy-wide sterilization phenomenon, e.g. a gamma-ray burster. (iii) Cultural or technological stagnation. (See also extraterrestrial civilizations, hazards to.)

They might be capable of only interplanetary or limited interstellar travel because of fundamental physical, biological, or economic restraints (see interstellar travel)

Notice that if there are millions of civilizations, one of the above would have to apply to ALL of them! Instead, our only example, humans, shows a history completely dominated by colonization. What reason would we have for not expecting that quality elsewhere? So maybe a few of them destroyed themselves, and others spend all their time painting or meditating, while still others are waiting for us to find their Bracewell code. But that still leaves plenty, among which there is probably one that has strong colonizational tendencies!

So what is the simplest answer to Hart's question: Where are they?