Today in Astronomy 106: the search

- The prospects for exploration in person:
  - Conventional space flight, using thrust: Project Orion.
  - Wormhole space travel, using gravity.

The Pale Blue Dot: Earth, as seen by NASA's *Voyager 1* from a distance of 4 billion miles (0.0007 ly).

Space flight

By contrast with communication, we are technologically very far away from being able to explore for extrasolar civilizations, in person or robotically. The means we can contemplate are these:

- Spacecraft which use thrust to accelerate up to near-light speed (*c*), and to decelerate at the end of the trip.
  - The best we have been able to do so far, with a combination of impulsive thrust and gravity boost on an unmanned spacecraft, is $6\times10^{-5}c$.
  - Still interesting to consider near-light speed travel
- Spacecraft which employ gravitational acceleration and specially-made shortcuts through spacetime, called **wormholes**.

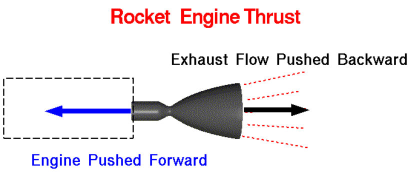
Space flight (continued)

Along with instruments, communication equipment, fuel, and gifts for the leaders of the civilizations we expect to encounter, the spacecraft has to carry

- nothing, if it's unmanned;
- many years of food and life-support systems for human passengers, if it's manned.
  - As we shall see, the life support systems must include artificial gravity and immense radiation shielding in order to keep the passengers alive.
  - Bonus if the thrust can be made constant, since that would also help keep the human passengers healthy.

Rocket Science

- ❑ Rockets work on the very simple principle of **Newton's 3rd Law**, namely for every action there is an equal and opposite reaction.



NASA

Conventional space flight

Currently, spacecraft generate thrust using controlled burning or explosions of chemical fuels, meaning that it's chemical energy being liberated in the production of fast-moving gases.

- ❑ Most popular: liquid hydrogen/ oxygen, hydrazine (N_2H_4)/ liquid oxygen, ammonium perchlorate (NH_4ClO_4)/ aluminum/ liquid oxygen.
- ❑ Of course, much more energy (and thrust) per gram of fuel would be liberated by using the fuel's **nuclear energy** instead of its chemical energy.

Launch of Apollo 11, 1969, on a mighty Saturn V booster (NASA).

Conventional space flight (continued)

Example: Liberate energy, in the form of heat or light, from 1000 kg (1 metric ton) of anthracite coal.

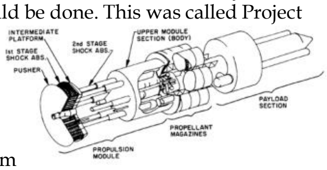
- ❑ Chemical energy: burn it (turns it all to CO_2 and H_2O): $\Delta E = 4.3\times10^{17}$ erg = 12,000 kWh .
- ❑ Nuclear energy: maximum-efficiency fusion in a star (turns it all to iron): $\Delta E = 4.1\times10^{24}$ erg = 1.1×10^{14} kWh .

This point has not been lost on scientists trying to invent better means of propulsion.

- ❑ The ultimate means of impulsive thrust: controlled explosion of nuclear weapons, specifically high-yield H bombs.

Project Orion

Physicist and Manhattan Project veteran Stan Ulam was the first to promote nuclear explosions as a means of spacecraft propulsion (1947). He enlisted Freeman Dyson – of whom we have heard several times in this course – and Ted Taylor to lead a study of how it could be done. This was called Project Orion (1958).



- The idea: detonate a nuclear device (with a bunch of refuse, to provide more momentum) about 60 m behind the spacecraft. Catch a large portion of the blast with a shock-absorbed "sail" to accelerate the spacecraft.

Project Orion (continued)

Projected performance of Orion spacecraft for interplanetary journeys (still a far cry from inter*stellar* journeys):

	Interplanetary	Advanced interplanetary	Saturn V
Ship mass	4,000 t	10,000 t	3,350 t
Ship diameter	40 m	56 m	10 m
Ship height	60 m	85 m	110 m
Bomb yield (sea level)	0.14 kt	0.35 kt	n/a
Bombs (to 300 mi Low Earth Orbit)	800	800	n/a
Payload (to 300 mi LEO)	1,600 t	6,100 t	130 t
Payload (to Moon soft landing)	1,200 t	5,700 t	52 t
Payload (Mars orbit return)	800 t	5,300 t	–
Payload (3yr Saturn return)	–	1,300 t	–

Project Orion (continued)

Upside:

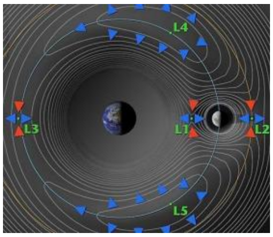
- Relatively inexpensive, as bombs are.
- Achieves both great thrust (force, acceleration of large mass) *and* large impulse (acceleration up to high speed). Chemical energy boosters can do the former but not the latter; "ion drives" can do the latter but not the former.

Downside:

- Nobody will let you use that many nuclear weapons to launch from the ground.
- Still impulsive: no constant thrust, which would be handy.
- Current designs still only reach 1000 km/sec (0.003*c*).

Still possible…

- Lagrange points: positions in an orbit where an object can remain stationary relative to the larger objects
- Assemble Project Orion and launch from space.
- Still hazardous.



Traveling at the speed of light

- Now we enter the realm of Einstein's theory of **special relativity**, which tells us as an object approaches the speed of light, with respect to an object at rest, it's:
  - Length becomes shorter in the direction of motion (Length contraction)
  - Mass becomes greater
  - Time becomes shorter (time dilation)

Traveling at the speed of light (continued)

- Traveling to Vega, near the speed of light:
  - d ~ 25 light years

Speed	Time Measured on Earth	Time Measured on Ship
0.00005*c*	1,000,000 yrs	1,000,000 yrs
0.1*c*	500 yrs	498 yrs
0.5*c*	100 yrs	86 yrs
0.7*c*	72 yrs	52 yrs
0.9*c*	56 yrs	24 yrs
0.99*c*	50 yrs	7 yrs

Want more? Register for Astronomy 102 this Fall.

Enough fantasy…let's move on to more practical things.

Wormholes

Wormholes are solutions to the Einstein field equations of general relativity that involve – potentially – shortcuts through spacetime.

- ❑ If a wormhole has mouths in two locations, travelling between these locations through the wormhole can be **orders of magnitude** faster than travelling "beside" the wormhole at the speed of light.
- ❑ One way to think of wormholes: a special overlap between the interiors of widely-spaced black holes.
- ❑ We can't manipulate black holes – for which masses start at a few solar masses – and thus have no idea whether this is even possible.

For more information, consult the relevant parts of AST 102.

Traversable, constructible wormholes (from AST 102)

Advising Carl Sagan in the writing of *Contact* got Kip Thorne and his grad student Mike Morris interested in how an advanced civilization might build wormholes for transportation. They wrote a set of instructions based on the following principles:

- ❑ For simplicity, the wormhole's geometry is taken to be spherical and static.
- ❑ It must represent a solution to the Einstein field equations, of course, and one stable against small perturbations.
- ❑ It must have a throat that connects two regions of flat spacetime, so that it can be used to connect places in our Universe. Thus its equatorial-plane embedding diagram looks like the classic "hyperspace tunnel."

Traversable, constructible wormholes (continued)

- ❑ There should be no horizon.
- ❑ The tidal forces and accelerations experienced by a traveler must be bearably small; they took < 1 Earth g.
- ❑ A traveler must be able to cross the wormhole in a finite time in both the traveler's frame and in a frame of reference at rest with respect to the wormhole's mouths; they took < 1 year.
- ❑ The matter and fields that generate the wormhole's spacetime curvature must be physically reasonable.
- ❑ It should be possible to assemble the wormhole: that is, it should require energy much less than the mass of the Universe times c^2, and take time much less than the age of the Universe.

Traversable, constructible wormholes (continued)

The down side: what happens if you try to enter the wormhole to employ the shortcut?

- You are accelerated to relativistic speeds on your way through. As a result, your energy (and mass) increase dramatically, in the rest frame of the wormhole.
- Your mass eventually becomes large enough, halfway through the wormhole, that your own gravity warps spacetime, collapsing the wormhole onto you.
- As your gravity "pinches off" the wormhole, singularities form again -but this time, they're of the black hole type. Your energy is added to the black holes, and the wormhole is destroyed (and you are, too).

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Traversable, constructible wormholes (continued)

How could we prevent the collapse of the wormhole under your gravitational influence, so you could make it through unscathed?

- By putting exotic matter into it. Exotic matter, with its negative energy density, would be "anti-gravity": it would warp spacetime in senses opposite to the way normal matter warps it.

In particular, adding exotic matter to a wormhole would tend to expand the diameter of its effective "hyperspace tunnel"

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Traversable, constructible wormholes (continued)

- In fact, if it were to have this property and be part of the structure, it would appear in the viewpoint of a distant observer to have negative energy density: that is, it's **exotic matter**.
- So there doesn't seem to be any way to avoid exotic matter in the construction of a traversable wormhole. All they could do was consider ways to minimize the amount.

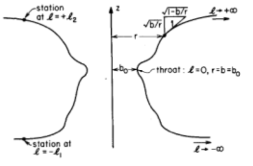

Fig. 2. Embedding diagram for a general wormhole, as seen in profile. (The diagram must be rotated about the vertical z axis to make it complete; cf. Fig. 1.).

Morris and Thorne 1987

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Traversable, constructible wormholes (continued)

Properties of the minimum-exotic-matter solution:

- Exotic matter provided as a spherical shell slightly larger than the throat of the wormhole. All the other matter is non-exotic.
- Characteristic size of the mouths is rather large (600 times the size of the Solar system) in order to keep the accelerations modest.
- Acceleration no greater than one Earth g, small tidal forces, so traversing it would be perfectly comfortable.
- It would take 200 days to traverse the wormhole.
- How long it is in physical space determines the total mass.

So all we need is that exotic matter!

Mid-lecture Break

- Homework #5 is up on WeBWorK; due Tomorrow by midnight
- Recitation today.
- **Exam #3** will take place Friday, in a 75-minute span of your choice between 10 AM and 6 PM.
- A Practice Exam appeared on WeBWorK this morning.

Where Has Man Been In Space ?

As of April 2010:

- 517 humans (from 38 countries) in outer space
- 3 suborbital
- 514 reached earth orbit
- 24 beyond low earth orbit
- 12 walked on the moon
- 29,000 person-days in space
- >100 person days of spacewalks

Senator "Barfin' Jake" Garn (R, Utah)

22 deaths, an unreported number of injuries and illnesses.

- At last report by NASA (2003), out of 508 astronauts, 498 had "medical events."

Space is a hostile environment.

The relevant concerns of space medicine:

- **Environmental**
- Physiological
- Psychological
- Occupational
- Social/cultural
- Communicational

Microgravity
Oxygen requirements
Hypothermia/
Hyperthermia
Water requirements
Nutritional requirements
Waste disposal-Trash
Management
and, especially,
Radiation.

Space is a hostile environment.

The relevant concerns of space medicine:

- Environmental
- **Physiological**
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- Communicational

Acceleration, Vibratory,
Acoustic
Weight loss
Fluid shifts
Vestibular
Loss of muscle mass
Osteopenia-osteoporosis
Slow wound healing
Hematologic changes
Immunological
Microbiological
Endocrine

Space is a hostile environment.

The relevant concerns of space medicine:

- Environmental
- Physiological
- **Psychological**
- Occupational
- Social/cultural
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Stress
Anxiety
Fear
Privacy
Depression
Sleep disorders
Maladaptation
Psychosexual

- Sunrise/ sunset q 90 minutes
- Excitement
- Position
- Mechanical & Human Noise
- Circadian rhythms-light dark -cortisol
- Insomnia-Cognitive impairment
- Sedatives *vs* melatonin

Space is a hostile environment.

The relevant concerns of space medicine:

- ❑ Environmental
- ❑ Physiological
- ❑ Psychological
- ❑ **Occupational**
- ❑ Social/cultural
- ❑ Communicational

•Trauma – in cabin crowding, floatation
•Work Overload- fatigue
•**Space Walking- art, balance, dangers**
•Competition-numbers vs opportunities

Suit puncture: loss of consciousness in 9-12 sec, death within 2 min.

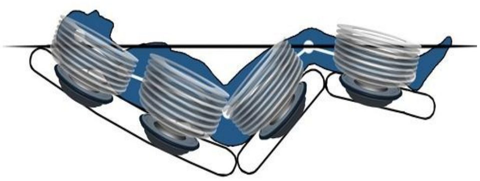
Progress of a space flight

Imagine yourself just before blastoff:

- ❑ strapped immobile in a launch chair
- ❑ uncomfortably suited up
- ❑ with 5 million gallons of propellant under you
- ❑ waiting-waiting- waiting
- ❑ knowing that most of our losses have occurred during the next 5 minutes after lift off.

Progress of a space flight (continued)

g-forces are anatomically super-compressive, diverse (orbit and trip related), and demanding both for takeoff and reentry, though their effects can be moderated through training.



Progress of a space flight (continued)

Vibration:
- ❑ Man most sensitive to vibration frequencies of 4-10 cycles per sec.
- ❑ Range of the major internal organs natural resonance!
- ❑ Following which there is pain, nausea, headache and dizziness
- ❑ Prolonged exposure: organs begin tearing away from the mesentery

Noise:
- ❑ Maximum tolerance for noise is 140-150 dB. for one minute only (> = permanent deafness)
- ❑ Space boosters generate 145-175 dB during lift-off.

Progress of a space flight (continued)

Deep space is reached in 3-8 minutes. Immediately you begin to experience the effects of the dreaded Space Motion Sickness.
- ❑ >70% of crew members get SMS
- ❑ Onset in first 48-72 hours of the mission
- ❑ Greater in larger space vehicles
- ❑ Need head fixation and eye control
- ❑ May recur on return to earth

Progress of a space flight (continued)

And, possibly connected, fluid shifts begin to occur as your circulatory system's response to microgravity:
- ❑ The wet brain
- ❑ Shifts are cephalad-transcapillary transudation
- ❑ Nasal and sinus congestion
- ❑ Facial swelling
- ❑ Cardiac and JV distention
- ❑ Renal reaction to Plasma Hypovolemia
- ❑ ADH fourfold increase, increased HCT and ICV, decreased erythropoeitin
- ❑ Anemia

(Leach et al. '96)

Progress of a space flight (continued)

And muscle loss starts up right away.

- 10-20% of muscle mass lost on short flight missions
- Loss of muscle tone and strength
- Deconditioning within 5 days
- Progressive with time in space
- Loss of volume –atrophy 5%/mo
- Less resistance to fatigue

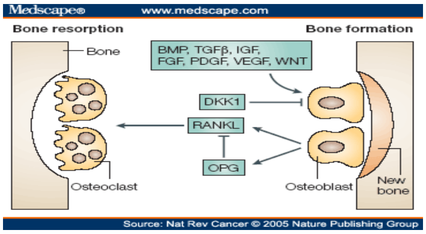
… even cardiac (heart) muscle!

- Studies by Perhonen et al. 2001 (U. Texas SW Medical Center) on 4 astronauts, 10 days space flight: LV mass decreased by 12+/-2.t% (P=.06).

Progress of a space flight (continued)

And then there's the also-dreaded bone loss:

- 1-3% per month.
- Increased loss of calcium in microgravity.



Progress of a space flight (continued)

But the most dangerous effects are those of high-energy, ionizing and atom-displacing radiation.

- Most GeV radiation in the solar system:
  - Protons 90%
  - Alpha particles 10%
  - HZEs (heavy nuclei) 1%
- No place in deep space is free of this cosmic radiation.
- Travel at near-light speed – as required for exploratory trips either propelled or mediated by wormholes – increases the energies involved and makes the shielding problems nearly insurmountable.

The close call of Apollos 16 and 17

Dr. Francis Cucinotta (NASA-JSC space medicine expert):

The legendary solar storm of August '72 (an X Class solar flare) by sheer luck occurred between two Apollo missions.

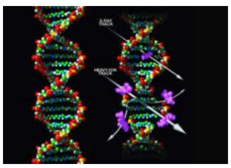
A moon walker caught in that storm would have absorbed a deadly dose of 400 rem.

Apollo 16 crew: Young, Mattingly, Duke. (NASA)

Progress of a space flight (continued)

If you are on your way to Mars, which would currently take three years,

- Estimates are that about 30 % of cells in the body will be traversed by HZE nuclei with Z values between 10 and 28.
- The 0g biologic effects of HZE nuclei on cancer induction, the central nervous system and eyes are not known but are possibly severe.



Basic requirements for human space flight to Mars and beyond

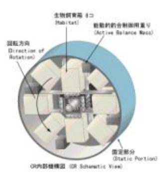
Artificial gravity, full time:

- Can do with the classic centrifuge concept, but this is bulky, heavy and expensive (~10 m radius, ~100 tons all by itself).

Radiation shielding, especially in forward direction:

- Probably kilotons of high-Z shield (e.g. lead), as magnetic shields would need fields both difficult to generate and dangerous to humans (Parker 2005).

It currently costs about $1M to launch a 1 kg brick into space. More, if more complex.



Small centrifuge designed for life science experiments on ISS: would be 1.25 m in radius and weigh about a ton (JAXA).

Still want to go to the Moon or Mars yourself?

A. Damn right. B. Yes please. C. No thanks.
D. Hell no.