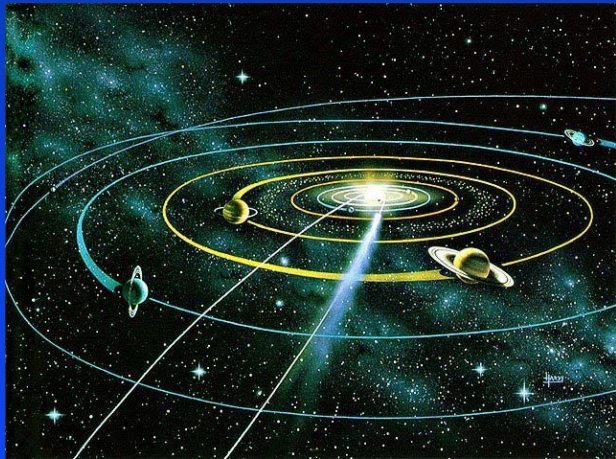


Advanced Space Propulsion Concepts for Interstellar Travel



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April 24, 2008

**American Institute of Aeronautics and Astronautics (AIAA)
Los Angeles Chapter Dinner Meeting**

Presentation Goals and Topics

- Provide a **high-level, information-only** overview of various propulsion concepts that, with sufficient development, may lead mankind to the stars.
 - Will give an **“evolutionary” overview** of propulsion technology.
- **No recommendations** of specific mission designs or propulsion systems will be made or implied.
- **No developmental timelines** or **cost estimates** will be given or assumed.

Discussion Chapters

- What is Interstellar Travel?
- Solar System and Interstellar Medium
- Challenges of “Manned” Star Flight
- Propulsion System Relationships/Requirements for Interstellar Travel
- Conventional Propulsion Schemes
- Advanced Conventional Schemes
- “Propellantless” Physics-Based Concepts
- Experimental Programs
- Concluding Remarks

What is Interstellar Travel?

- “Interstellar” is defined as “the region between stars”.
- **Why venture beyond our Solar System?**
 - ⚡ Explore the **Kuiper Belt** and the **Oort Cloud**, the theoretical home to long-period comets.
 - ⚡ Explore the nature of the **interstellar medium**.
 - Magnetic fields, low-energy galactic cosmic rays, etc.
 - ⚡ Explore the **influence** of the interstellar medium on the solar system, its dynamics and evolution.
 - And vice versa.
 - ⚡ Explore or better observe **nearby solar systems** (e.g. Alpha Centauri).
 - ⚡ **Search for life** beyond our local region of the galaxy.
 - ⚡ Because humans **love to explore!!!**

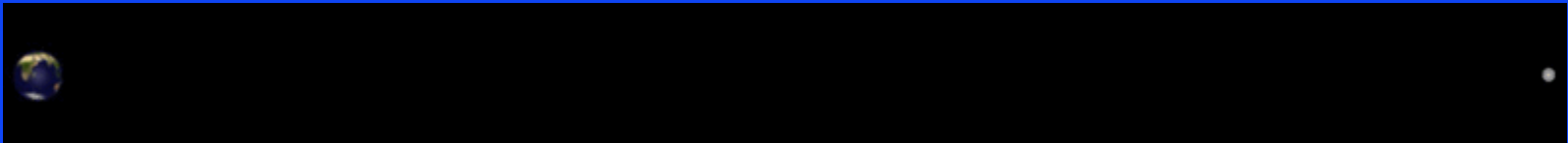
The Ultimate Objective:

For mankind to travel to the stars and return to Earth within a “reasonable fraction” (around 15 years) of a human lifetime.

Interstellar Measurement Definitions

Interstellar discussions require *large* units of measurement.

- Speed of Light, c :
(in vacuum)
 - 670,616,630 miles/hour
 - 186,282 miles/sec**
 - 983,571,056 feet/sec
 - $\sim 3 \times 10^8$ meters/sec**
- Astronomical Unit, AU:
 - Mean distance from Sun to Earth
 - 92,955,807 miles (1 AU)**
 - ~ 8.32 light-minutes
 - ~ 0.0000158 light years
- Light Year, LY:
 - Distance light travels in one year**
 - $\sim 5.88 \times 10^{12}$ miles
 - $\sim 63,241$ AU**



Earth

Moon



235,184 miles, 0.00253 AU, 1.26 seconds

Solar System and Local Interstellar Medium

▲ Pioneer 10



Launched 1972
 Distance: 89.7 AU
 Speed: 27590 mph
 (2.6 AU/yr =
 0.000041c)

✚ Voyager 1



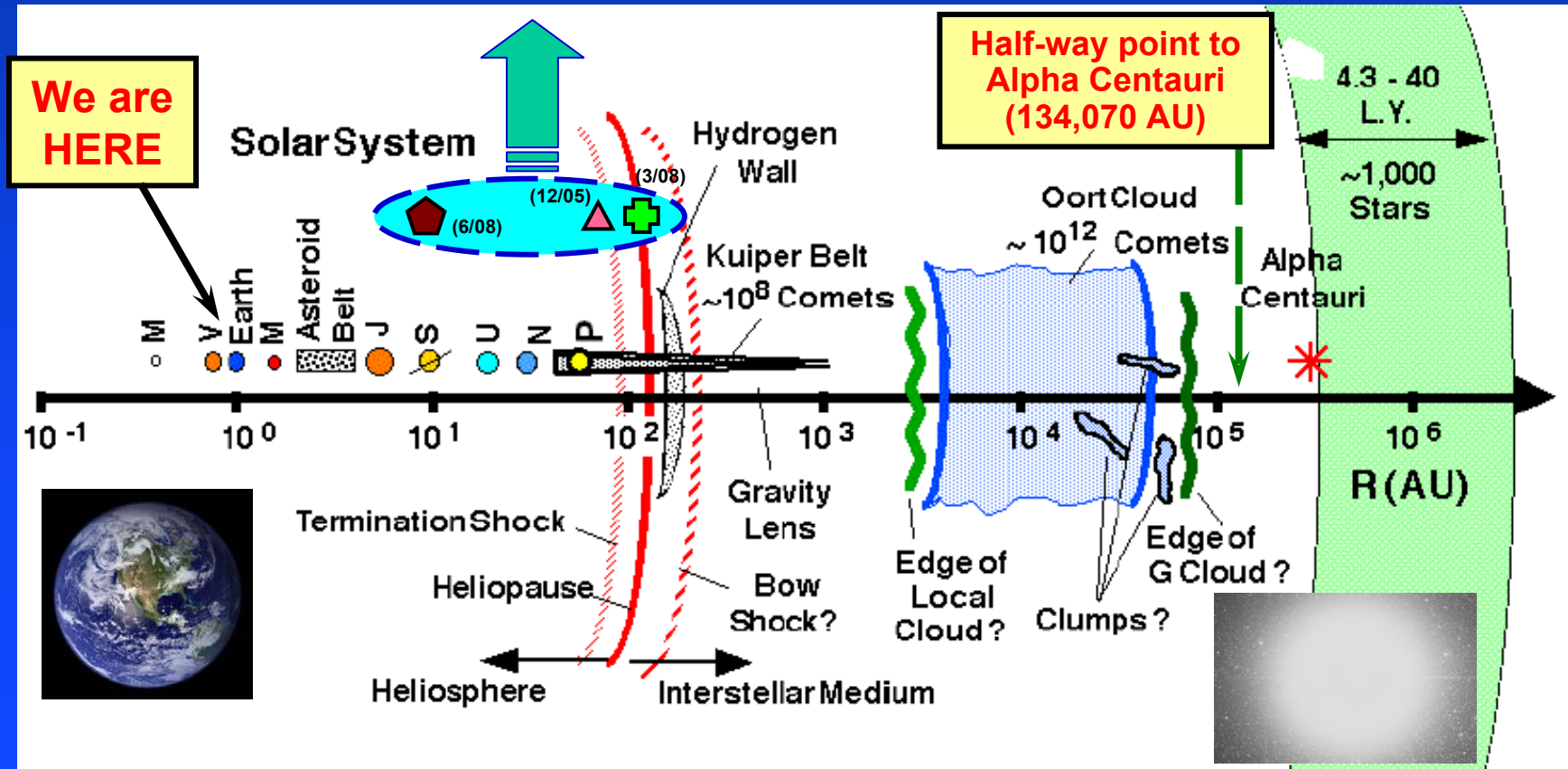
Launched 1977
 Distance: 105.9 AU
 Speed: 38350 mph
 (0.000057c)

◆ New Horizons



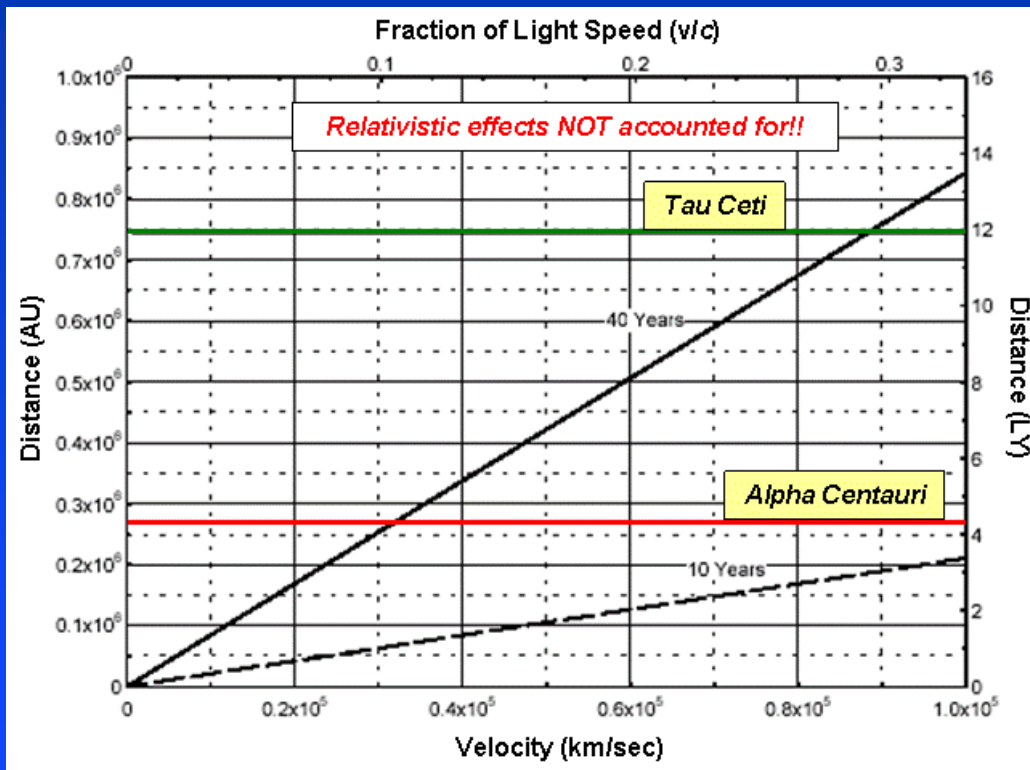
Launched 2006
 Distance: 9.6 AU
 Speed: 51559* mph
 (*Jupiter flyby
 0.000077c)

Pioneer 11 and Voyager 2 not shown



Challenges of "Manned" Star Flight

- For human star flight to be conceivable, spacecraft velocities need to be in the **tens of percent of the speed of light, or greater**.
 - Must account for Einstein's Relativity effects.



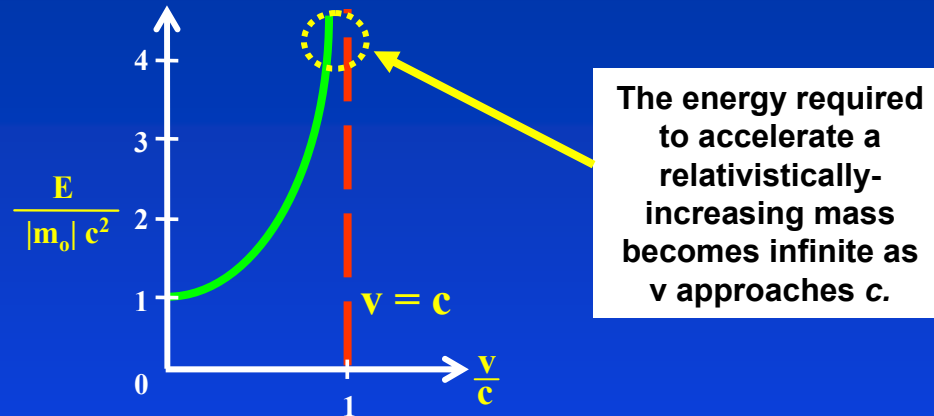
Minimum Requirements on Peak Velocity for Various 40-Year Interstellar Missions of Interest (Note: constant acceleration of 0.1 g assumed)

Destination	Minimum Peak Velocity		
	km/s	AU/year	V/c
Kuiper Belt	3.60	0.76	0.000012
Heliopause	14.39	3.04	0.000048
Oort Cloud	1,199	253	0.004
Alpha Centauri	37,474	7,905	0.125
Sirius	89,938	18,973	0.30
Epsilon Eridani	119,917	25,297	0.40
Tau Ceti	137,905	29,091	0.46

Current space probes are here

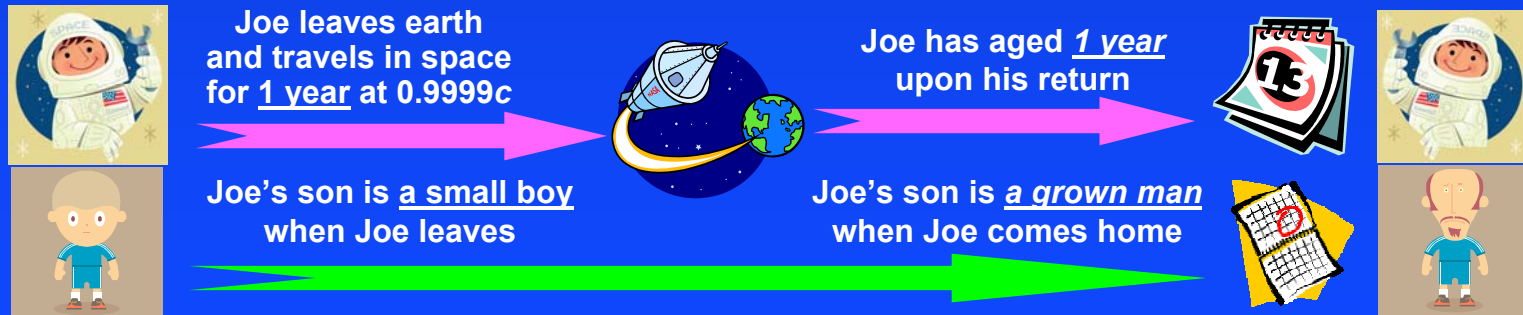
Challenges of "Manned" Star Flight

- **Relativity effects** must be considered even at very low sublight speeds.
 - 1) Relative **mass increases** as velocity gets closer to c , which requires more energy to further accelerate the mass ($E = mc^2$). **Scientifically Proven!**



Particles with mass can **NEVER** be accelerated to the speed of light!

- 2) The passage of **time is slower** for moving objects when measured with respect to a stationary observer (time dilation). **Scientifically Proven!**



- Issues with human aging during high-velocity trips.
- Communication delays between spacecraft and Earth.

Challenges of "Manned" Star Flight

- Impacts to **human physiology** during multi-year journeys through interstellar space.
 - ⚡ Extended exposure to zero-gravity, cosmic radiation, lack of reference or "familiarity" of surroundings.
 - ⚡ May have to place crew in hibernation for a majority of the journey.



From *Star Trek: Voyager*



From *Alien*



From *2001: A Space Odyssey*

From *Star Wars: The Empire Strikes Back*

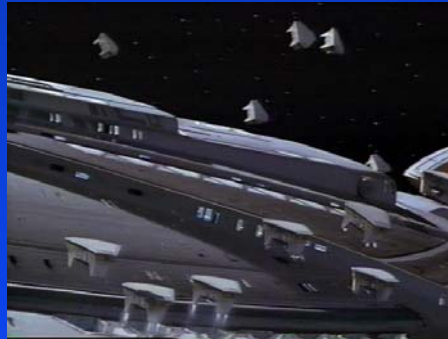


■ Hazards of Interstellar Space:

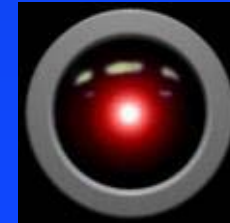
- ⚡ Radiation – Cosmic Background, vehicle power sources, gamma rays.
- ⚡ Dust and Small Bodies – particularly near the Kuiper Belt and Oort Cloud.
- ⚡ Extremely cold thermal environment (2-4°K)– solar light not strong enough to heat.

Challenges of "Manned" Star Flight

- No external resources for vehicle and crew systems.
 - ⚡ Solar power not viable between stars – too dim.
 - ⚡ Light from stars too dim for plant growth – affects food supply considerations.
 - ⚡ No planets or celestial bodies from which to mine/extract fuel, oxygen or water.
- Emergency plans - no rescue available, where to go if ship evacuated?



- System reliability and degradation.
- Self-repairing, autonomous systems – some form of artificial intelligence computing required.
- ***Many, many others.....***



Propulsion System Requirements

Based on **Conventional Propulsion Science**, here's what's needed:

- Stable and Continuous Thrust, F :

$$F_{\text{thrust}} = v_e \cdot \frac{\Delta m}{\Delta t}$$

- /// Vehicle **mass**, desired **acceleration** rate and desired final cruising **speed** will determine the thrust required.
- /// Used for **slowing down** close to destination since gravity-assist would have opposite effect.

- High Specific Impulse, I_{sp} :

$$F_{\text{thrust}} = I_{\text{sp}} \cdot \frac{\Delta m}{\Delta t} \cdot g_0 \Rightarrow I_{\text{sp}} = \frac{v_e}{g_0}$$

- /// Generally defined as the time (measured in **seconds**) to burn one pound mass of propellant while producing one pound force of thrust.
- /// Related to **exhaust velocity**, v_e .
- /// The higher the I_{sp} , the more "**propellant-efficient**" the engine.

- High Thrust-to-Weight:

- /// A high-thrust, low-weight propulsion system yields more manageable **vehicle mass** and allowable payload or fuel.

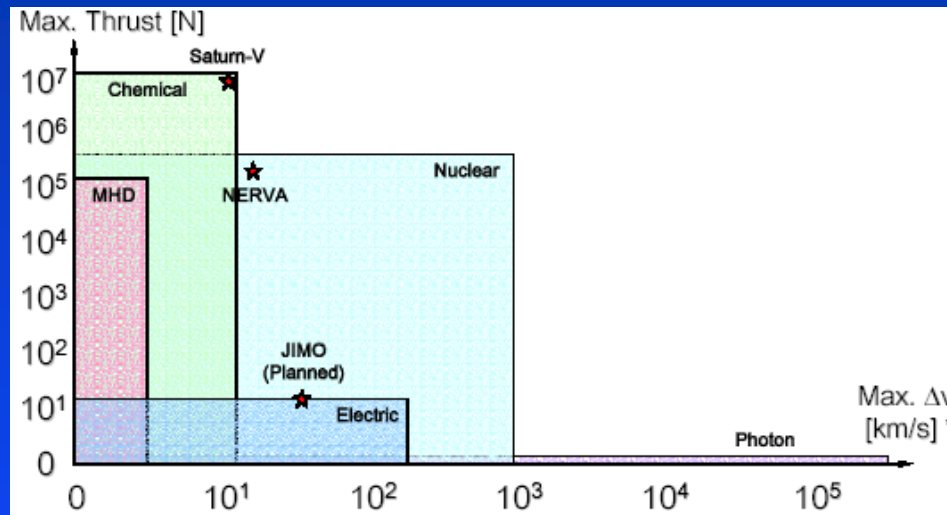
- Reliability:

- /// The engine system must be able to withstand the **harsh environments** and extended **duty cycles** required for interstellar missions.

Propulsion System Requirements

■ High Δv Capability:

- ⚡ The change required in the vehicle velocity vector to overcome gravitational effects and momentum in order to change direction or accelerate.
- ⚡ The higher the Δv , the more **propulsive energy** available.
- ⚡ Vehicle mass and trajectory determine Δv required.



Satellites
Solar Sys. Expl.
Oort Cloud
Slow Interstellar
Fast Interstellar

State-of-the-Art

Mission	Description	Typical Δv [km/s]
LEO, GEO, Planetary Targets	Satellites, Robotic missions	10-15
Human Planetary Exploration	Fast, direct trajectory	30 – 200
100 – 1,000 AU (Distance Sun-Earth)	Interstellar precursor mission	100
10,000 AU	Mission to Oorth cloud	1,000
Slow Interstellar	4.5 light-years in 40 years	30,000
Fast Interstellar	4.5 light-years in 10 years	120,000

Wow!



Propulsion Relationships

Generalized Isp, Δv and Thrust for select propulsion system types:

State-of-
the-Art

Propulsion System		Specific Impulse [s]	Maximum Δv [km/s] *	Maximum Thrust [N]
Chemical	Solid	250 – 310	5.7 – 7.1	10^7
	Liquid	300 – 500	6.9 – 11.5	10^7
MHD		< 200	4.6	10^5
Nuclear	Fission	500 – 800	11.5 – 20.7	10^6
	Fusion	10,000 – 100,000	230 – 2,300	10^5
	Antimatter	60,000	1,381	10^2
Electric	Electrothermal	150 – 1,200	3.5 – 27.6	10^1
	Electrostatic	1,200 – 10,000	27.6 - 230	3×10^{-1}
	Electromagnetic	700 – 5,000	16.1 – 115	10^2
Propellantless	Photon Rocket	3×10^7	unlimited	10^{-4}
Breakthrough		?	?	?

Assumes 90% of vehicle is propellant ($m/m_0 = 0.1$)

Propulsion System Caveats & Overview

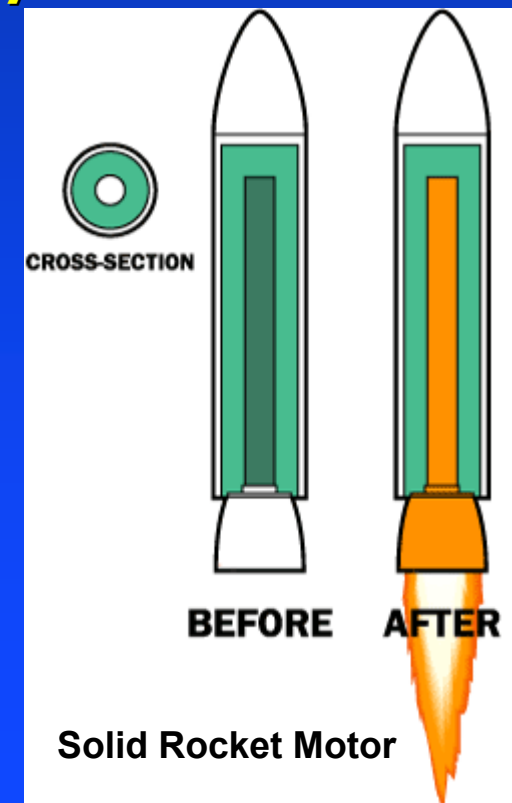
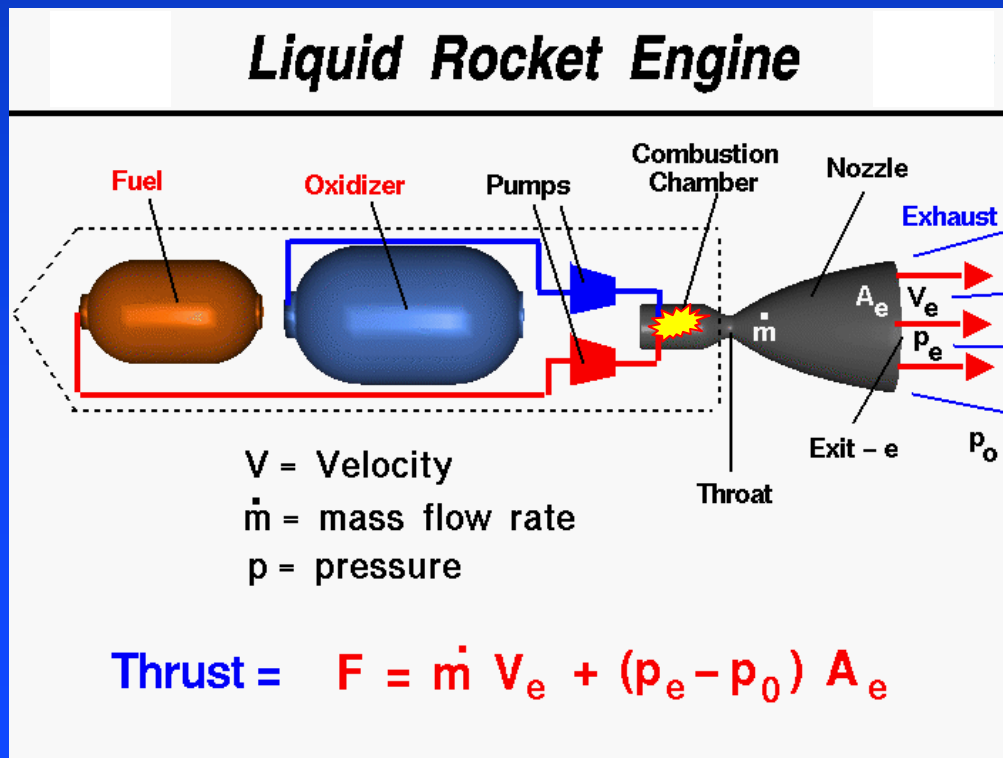
- Candidate concepts to be discussed are intended for a vehicle's **primary interstellar propulsion system.**
- Propulsion systems not discussed:
 - ⚡ Attitude control
 - ⚡ Earth-to-Orbit launch
 - ⚡ Electric
 - ⚡ Sail-type
 - ⚡ Beamed energy
- Estimated status and **NASA TRL**, if available.

Discussion Categories

- "State-of-the-Art": Conventional "Mass Ejection" Systems
 - ⚡ Best Available and Improvements
- Advanced Conventional Concepts
 - ⚡ Nuclear Fission
 - ⚡ Nuclear Fusion
 - ⚡ Matter/Antimatter
 - ⚡ Other Concepts
- "Propellantless" Physics-Based Approaches
 - ⚡ Space-Time Warp Drives
 - ⚡ Gravity-Inertia-Electromagnetic
 - ⚡ Alternate Dimension / Hyperspace

State-of-the-Art: Conventional Mass Ejection

- 99% of all rocket engines operate on the principle of **chemical combustion**.
- Pump fuel and oxidizer into a chamber, burn them, eject hot, high-pressure products through a nozzle. Or burn a solid propellant.
- Multiple variations on liquid engine cycle design each with pros/cons depending on application.
- Decades of flight history – **proven technology**.



The Best Available Today

- **Liquid Hydrogen (LH₂) / Liquid Oxygen (LOX)** engine system.
- **Max. Theoretical I_{sp}: ~470 sec**
- Other readily-available fuel/oxidizer combinations and solid-fueled engines have lower Isp and Δv.
- Technology has reached an upper limit of development.
 - Substantial investments for marginal improvements.



RS-68 (Delta IV)
LH₂/LOX Gas Generator
Vac I_{sp} = 410 s
Max. F_{vac} = 751,000 lbf



SSME (Space Shuttle)
LH₂/LOX Fuel-Rich Staged Comb.
Vac I_{sp} = 453 s
Max. F_{vac} = 513,000 lbf



RL10 (Upper Stages)
LH₂/LOX Expander
Vac I_{sp} = 444 s
Max. F_{vac} = 23,500 lbf

Improvements to the State-of-the-Art

- “Easier said than done.”
- **Increasing propellant density** by 10% may yield a 25% increase in payload capacity.
 - ⚡ Example: Use slush hydrogen instead of liquid hydrogen.
- **Increasing I_{sp}** by 10% may yield a 40% increase in payload capacity.
 - ⚡ **Tripropellants:**
 - More energetic than LH2/LOX, but products are not gaseous.
 - Could be highly toxic.
 - ⚡ **High Energy Density Materials (HEDM):**
 - Metastable helium could yield $I_{sp} \approx 3,100$ s.
 - Metallic hydrogen could yield $I_{sp} \approx 1,700$ s. (J. Cole NASA/MSFC)
- Each requires significant investment and technology development.
- The chemical mass required to get to Alpha Centauri in 900 years using chemical systems **exceeds the mass of the known universe!**

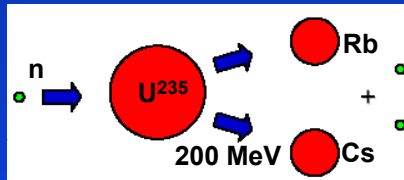
In any case, chemical-combustion systems are NOT viable for interstellar missions.

Advanced Conventional Systems

- Utilizes alternative methods to combustion for adding heat energy to a **working fluid** propellant.

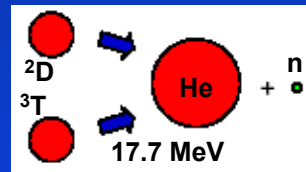
Nuclear Fission

"Split" atomic nuclei by bombardment of energetic particles.



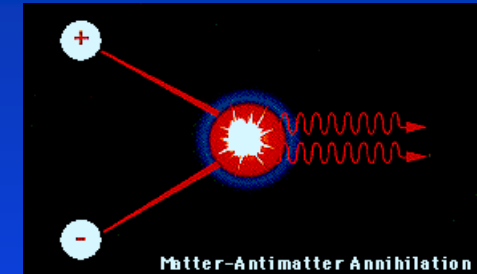
Nuclear Fusion

Fuse atomic nuclei by high-energy collisions.

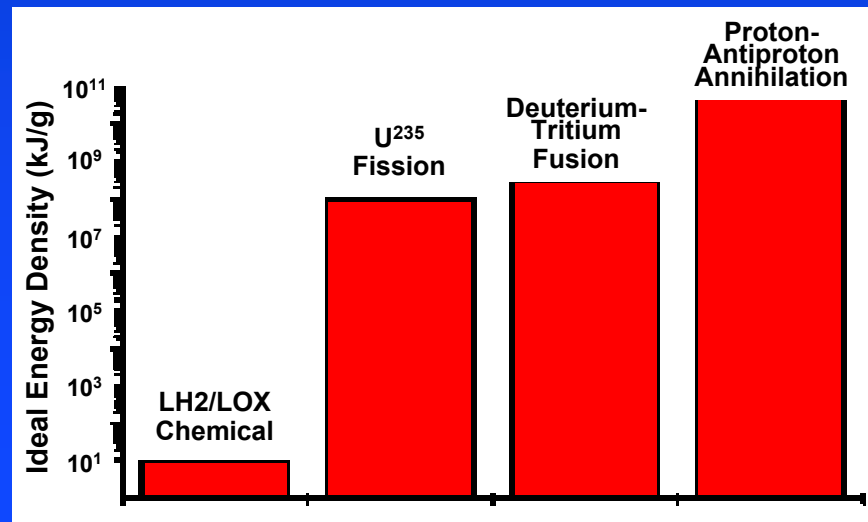


Matter/Antimatter Annihilation

Convert oppositely-charged particles to energy.



- Can provide **9 orders of magnitude higher energy density** than the best chemical system – **yields high Isp!**

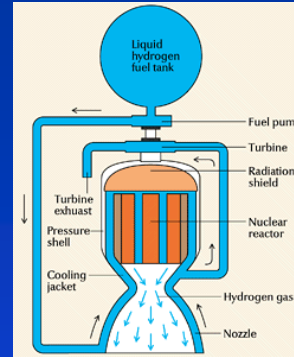


Solid-Core Nuclear Fission

- Use nuclear **fission** to heat hydrogen and expel it through nozzle.

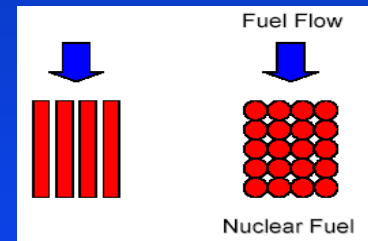
- ▣ **NERVA** – 1961-1972

- One of many nuclear programs.
- Ground tested for **3 hrs 48 min** continuous at 74.8 klbf thrust.
- Potential for $I_{sp} \sim 1000$ sec.
- \$2.4B spent



- ▣ **Particle Bed Reactor** – 1980's

- More surface area for fission process, higher fission density, compact design.
- Thrust: 180 kN (40 klbf)
- I_{sp} : ~ 1000 sec.



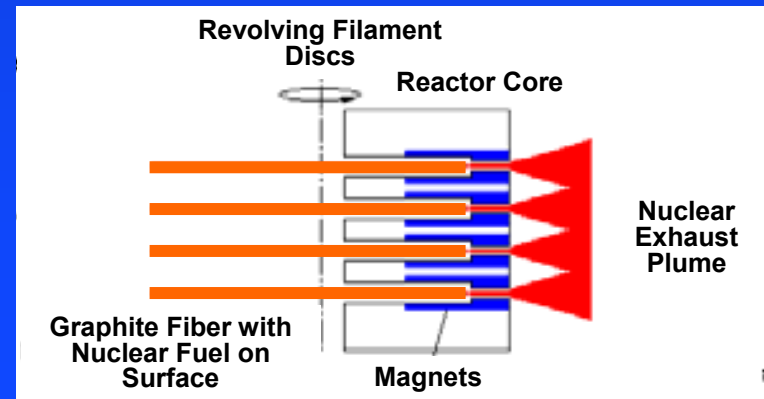
Linear fuel rod arrangement

Particle bed arrangement



- ▣ **Fission Fragment Concept** – (c. 2000)

- Magnetically accelerates the ionized products of nuclear fission as exhaust.
- No working fluid.
- I_{sp} : 1,000,000 sec to \sim speed of light, c .
- Highly radioactive!!

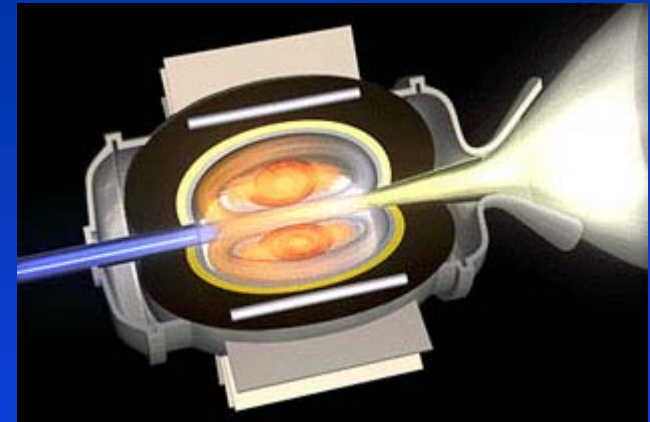


Gas-Core Nuclear Fission

- Fission fuel in **liquid or gas form** is injected and contained in high-temperature, magnetically-confined fission **plasma**.

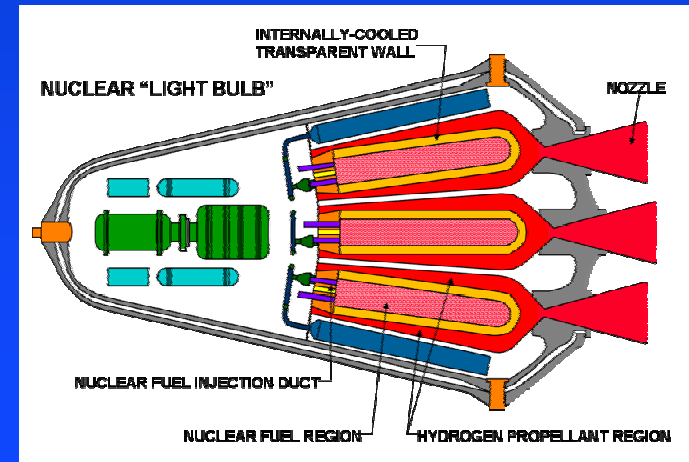
/// Open-Cycle Gas Core

- Working fluid (LH2) heated through plasma and ejected through nozzle.
- **Exhaust is irradiated** and carries fissionable fuel with it – not good!
- Magnetic containment of plasma is challenging.
- I_{sp} : 3,000 – 7,000 sec
- Can be launched in dormant state (off).



/// Closed-Cycle Gas Core

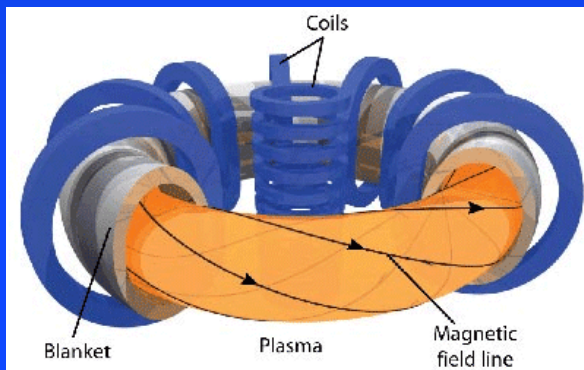
- Gaseous fission process contained in ablatable transparent vessels (quartz).
- Hydrogen used to cool containment vessel walls.
- I_{sp} : 1,500 – 2,100 sec
- Thrust: 45 – 450 kN (101 klbf).



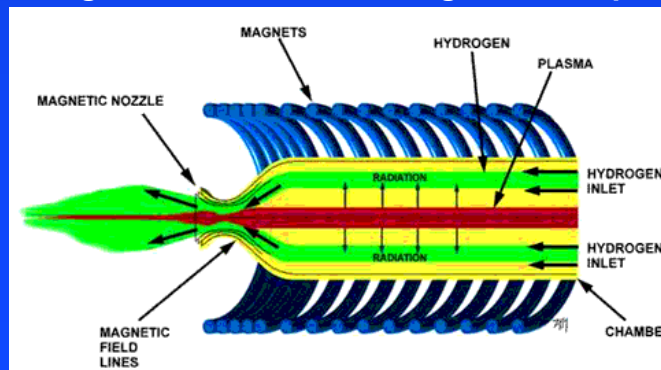
Nuclear Fusion

- Fusion requires overpowering the **electrostatic repulsion** of two nuclear cores and keeping them together.
- Fusion products and energy release are contained within a **plasma**.
 - ⚡ Plasma can not contact the containment vessel walls or it will cool and neutralize, thus stopping the fusion process.
- Has yet to yield **greater than 1%** of the energy required to sustain it.
 - ⚡ Joint European Torus (JET) achieved a 60% initial energy output for one minute (1997).
- For propulsion, heat a working fluid or expel reaction products directly.
- The primary technical challenges are **containment** and **sustainment**.
- Three main types of fusion plasma containment and propulsion concepts:
 - ⚡ **Magnetic Confinement (MCF)**
 - Magnetic fields and magnetic mirrors keep plasma away from walls.
 - **Tokamak** arrangement or linear device with magnetic mirrors.

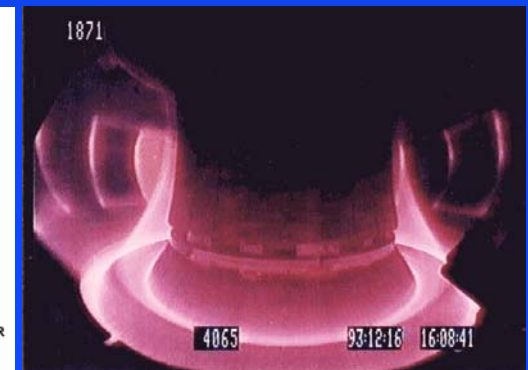
Tokamak Fields



Magnetic Mirror Fusion Engine Concept



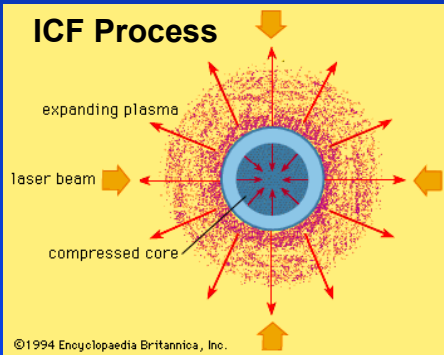
Fusion Plasma



Nuclear Fusion

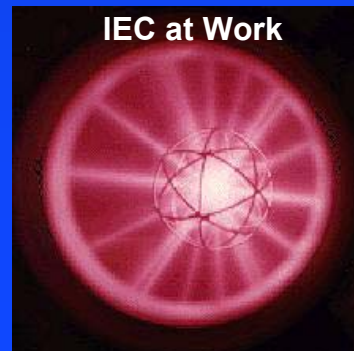
/// Inertial Confinement (ICF)

- Ultra-high-power lasers or particle beams focus plasma into a small region.
- Some concepts use pellets of fusible material compressed by the beams (pulse fusion).
- Pellet core can reach temps of **100 million degrees K!**



/// Inertial Electrostatic Confinement (IEC)

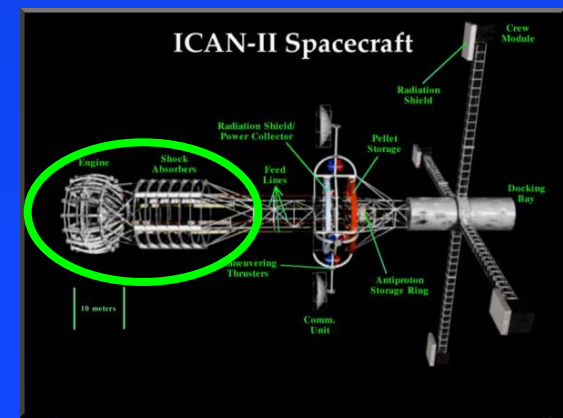
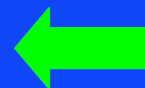
- Bombards fusion plasma with particles or ions to hold it in place.
- Ions generated by 100 kV potential have enough energy to perform fusion.



Matter/Antimatter Annihilation

- Every elementary particle has a counterpart that is of opposite charge, but same mass.
 - ▄ Electron (-) → **Positron (+)** -and- Proton (+) → **Antiproton (-)**
- When two similar mass particles collide, they are **completely converted to energy**.
 - ▄ **Highest energy density** process in nature: 1 kg matter + 1 kg AM = **1.8×10^{17} J!**
 - ▄ Antimatter can be sustained indefinitely as long as it does not contact normal matter.
 - ▄ Must be confined using magnetic fields.
- A few **grams** of antimatter would contain enough energy to propel a spacecraft to Mars in one month, but creating it would take **millions of years!**
 - ▄ Global annual production is **2-20 nanograms/yr** at a cost of **\$300B per milligram!** Very inefficient creation process.
- M/AM propulsion systems could reach $I_{sp} \sim 10,000,000$ sec - Viable for multi-decade, unmanned interstellar missions, but not for shorter, manned missions.

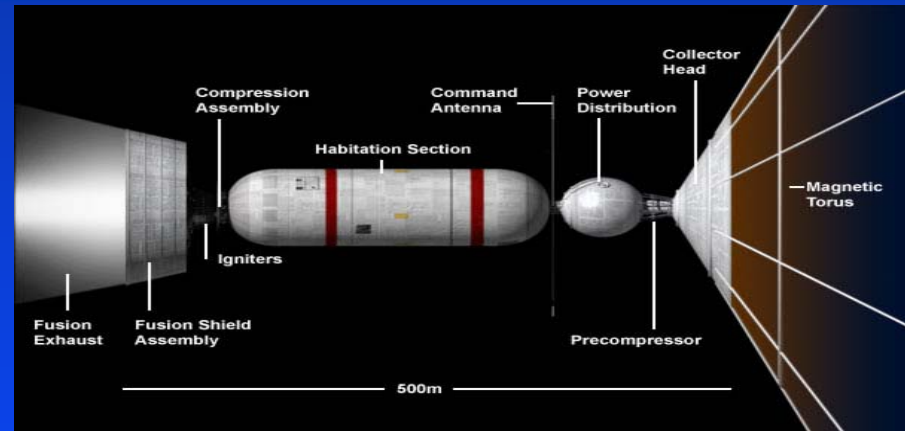
ACMF: Antimatter Catalyzed
Microfission/Fusion



Other Advanced Conventional Systems

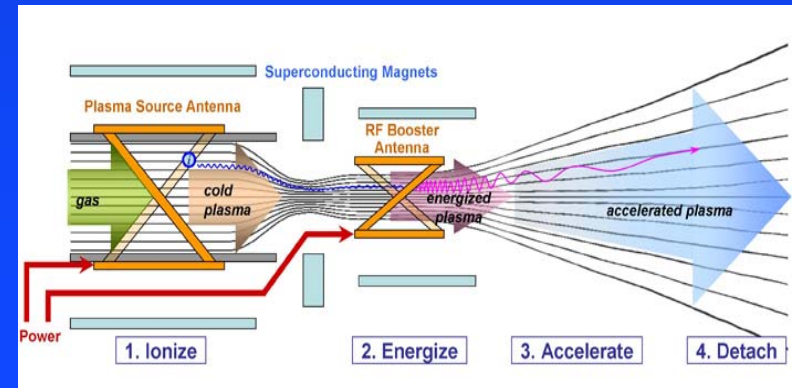
■ Interstellar Ramjet / Bussard Hydrogen Ramjet (c.1960)

- ⚡ Scoops up interstellar hydrogen for propulsion/power by funneling it into a collector using magnetic fields.
- ⚡ Fields must sweep **10^{18} cu. meters** of space to collect **1 gram** of hydrogen!
- ⚡ **Infinite I_{sp}** since hydrogen fuel collected in-situ.



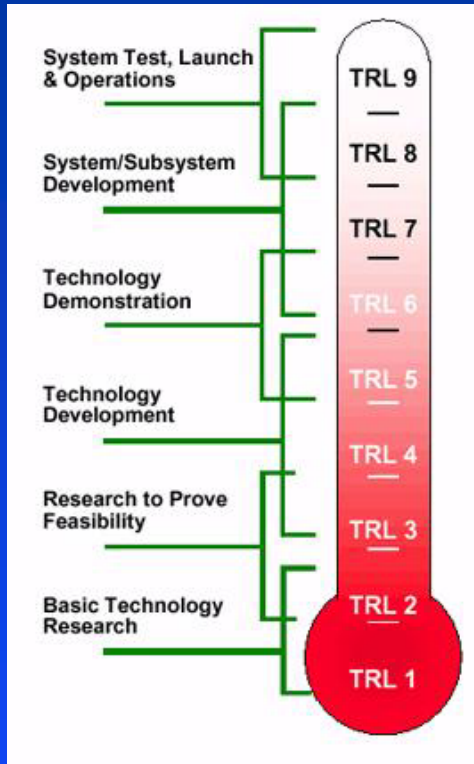
■ VArIable Specific Impulse Magnetoplasma Rocket (VASIMR)

- ⚡ Heats and confines hydrogen plasma through the use of magnetic fields and EM energy.
- ⚡ I_{sp} variable by changing RF heating energy.
- ⚡ I_{sp} : 3,000 – 30,000 sec.
- ⚡ Thrust: 1 - 2 kN (450 lbf)
- ⚡ Component testing in progress.



Current Status on Conventional Systems

NASA Technical Readiness Level (TRL) Guide



Concept	NASA TRL*	Notes
Chemical	9	Interstellar applications unknown
Solid-Core Fission	5	Extensive history, NERVA, systems well-understood
VASIMR	4	Experimental R&D testing of specific components
Fusion	3	Significant R&D work on terrestrial systems
Gas-Core Fission	3	Critical proof-of-concept work performed
Interstellar Ramjet	2	Concept and formulation work, major technology issues to be addressed
Fission Fragment	1	Little work done beyond conceptual
Matter/Antimatter	1	Basic issues and exploratory work, major technology issues to be addressed

* TRL Assessment from Chew, G., Doyle, M., and Stancati, M., "Interstellar Spaceflight Primer," Report for NASA Contract NASW-5067, Prepared for NASA Headquarters, Code SD, by Science Applications International Corporation, Schaumburg, IL, February 2001, pp. 86 & 87.

Bottom Line on Conventional Systems

Current/near-term propulsion technology would allow exploration of the **solar system** within a "reasonable" time, but won't work for a manned interstellar mission within a human lifetime.

Science needs a **paradigm shift** in propulsion technology:
Move from mechanics-based to **physics-based concepts**.

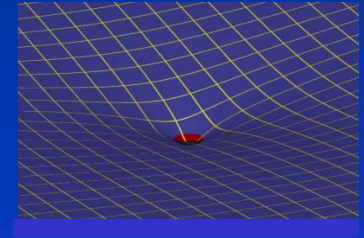
"Propellantless" Physics-Based Concepts

- What's different about these concepts compared to the others?
 - ⚡ **No mass ejection** (propellantless)!
 - **Eliminates** the necessity to carry fuel or propellant.
 - ⚡ Use the **space-time medium** as the energy source or "working fluid".
 - I_{sp} becomes meaningless.
 - ⚡ Rely on **fluidic space-time, quantum physics, string theory, electromagnetism** and/or **gravity** to possibly create propulsive forces.
 - ⚡ Some employ aspects of cosmological genres like **dark matter, dark energy, black holes, gravity waves, alternate dimensions and universal expansion**.
 - ⚡ All are **highly-speculative**, but have strong foundations rooted in current scientific knowledge and experimental observations.
- These concepts could not only propel a vehicle at very high sublight speeds ($\sim 70-99\%$), but at **the speed of light or beyond!**
- **Necessary for truly reasonable, manned interstellar missions!**

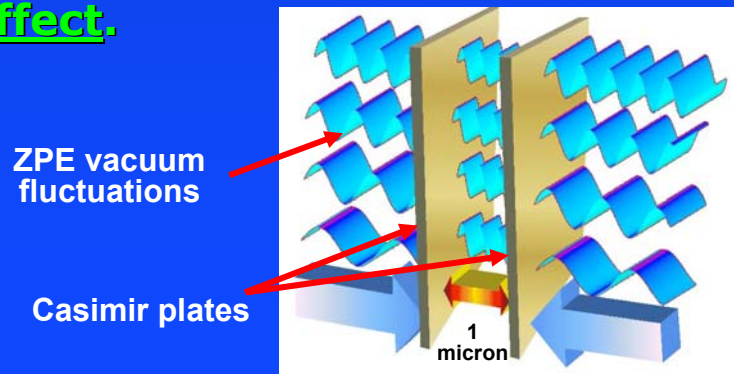
And now for something completely different...

Important Definitions

- Space-time Metric – The 3 spatial +1 temporal dimensional continuum in which all physical quantities exist. The medium through which electromagnetic energy permeates.



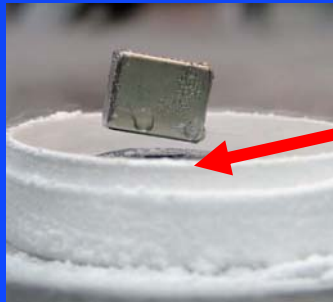
- Negative Mass/Matter – Matter that produces negative (anti) gravity contrary to normal, positive matter. A negative mass object would have repulsive gravity. Sometimes called “exotic” matter. Antimatter is not negative matter since it has positive mass, but opposite charge.
- Zero-Point Energy/Field (ZPE/ZPF) - The random, instantaneous, quantum energy fluctuations in a volume of empty space proposed through the quantum-mechanical view of the Universe. The smaller the length scale under consideration (approaching “zero” length), the larger the random fluctuations in energy, hence “zero-point energy”. Demonstrated through the Casimir effect.



- ZPF “radiation pressure” forces two parallel conducting plates together with a measurable force.
- 1 cm sq. plates spaced at 1 micron generates $10^{-7}N$

Important Definitions

- **String Theory** – A universe model that proposes a theory for the existence of everything. Proposes that space-time itself is composed of single-element entities called “strings” at imperceptible lengths (Planck lengths or smaller) that randomly interact to produce all elementary particles and EM fields.
- **Brane or Brane World** – Membrane-like continuum composed of strings. Sometimes considered as “alternate universe”, compactified dimension, alternate dimension or space-time called a D-Brane.
- **Planck Length** - 1.6×10^{-35} m, 6.3×10^{-34} in., or about 10^{-20} times the diameter of a proton. Derived from c , G and \hbar .
- **Superconductor** – A material that, at some critical temperature, will develop the ability to store current without resistance and will produce a magnetic field. This is accomplished by the binding of electrons to form Cooper pairs at some critical temperature (usually only a few degrees K) dependant on the material.



Superconductor
demonstrating the
Meissner Effect



Things to Remember...

- Einstein's field equations, quantum field theory and both Special and General Relativity **do not discount FTL travel!**
- Science does not know the true **nature of space-time**.
 - /// Does it have fluid-like properties?
 - /// Is it pure ZPE?
 - /// Can energy be extracted from it?
 - /// Can it be manipulated without using mass?
- Science does not know the true **nature of mass**.
 - /// Created by Higgs particles and fields?
 - /// Formed by knotted strings and quantum filaments?
- Science does not know the true **nature of gravity and inertia**.
 - /// Created by "gravitons"?
 - /// Caused by the distortion and displacement of space-time?
 - /// Generated as the force from distant matter in the universe?
 - /// How fast does it propagate through space-time?
- No proven model exists that explains **"everything"**.
 - /// Gravity-electromagnetism (GEM)?
 - /// String/Brane theory?
 - /// Heim's theories?
 - /// Tri-Space?
- Science does not know the nature of **Dark Matter & Dark Energy**.
 - /// Can it be synthesized?
 - /// Can it be used for propulsion?



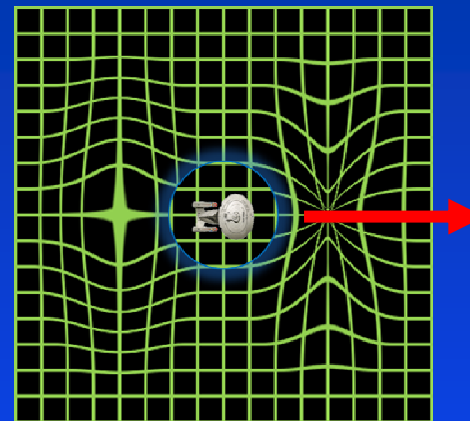
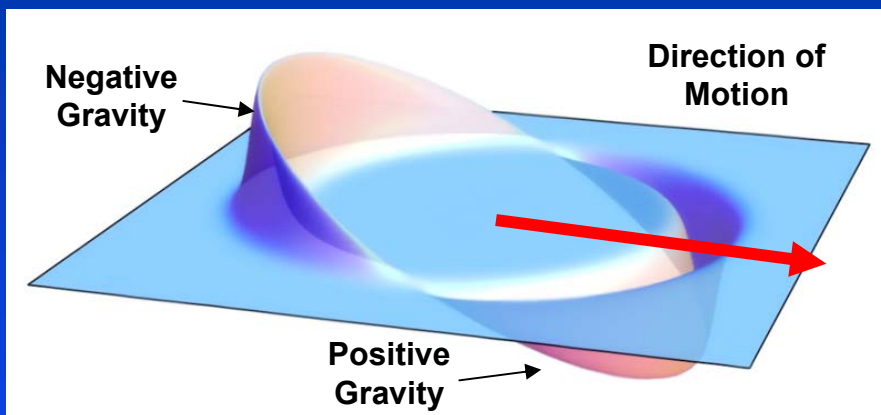
Categories of Propellantless Concepts

The concepts listed below are some of the “more popular” ones in their genre and have many variants beyond those presented.

- *Space-Time Warp Systems* – Modify the space-time continuum to mitigate relativistic effects and allow for travel.
 - ⚡ **Alcubierre Warp Drive**
 - ⚡ **Traversable Wormholes**
- *Gravity/Inertia/Electromagnetic Coupling* – Mitigate, reduce or artificially create gravity/inertia propulsive forces through novel electromagnetic interactions (Grand Unified Theory).
 - ⚡ **Heim Theory**
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 - ⚡ **Mach’s Principle and Mass Fluctuations**
- *Alternate Dimensions / “Hyperspace”* – Enter an alternate space-time where relativistic effects are circumvented and faster-than-light travel is natural and possible.
 - ⚡ **Hyperspace in General Relativity**
 - ⚡ **String Theory-Based Alcubierre Drive**
 - ⚡ **Tri-Space and Fluidic Space-Time**

Alcubierre Warp Drive

- Generate a positive (attractive) gravity well in front of the vehicle and a negative (repulsive) well behind it. The region between the two fields will move through space-time at c or greater unaffected by relativistic effects.
- An elegant approach for a vehicle to “ride a gravity wave”.



■ Pros:

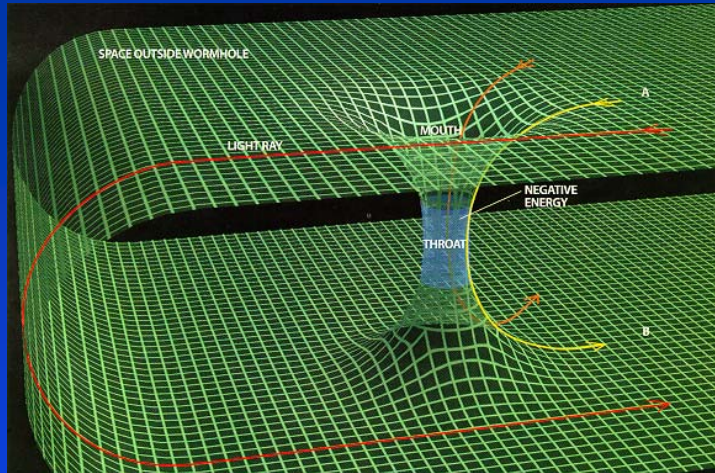
- ⌘ Simple and makes sense. A sound theory.
- ⌘ Many variants explored by many theoretical physicists.
- ⌘ The mathematics have been contrived and solved (general relativity).
- ⌘ Negative energy may be possible through the **Casimir effect and ZPE**.

■ Cons:

- ⌘ Requires **controllable, negative mass** to create repulsive gravity, possibly as much as **10^{67} grams**. Others claim only a few milligrams are required.
- ⌘ Not guaranteed to move FTL.
- ⌘ Navigation difficult or impossible.

Traversable Wormholes

- Connect two regions of space with a “tunnel” through which information/mass can travel.



■ Pros:

- ⚡ Instantaneous travel between two points – **no relativistic effects**.
- ⚡ Light speed never exceeded locally.
- ⚡ The mathematics have been extensively studied and deemed possible.

■ Cons:

- ⚡ Requires **gigantic quantities** (neutron star equivalent) of both negative and positive mass as well as **enormous magnetic fields** ($>10^{13}$ Tesla) to create a tunnel large enough for a spacecraft.
- ⚡ Requires that the other end of the “hole” be taken through.
- ⚡ Single-point destination, if known. Navigation not possible.
- ⚡ Stability issues and collapse during transit.

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Heim Theory

- Developed by Burkhard Heim in the 1970's-1980's as an approach to the "Theory of Everything".
 - /// Heavy in mathematics.
 - /// Attempts to unify gravitation and quantum mechanics.
- Involves a 6, 8 or 12-dimension "quantum hyperspace" in which fundamental particles and their interactions are predicted.
 - /// Predictions of the masses of neutrino.
 - /// Predictions of new particles.
 - /// Predictions of excited states of existing particles.
- Convert photons into "**gravito-photons**" via quantum hyperspace resulting in a measurable force.
 - Could be used for propulsion.

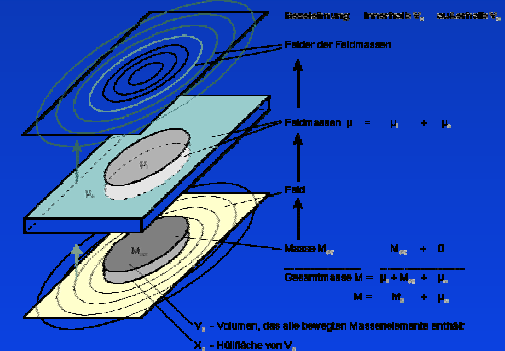
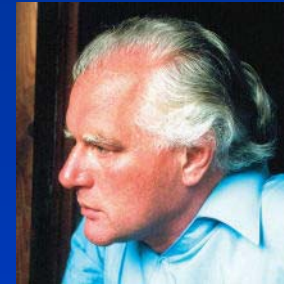


Abbildung aus Burkhard Heim: Überholgeschwindigkeit des Lichtes?, Kap. 10, (© Carl Friedrich, 1989) Verlag-Bloch

■ Pros:

- /// Walter Dröscher and Jochem Häuser (Germany) have devised several ways to extend Heim Theory into advanced propulsion concepts.
- /// Beginning to gain recognition as a viable alternate to the Standard Model, modern physics and quantum mechanics.

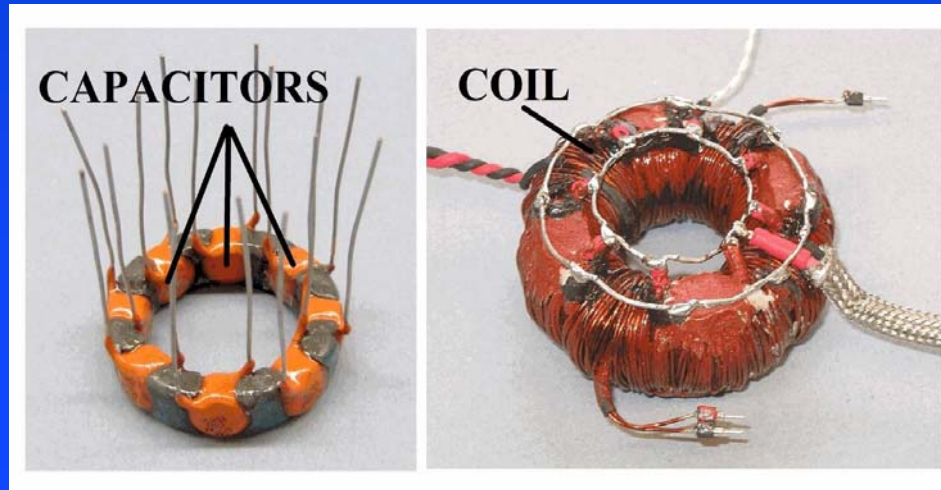
■ Cons:

- /// Predicts new particles and forces not yet observed or experimentally verified.
- /// Does not account for some particles and forces observed.
- /// Only one peer-reviewed publication by Heim (1977), but other non-reviewed documents exist.

Mach's Principle and Mass Fluctuations

- **Mach's Principle:** Inertia is felt by an accelerating object due to the radiative gravitational effects of the distant matter in the universe.
- Accelerating masses will have a different internal energy than when at rest.
 - ⚡ Mass energy is not Lorentz invariant (changes wrt/observer).
 - ⚡ How does the energy change when the "resistive" inertial forces are accounted for?
- If the mass of an object could be made to fluctuate rapidly, the time-averaged "pull" on the object due to Mach's Principle may result in a **directional force**.
- Use EM fields to rapidly create mass fluctuations which the distant matter in the universe will react upon to develop a net force.
 - ⚡ Accelerate the dielectric ions in charged capacitors and subject them to an oscillating magnetic field.

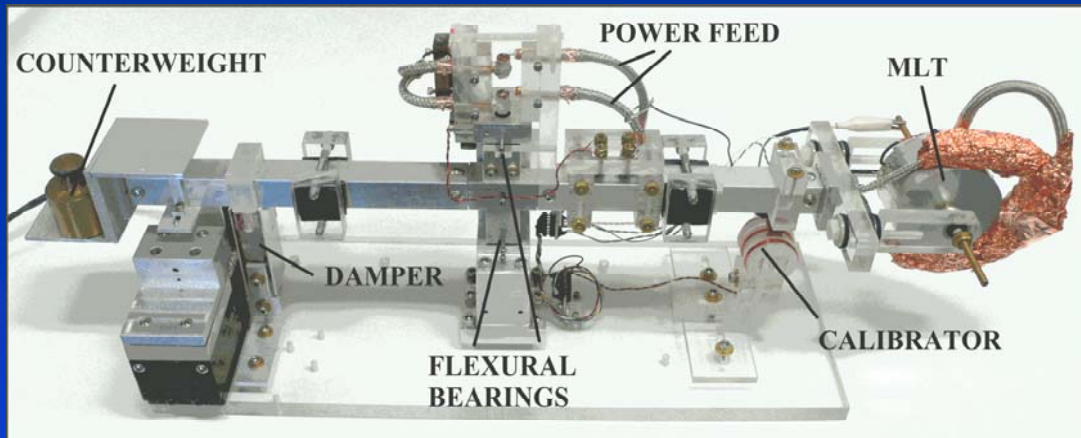
Under
construction



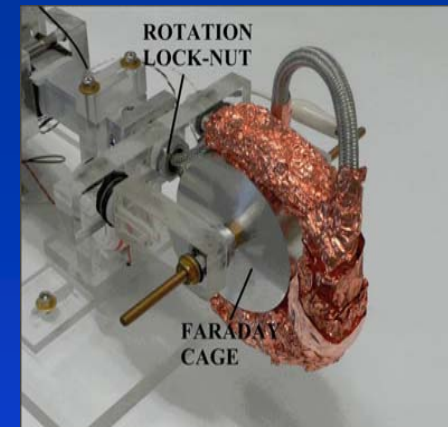
Completed

A Mach-Lorentz Thruster (MLT)

Mach's Principle and Mass Fluctuations



Custom-Built Force Balance



MLT Mounting

■ Pros:

- **Experiments in progress** by Dr. James Woodward (CalState/Fullerton) and Paul March (retired, Lockheed-Martin) **with favorable results!**
- To date, laboratory MLTs have produced up to **100 μN** (comparable to small electric thrusters), but measurements need to be refined.
- Large-scale MLTs or Unidirectional Force Generators (UFGs) may also **produce "negative" mass** required for other propellantless concepts.
- Simple hardware with reasonable power requirements.

■ Cons:

- Fundamental theory difficult to understand.
- Difficult to measure and quantify mass fluctuation effects due to signal noise contamination and balance effects.
- Propulsive performance of MLTs not yet quantified (may only be capable of sublight speeds).

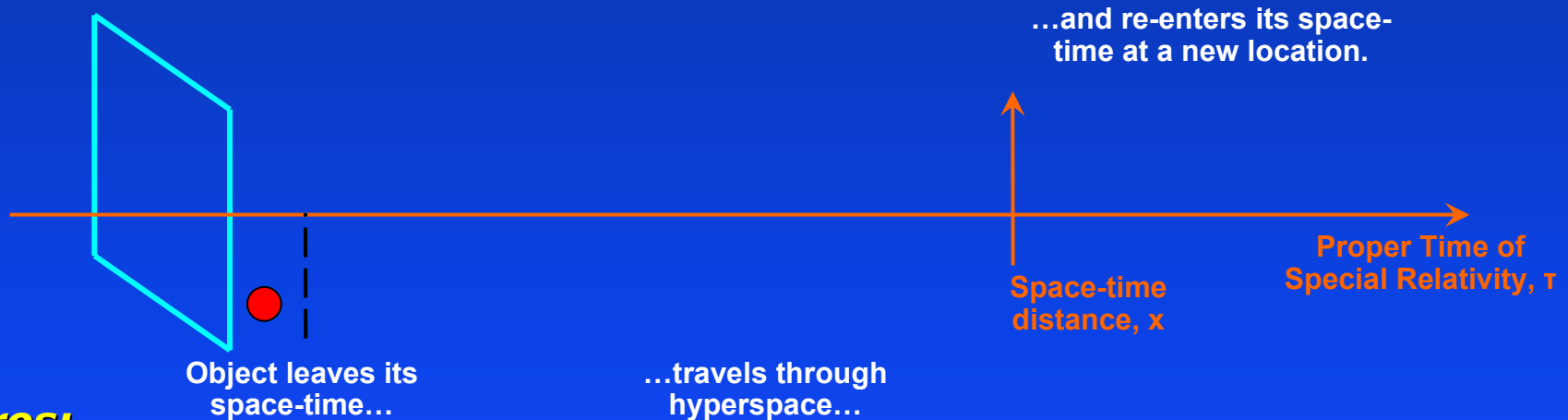
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Hyperspace in General Relativity

- Provides the construct of an **added dimension, or "hyperspace"**, to our 3+1 space-time through General Relativity.
 - ▮ Based on a re-definition of time.
 - ▮ All particles in hyperspace move at the speed of light.
 - ▮ Hyperspace topology may also help to explain universal expansion.
- Shift or "rotate" the object into hyperspace where time is measured differently, but where travel is allowed at c or greater.



■ Pros:

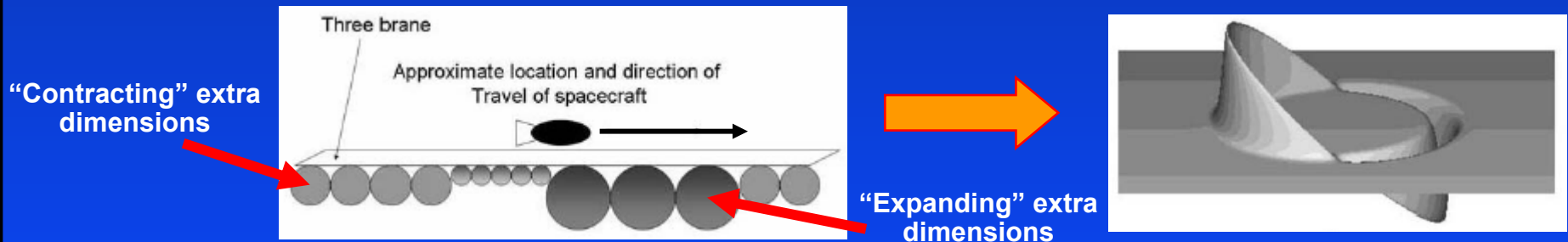
- ▮ Causality is eliminated by definition of hyperspace.
- ▮ **Faster than light travel is possible!**
- ▮ Examines hyperspace "optics" to utilize high-frequency gravitational waves and particle interaction.
- ▮ G. Fontana (University of Trento, Italy) continually refining theory.

■ Cons:

- ▮ Highly mathematical and somewhat esoteric.
- ▮ Hyperspace only exists in a mathematical sense – may be untestable.

String Theory-Based Alcubierre Drive

- Relates the cosmological constant to **Casimir energy** of Planck-scale, compactified (extra) dimensions in brane-world theory.
 - ⚡ Utilizes quantum field theory instead of Special Relativity.
 - ⚡ Requires ultra high energies to explore.
- Would utilize the negative energy densities generated by the Casimir effect to influence extra dimensions.
- Adjust the radii of the extra dimensions fore and aft of the vehicle leading to local space-time changes in the cosmological constant.
 - ⚡ Develops an Alcubierre-like space-time distortion.



■ Pros:

- ⚡ No relativistic effects (similar to Alcubierre Drive).
- ⚡ Does not directly use negative mass.
- ⚡ **Faster than light travel is possible with upper limit of $1032c!$**
- ⚡ R. Obousy (Baylor University) continuing to refine theory.

■ Cons:

- ⚡ Requires the existence and manipulation of as yet unobserved extra dimensions.
- ⚡ A significant/infinite number of extra dimensions may need to be altered.
- ⚡ Navigation not considered.

Tri-Space and Trans-Space FTL Travel

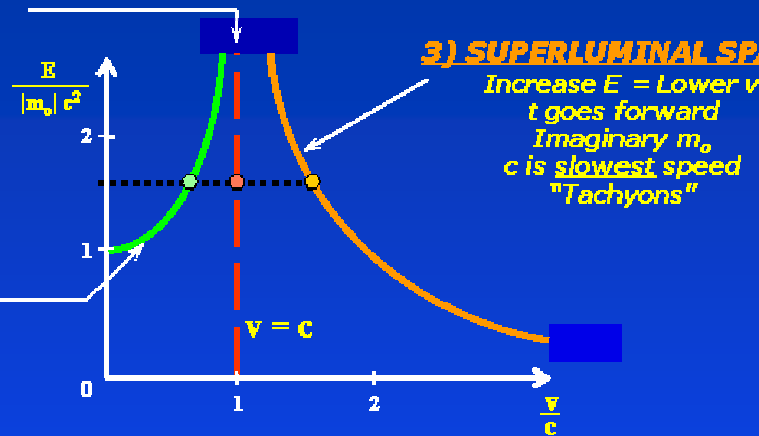
- Proposes that the universe consists of **three, co-located space-times**: subluminal ($v < c$), luminal ($v = c$) and superluminal ($v > c$). Hence "Tri-space".

2) LUMINAL SPACETIME:

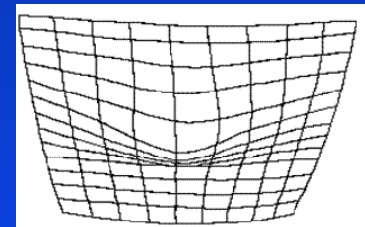
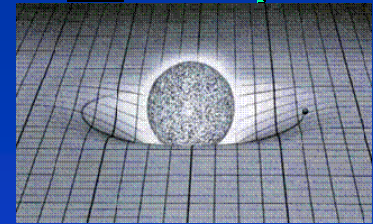
Real E , $m_0 = 0$
Time = space
 v always $\equiv c$
"Luxons"

1) SUBLUMINAL SPACE:

Increase $E =$ Higher v
Real m_0
 t goes forward
 c is fastest speed
"Tardions"

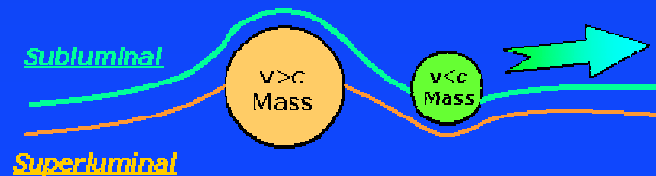


Subluminal Space



Superluminal Space

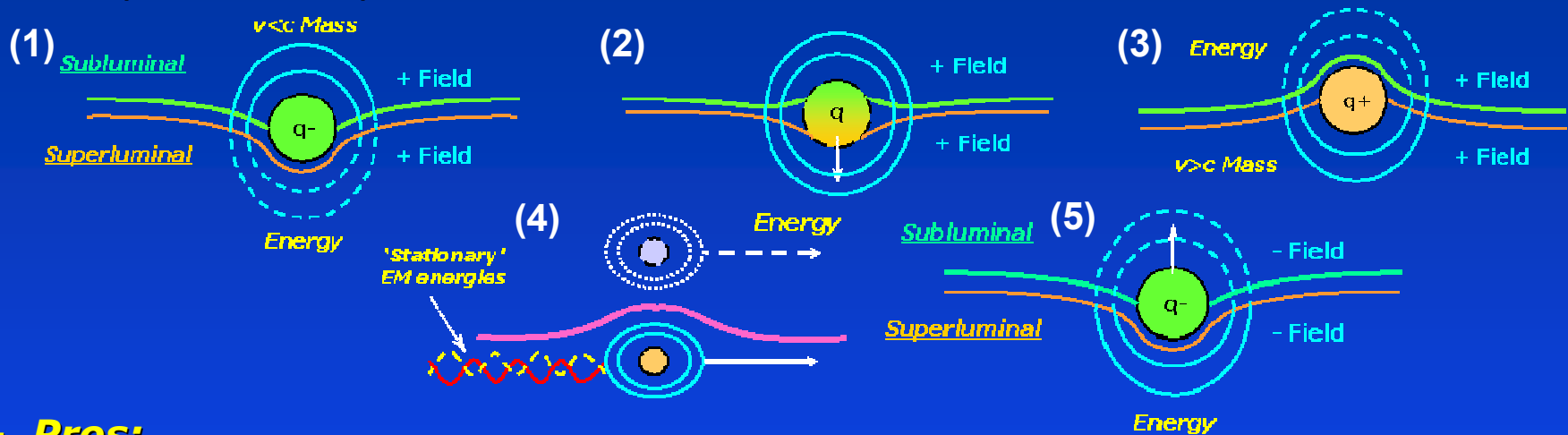
- Energy **removal** results in **higher** velocities.
- Real, positive mass** energy can exist in only one space at a time.
- In superluminal space, **rest mass becomes imaginary** and only velocities **greater than c** exist.
- Superluminal mass is made of **tachyon equivalents** of subluminal particles.
- Superluminal mass has a **repulsive gravitational effect** in subluminal space.



- Either space is unobservable from the other, but gravity acts across all spaces.

Tri-Space and Trans-Space FTL Travel

- **Trans-Space FTL Travel:** Traverse subluminal space by traveling through superluminal space.



- **Pros:**

- /// Relativity not violated in either space. **No relativistic effects.**
- /// **Velocities always greater than light speed** (theoretical infinite velocity).
- /// **Navigation possible.**
- /// No negative matter required.
- /// Many plausible theories exist for entering superluminal space.
- /// Tri-Space model is consistent with current discoveries in many areas of science.
- /// Evidence suggests existence of superluminal space and fluidic space-time.

- **Cons:**

- /// Mathematics partially understood, requires analysis of **fluidic space-time.**
- /// Assumes existence of superluminal space (possibly dark matter/energy).
- /// Characteristics of superluminal space need to be understood.

Comparison of FTL Concepts

Trans-Space FTL Travel has many advantages over other FTL concepts...

Trans-Space FTL Travel

Other FTL Travel Concepts

Basic
Concept

Matter energy transferred from one space to another through spacetime medium

- Disturbance created in spacetime via holes, warps, folds, etc.

- Access to multi-dimensional spaces/branes

Mass

Vessel traverses *subluminal* space by traveling through *superluminal* space

Vessel travels through holes, warps, folds, or hidden dimensions in spacetime

Energy

- Absolute throughout tri-space
- Conserved between all spaces

- Large amounts required
- 'Negative' energy required (?)

Time

- No causality effects
- Time travel not possible

- *Sometimes* instantaneous - no causal effects
- 'Negative' energy may pose temporal issues

Navigation/
Control

- Possible in superluminal space (similar to subluminal space)
- Detection/Interaction using gravity wells
- 'Stationary' EM energies for attitude control

- Unknown, difficult or impossible
- Destination must sometimes be known beforehand

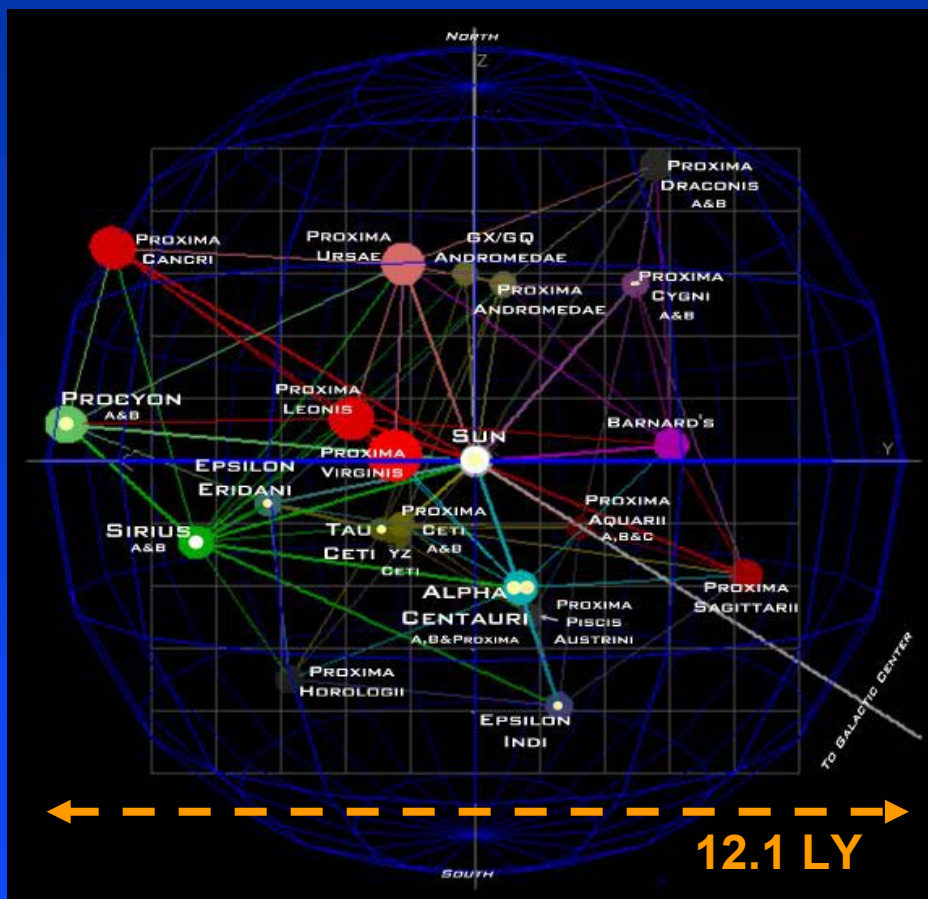
Other

- No 'negative' quantities required
- Transition to FTL state at subatomic level
- No initial velocity required to transition

- No guarantee of FTL velocities
- Quantum effects not defined
- "Brute force" to get to near-c velocities

Interstellar Destinations with FTL Travel

Within a **15-year** mission, where can we go if FTL travel were possible?



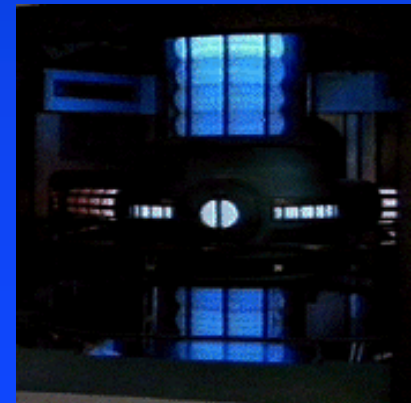
<u>Distance (Light Years)</u>	<u>Name</u>
0.00	Sun (Sol)
4.24	Proxima Centauri (Alpha Centauri C)
4.36	Alpha Centauri (A&B)
5.96	Barnard's Star (Proxima Ophiuchi)
7.78	Proxima Leonis (Wolf 359, CN Leonis)
8.29	Proxima Ursae Majoris (Lalande 21185)
8.58	Sirius (A&B, Alpha Canis Majoris)
8.73	Proxima Ceti (A&B, Luyten 726-8, UV & BL Ceti)
9.68	Proxima Sagittarii (Ross 154, V1216 Sagittarii)
10.32	Proxima Andromedae (Ross 248, HH Andromedae)
10.52	Epsilon Eridani (Proxima Eridani)
10.74	Proxima Piscis Austrini (Lacaille 9352)
10.92	Proxima Virginis (Ross 128, FI Virginis)
11.27	Proxima Aquarii (A,B&C, EZ Aquarii)
11.37	Proxima Cygni (A&B, 61 Cygni)
11.40	Procyon (A&B, Alpha Canis Minoris)
11.52	Proxima Draconis (A&B, Struve 2398)
11.62	GX/GQ Andromedae (Groombridge 34 A&B)
11.82	Epsilon Indi (Proxima Indi)
11.83	Proxima Cancri (DX Cancri)
11.89	Tau Ceti
11.99	Proxima Horologii (GJ 1061)
12.10	YZ Ceti (LHS 138)

Orange Text denotes presence of planetary system

Green Text denotes possible planetary system

Summary of Propellantless Ideas

- All “back of the napkin” concepts, so **NASA TRL is about 0 or 1.**
- Of the propellantless concepts described, most appear to offer the possibility of **light speed or FTL travel:**
 - ⚡ Alcubierre Warp Drive
 - ⚡ Traversable Wormholes
 - ⚡ Hyperspace in GR
 - ⚡ String-Based Alcubierre
 - ⚡ Tri-Space and Trans-Space FTL Travel
- Subsystems required to support these concepts are still being conceived, as are the actual “devices”.
- Cosmology and quantum mechanics are intimately related.
- An “alternate space” is necessary for light speed or FTL travel to be possible.



Bottom Line on Propellantless Concepts

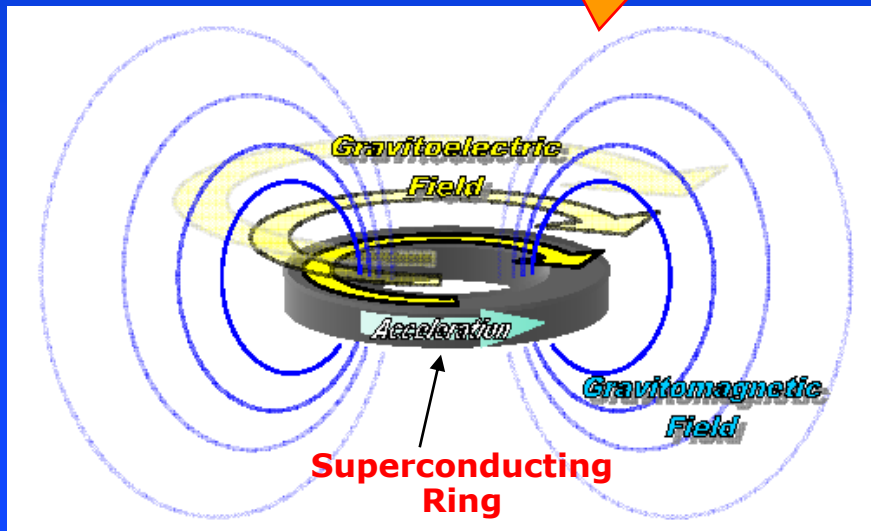
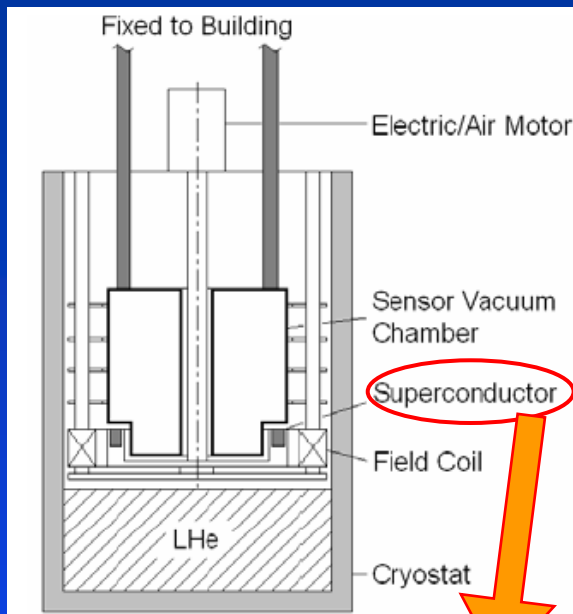
Right now, these are the only ideas that will allow human interstellar travel within a reasonable timeframe (if they work at all)!

So what are we doing about it??

Experimental Programs

- **Breakthrough Propulsion Physics** (BPP) Program at operated by NASA Glenn Research Center (M. Millis), 1996-2002.
 - ⚡ GOAL: Exceed the fundamental limits of existing propulsion by further advancing physics to discover the breakthroughs that could revolutionize spaceflight and enable interstellar voyages.
 - ⚡ Developed a rigorous process for determining the scientific credibility and validity of unique propulsion ideas involving "new" or "breakthrough" physics.
 - ⚡ First dedicated effort to experimentally explore fundamentals of physics-based propulsion concepts.
- Summary of BPP Program:
 - ⚡ Assessed **16 research approaches** (\$1.55M spread over 1996-2002).
 - Co-sponsored by WV, NASA-HQ, NASA-MSFC, ESA-ESTEC, NRL, & private industry.
 - **5 not viable (null)**
 - **7 unresolved**
 - **4 open for continued study**
 - ⚡ Produced **16 journal publications**.
 - ⚡ Produced award-winning public education **website**; "Warp Drive, When?"
 - ⚡ **Book**: "Frontiers of Propulsion Science" to be released **Sept. 2008**.
 - 23 chapters from 18 contributing authors (including editors).
- Some experimental programs are continuing with **favorable results!**

Superconductor Gravitomagnetic Fields

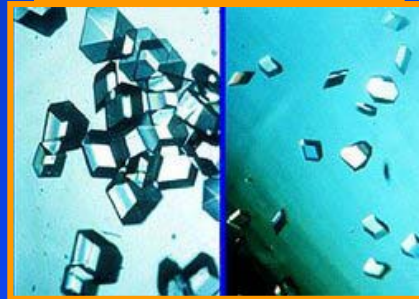
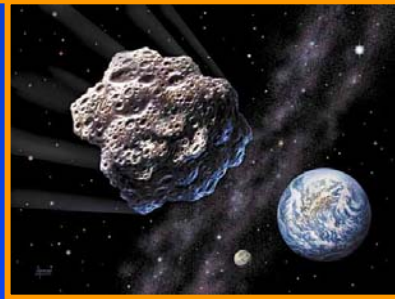


- Dr. Martin Tajmar and his associates at the Austrian Research Centers (ARC) have **experimentally observed** a gravity-like (gravitomagnetic) field generated within the vicinity of rotating, superconducting rings.
 - ⚡ Field behaves like gravity, hence "gravity-like".
 - ⚡ A "frame dragging" field is predicted by General Relativity.
 - ⚡ Characterization of the field is still on-going.
- The field is **20-30 orders of magnitude greater** in magnitude than theory prediction.
 - ⚡ General Relativity may not be the parent theory to explain the phenomenon.
 - ⚡ Observed field is in the **$10^{-5} g$** range.
- Experimental observations are not produced by electrical, magnetic, mechanical or instrumentation disturbances.

No known theory in physics can readily explain the strength of the field and the observations made to date.

Potential Gravitomagnetic Field Applications

If the gravitomagnetic field can be amplified, controlled, directed, and efficiently produced, the foundation may exist for a remote force generation technology to potentially be used for...



Vehicle Control

- “Propellantless” satellite or upper stage RCS
- De-orbit capability

Object Deflection

- Projectile-less, satellite-based missile defense
- Asteroid or “space junk” deflection

Gravity Gradients

- “Artificial” gravity in space
 - Extends astronaut endurance
 - Changes space structure construction techniques
- “Zero”/microgravity on earth
 - Crystal growth

Propellantless propulsion?

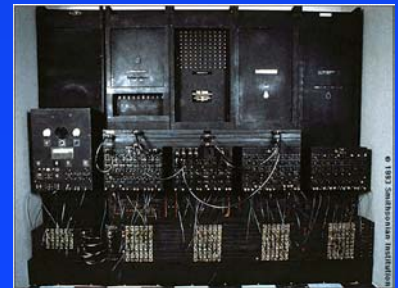
...Plus a myriad of other medical/manufacturing possibilities.

A wide-field astronomical image of a galaxy, likely a barred spiral galaxy, viewed at an angle. The galaxy's core is bright and yellowish-white, with a prominent bar structure. The spiral arms are visible, showing a mix of colors including blue, purple, and red, indicating different stellar populations and dust content. The background is filled with numerous stars of various colors and magnitudes. The text "Concluding Remarks" is overlaid in the center in a bold, italicized yellow font.

Concluding Remarks

Skeptics and Quotations

- “There is practically no chance communications space satellites will be used to provide better telephone, telegraph, television, or radio service in the United States.”
 - T. Craven, FCC Commissioner, in 1961 (the first communications satellite went into service in 1965).
- “The concept is interesting and well-formed, but in order to earn better than a ‘C’, the idea must be feasible.”
 - Mid-1960s. A Yale University management professor in response to Fred Smith’s paper proposing reliable overnight delivery service (Smith went on to found Federal Express Corp.).
- “Where a calculator on the ENIAC is equipped with 18,000 vacuum tubes and weighs 30 tons, computers in the future may have only 1,000 vacuum tubes and weight only 1.5 tons.”
 - Popular Mechanics, March 1949.



What's Out There?

- Mankind **needs** to venture out into the universe and seek the answers to questions about our evolution, and our fate.
 - ▄ Terrestrial-based and robotic exploration has extreme limitations.
- Current propulsion technology and near-term advancements **will not** facilitate rapid, human exploration of the solar system or local stars.
- A paradigm shift in propulsion technology **must happen** if we are ever to become a thriving, space-faring civilization.
 - ▄ A departure from the conventional systems into the more **physics-based** concepts enabling travel at **light speed or faster**.
- Contrary to popular belief, the speed of light is **NOT** the speed limit!
 - ▄ Einstein and others have shown this to be true.
- Some of the concepts that could take us to the stars could be developed within 50 years with proper program structure, dedicated research, and of course funding.

And finally...

- **Open minds** and the defiance of convention are essential for the advancement of technology.

SO LET'S GO!!!

Star Trek



Star Wars



**Interstellar Exploration Vessel
Orion Star
(No...This isn't from Star Trek)**

Photo/Graphics Credits (1)

Title Slide	Solar System – http://ast.qeny.net/index.php , April 14, 2008. Milky Way – http://www.news.wisc.edu/newsphotos/milkyway.html , April 14, 2008.
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