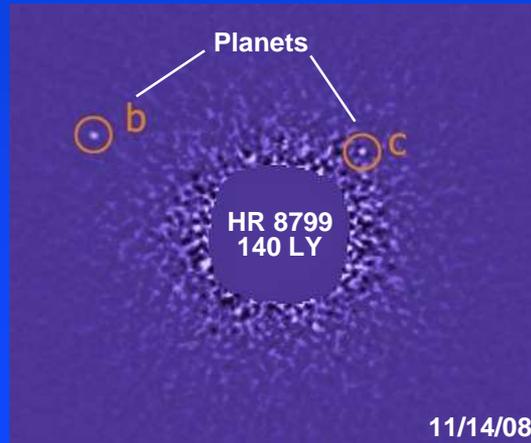


# Advanced Space Propulsion Concepts for Interstellar Travel



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# Presentation Objectives and Caveats

- Provide a **high-level, “evolutionary”, information-only overview** of various propulsion technology concepts that, with sufficient development (i.e. \$), may lead mankind to the stars.
- Only candidate concepts for a vehicle’s **primary interstellar propulsion system** will be discussed.
  - ⚡ No attitude control
  - ⚡ No earth-to-orbit launch
  - ⚡ No traditional electric systems
  - ⚡ No sail-based systems
  - ⚡ No beamed energy
- **None of the following will be given, assumed or implied:**
  - ⚡ Recommendations on specific mission designs
  - ⚡ Developmental timelines or cost estimates
- **Not all propulsion options will be discussed** – that would be impossible!
  - ⚡ Please refer to the Supplemental Information slides for more details

# Chapters

1. The Ultimate Space Mission
  2. The Solar System and Beyond
  3. Challenges of Human Star Flight
  4. "Rocket Science" Basics
  5. Conventional Mass Ejection Propulsion Systems
    - ⚡ State-of-the-Art
    - ⚡ Possible Improvements
  6. Alternative Mass Ejection Systems
    - ⚡ Nuclear Fission
    - ⚡ Nuclear Fusion
    - ⚡ Matter/Antimatter
    - ⚡ Other Concepts
  7. Physics-Based Concepts
    - ⚡ Definitions and Things to Remember
    - ⚡ Space-Time Warp Drives
    - ⚡ Fundamental Force Coupling
    - ⚡ Alternate Dimension / Hyperspace
    - ⚡ Comparison, Reference Books and Summary
  8. Closing Statements
- Graphics References and Supplemental Information

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***Chapter 1:***  
***The Ultimate Space Mission***

# The Ultimate Space Mission

**For humans to travel to the stars and return to Earth within a "reasonable fraction" (around 15 years) of a human lifetime.**



## ■ Why venture beyond our Solar System?

- ⚡ Because we have to - humans **love to explore!!!**
- ⚡ Visit the **Kuiper Belt** and the **Oort Cloud**
  - Theoretical home to long-period comets
- ⚡ Investigate the nature of the **interstellar medium** and its **influence** on the solar system (and vice versa)
  - Magnetic fields, low-energy galactic cosmic rays, composition, etc.
- ⚡ Explore or better observe **nearby solar systems** (e.g. Alpha Centauri)
- ⚡ Look for other **earth-like planets**
- ⚡ **Search for life** beyond our local region of the galaxy



***Chapter 2:***  
***The Solar System and Beyond***

# Interstellar Measurements

Interstellar discussions require *large* units of measurement.

- **Speed of Light,  $c$ :** **186,282 miles/sec**  
(in vacuum)  **$2.99 \times 10^8$  meters/sec**  
670,616,630 miles/hour



Earth

Moon

235,184 miles, 0.00253 AU, 1.26 seconds

- **Light Year, LY:** **Distance light travels in one year**  
 $5.88 \times 10^{12}$  miles  
**63,241 AU**
- **Astronomical Unit, AU:** Mean distance from Sun to Earth  
**92,955,807 miles (1 AU)**  
8.32 light-minutes  
0.0000158 light years

# Solar System and Interstellar Medium

## ▲ Pioneer 10



Launched 1972  
 Distance: ~121 AU  
 Speed: 26930 mph  
 (2.6 AU/yr =  
 0.0041% c)

## ✚ Voyager 1



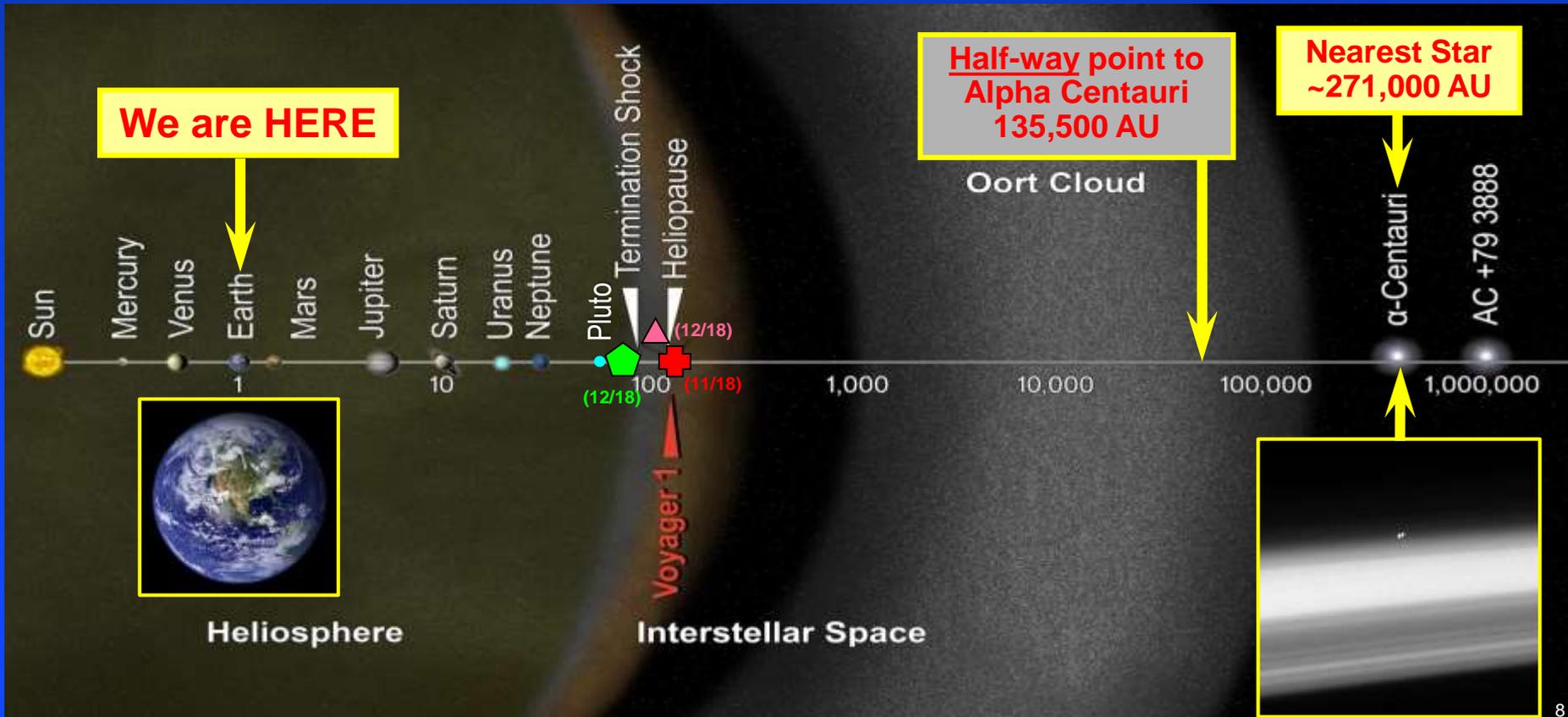
Launched 1977  
 Distance: 142 AU  
 Speed: 38120 mph  
 (3.6 AU/yr =  
 0.0057% c)

## ◆ New Horizons



Launched 2006  
 Distance: 43 AU  
 Speed: 33000 mph  
 (3.0 AU/yr =  
 0.0056% c)

*Pioneer 11 and Voyager 2 not shown*





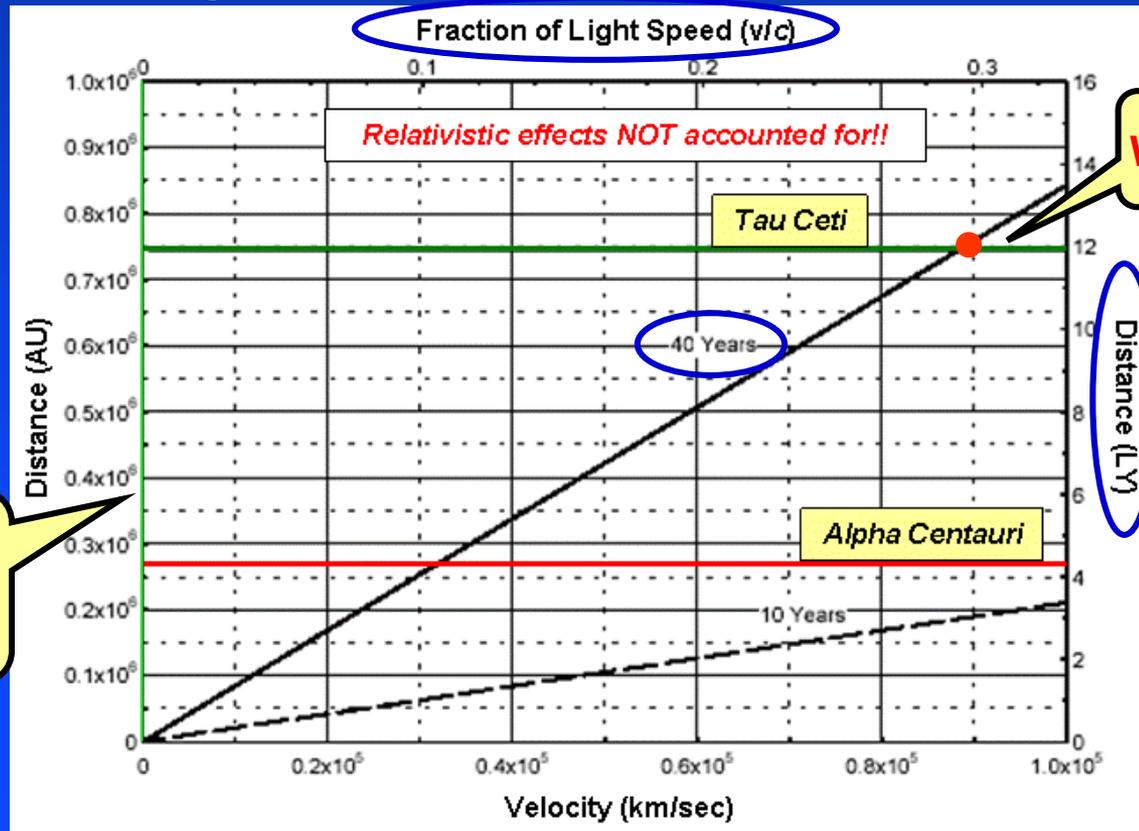
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***Chapter 3:***  
***Challenges of Human Star Flight***

# Challenges of Human Star Flight

## Spacecraft velocity limitations:

- Our spacecraft are far too SLOW!
- To reach **Tau Ceti (12 LY) in 40 years**, you would need to travel at **30% c** or  $\sim 90,000$  km/sec (202,500,000 mi/hr) **Wow!**
- Velocities need to be **tens of percent of the speed of light, or greater** for human star flight to be conceivable



**PROBLEM:**

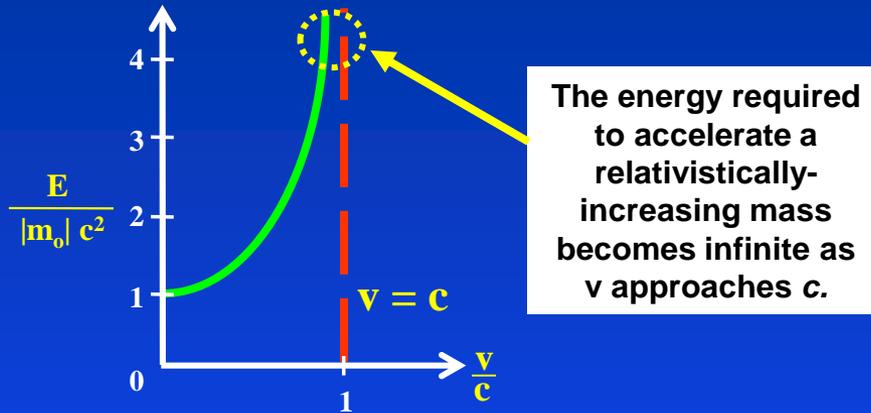
**WE ARE HERE**  
Current space probe  
velocities are far  
less than 0.05% c

**WHAT WE NEED**

# Challenges of Human Star Flight

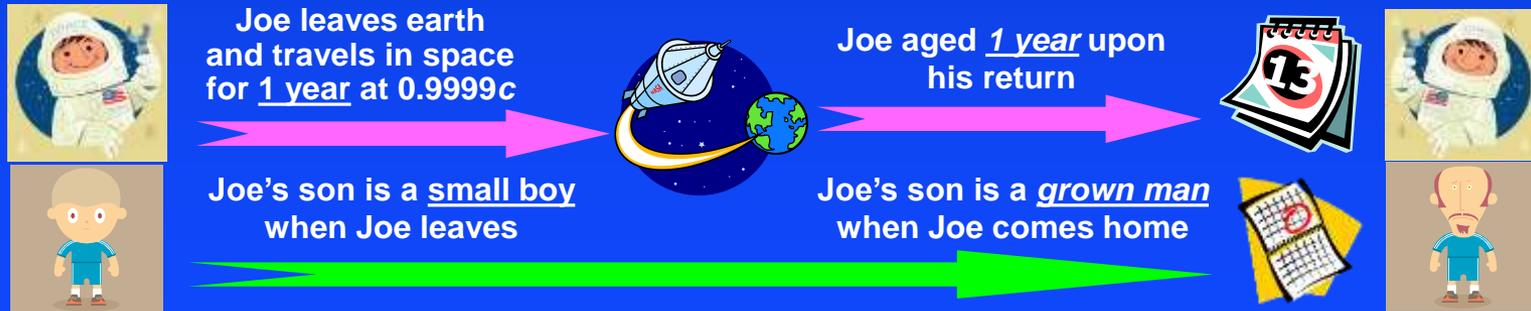
- **Special Relativity:** Must be considered even at very low sublight speeds

- 1) **Mass increase-** As velocity approaches  $c$ , mass appears to increase, thus more energy is required to further accelerate it ( $E = mc^2$ ).



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

- 2) **Time dilation-** Time passes **slower** for moving objects when measured against that of a stationary observer. **Scientifically Proven!**



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

# Challenges of Human Star Flight

- **Human physiology:** How will humans cope with 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, etc.
  - Could employ plasma “deflector shield” around spacecraft
- ⚡ Dust and Small Bodies – particularly near the Kuiper Belt and Oort Cloud
- ⚡ Extreme cold (**2-4°K**)
- ⚡ Spurious hot gases and charged particles

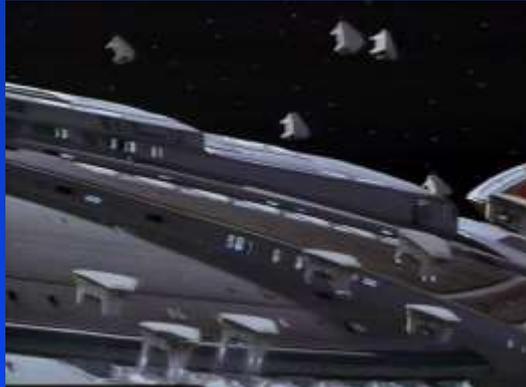
# Challenges of Human Star Flight

- **Lack of external resources:**

- ▄ No solar energy available between stars – too dim for heat, light or power
- ▄ Starlight too dim for plant growth – affects food supply considerations
- ▄ No celestial bodies from which to mine/extract fuel, oxygen or water

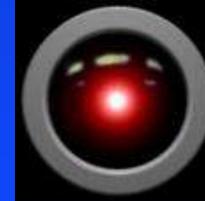
- **Emergency plans:**

- ▄ No rescue possible. Where to go if ship evacuated?



- **Intelligent, reliable autonomous systems:**

- ▄ Self-repair/learning required to reduce system degradation and maintain reliability



- **Close encounters:**

- ▄ Would we be ready for first contact?



- **Many, many others.....**

"WTF??"



***Chapter 4:***  
***"Rocket Science" Basics***

# "Rocket Science" Basics

Based on **Conventional Propulsion Science**, here are what's needed for an interstellar rocket engine:

- **High Delta-v ( $\Delta v$ ):**

The **Rocket Equation** (1903, Tsiolkovskii)

$$\Delta v = v_e \ln \frac{m_0}{m_1}$$

$v_e$  = exhaust velocity of engine  
 $m_0$  = initial mass  
 $m_1$  = final mass

- ⚡ The **change in velocity** required to change direction or accelerate
- ⚡ Measure of **propulsive energy** required/delivered
- ⚡ Based on **exhaust velocity** of propulsor
- ⚡  $\Delta v$  is **cumulative** whether accelerating or decelerating
- ⚡ Vehicle **mass and trajectory** determine  $\Delta v$  required

**PROBLEM:**

**WE ARE HERE**  
**State-of-the-Art**

Mission	Description	Typical $\Delta v$ [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

**WHAT WE NEED**

**Wow!**

Assumes 90% of vehicle is propellant ( $m_1/m_0 = 0.1$ )

- The propulsion system **MUST** be capable of providing the  $\Delta v$  required for a mission

# "Rocket Science" Basics

- **High Specific Impulse,  $I_{sp}$ :**

$$I_{sp} = \frac{v_e}{g_0}$$

$v_e$  = exhaust velocity of engine  
 $g_0$  = earth gravitational accel

- ⚡ "The time to burn one unit mass of propellant while producing one unit force of thrust." Units in **seconds**
- ⚡ Directly related to **exhaust velocity** and directly impacts  **$\Delta v$**
- ⚡ The higher the  $I_{sp}$ , the more "**propellant-efficient**" the engine

- **Stable and Continuous Thrust,  $F$ :**

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

- ⚡ Desired **acceleration** rate and  **$\Delta v$**  will determine the thrust required
- ⚡ Also used for **slowing down** close to destination

- **High Thrust-to-Weight,  $T/W$ :**

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

- **Excellent Reliability:**

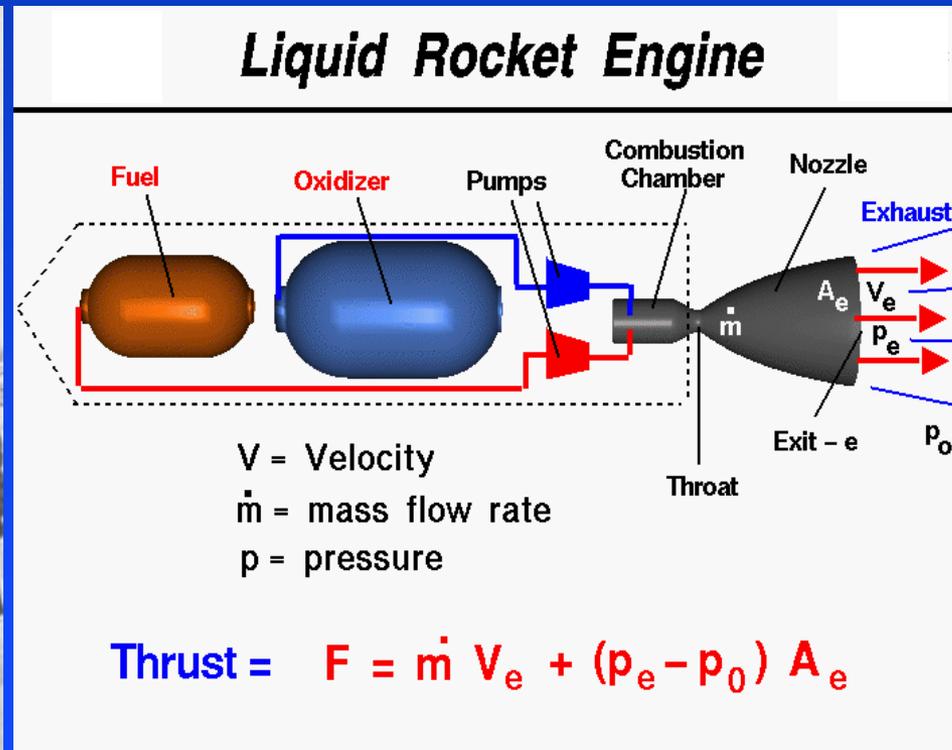
- ⚡ The propulsion system must withstand **extremely harsh environments** and **extended duty cycles** required for interstellar missions

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***Chapter 5:***  
***Conventional Mass Ejection***  
***Propulsion Systems***

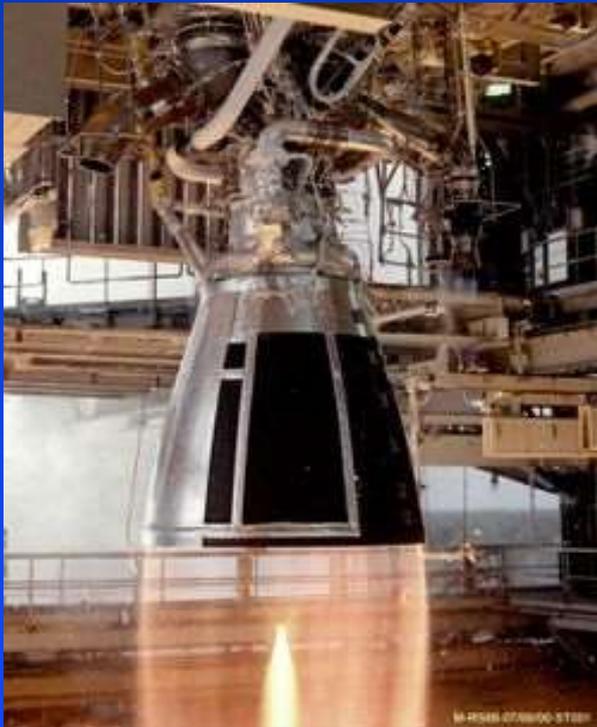
# State-of-the-Art: Chemical Combustion

- 99% of all rocket engines operate on the principle of **chemical combustion**:
  - Put fuel and oxidizer into a chamber, burn them, accelerate products through a nozzle
- Multiple variations on engine cycles and designs, each with pros/cons depending on application
- Over 90 years of flight history – **proven technology, “same stuff”**



# The Best Available Today: LH<sub>2</sub>/LOX

- **Liquid Hydrogen (LH<sub>2</sub>) & Liquid Oxygen (LOX) engine systems**
  - ▄ **Max. Theoretical I<sub>sp</sub>: ~470 sec**
- Other common propellant combinations (liquid or solid) have lower I<sub>sp</sub>
- This technology has reached an upper limit of development
  - ▄ Substantial investment would only lead to marginal improvement



**RS-68 (Delta IV)**  
LH<sub>2</sub>/LOX Gas Generator  
Vac I<sub>sp</sub> = 410 s  
Max. F<sub>vac</sub> = 751,000 lbf



**RL10 (Upper Stages)**  
LH<sub>2</sub>/LOX Expander  
Vac I<sub>sp</sub> = 444 s  
Max. F<sub>vac</sub> = 23,500 lbf



**RS-25 (Space Shuttle and SLS)**  
LH<sub>2</sub>/LOX Fuel-Rich Staged Comb.  
Vac I<sub>sp</sub> = 453 s  
Max. F<sub>vac</sub> = 513,000 lbf

# Options for Chemical Propulsion

- Improvements to state-of-the-art are much “easier said than done.”
- **Option 1: Increase propellant density**
  - ⚡ Example: Use slush hydrogen instead of liquid hydrogen
  - ⚡ Reduces structural weight by allowing smaller tanks
- **Option 2: Increase  $I_{sp}$  by using High Energy Density Materials (HEDM)**
  - ⚡ More energetic than  $LH_2/LOX$ ;  $I_{sp}$  over 500 sec possible
    - *Metastable helium* could yield  $I_{sp} \approx 3,100$  sec
    - *Metallic hydrogen* could yield  $I_{sp} \approx 1,700$  sec (J. Cole NASA/MSFC)
  - ⚡ Not producible in mass quantities and are highly unstable
  - ⚡ Combustion products could be non-gaseous, toxic or highly reactive
- Either option would require significant investment, technology development and an entirely new launch infrastructure
- To reach Alpha Centauri (4.2 LY) in 900 years using internal combustion propulsion, the required **propellant mass exceeds the mass of the known universe!**

**Chemical combustion systems are  
NOT viable for interstellar missions.**

**Is there anything else?**



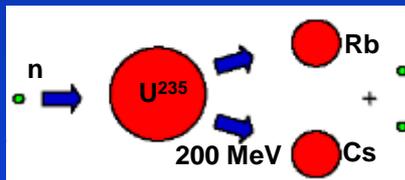
***Chapter 6:***  
***Alternative Mass Ejection Systems***

# Alternative Mass Ejection Systems

- Add thermal energy to a **working fluid** propellant by means other than combustion:

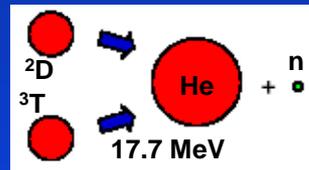
## Nuclear Fission

Split atomic nuclei by bombarding them with energetic particles



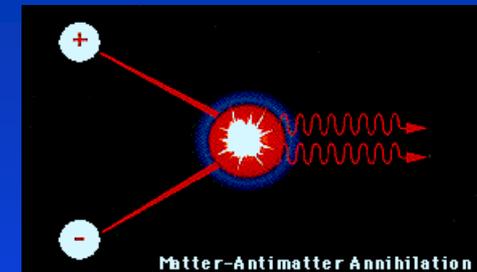
## Nuclear Fusion

Fuse atomic nuclei by high-energy collisions

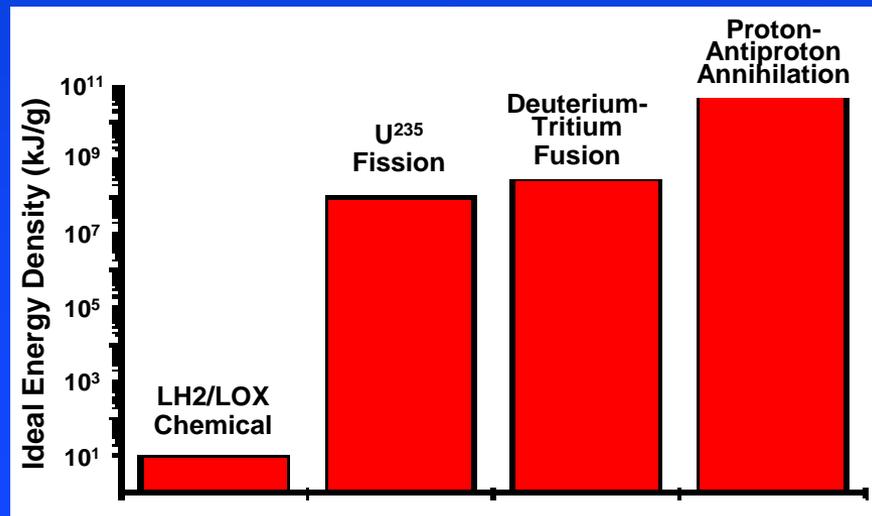


## Matter/Antimatter Annihilation

Convert oppositely-charged particles to energy



- Can provide **7-9 orders of magnitude higher energy density** than the best chemical system – **yields very high  $I_{sp}$ !**

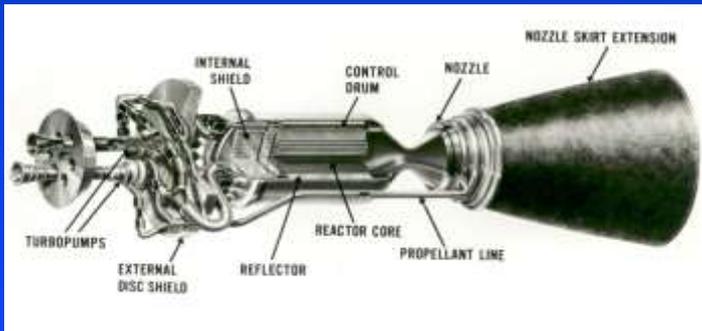
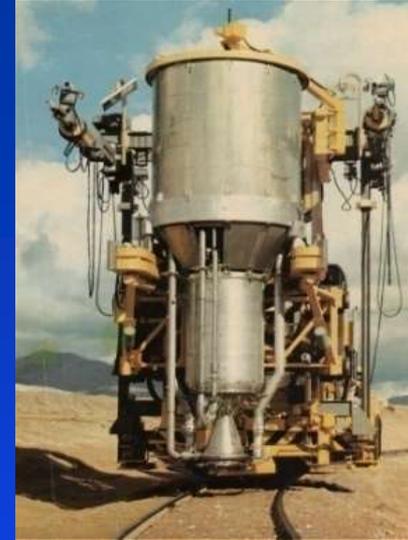
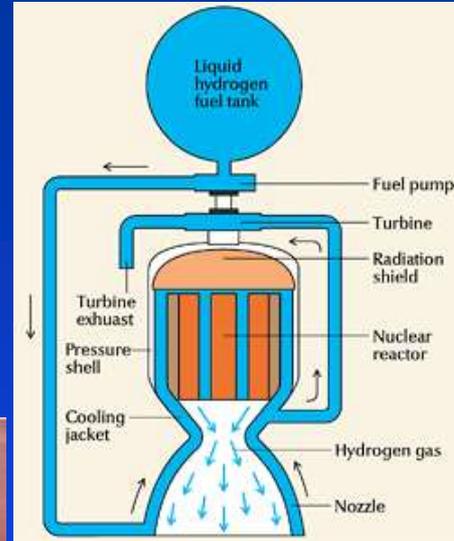


# Solid-Core Nuclear Fission

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

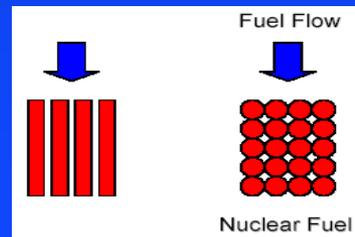
## NERVA/Rover – 1961-1972

- Successful program - \$2.4B
- Nearly flight qualified
- Continuous thrust of  $\sim 75$  kbf for **3.75 hrs**
- $I_{sp}$ :  $\sim 850$  sec, growth to  $\sim 1100$
- NASA LEU-NTP project started in 2016 to resurrect technology



## Particle Bed Reactor – 1980's

- More surface area for fission process, higher fission density, compact design
- Thrust: 180 kN (40 kbf)
- $I_{sp}$ :  $\sim 1000$  sec



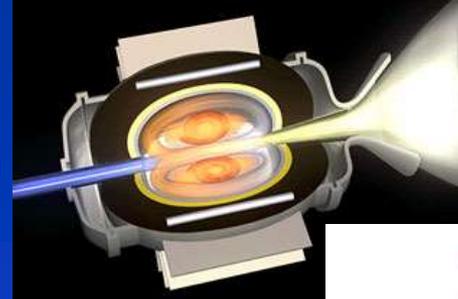
Linear fuel rod arrangement

Particle bed arrangement



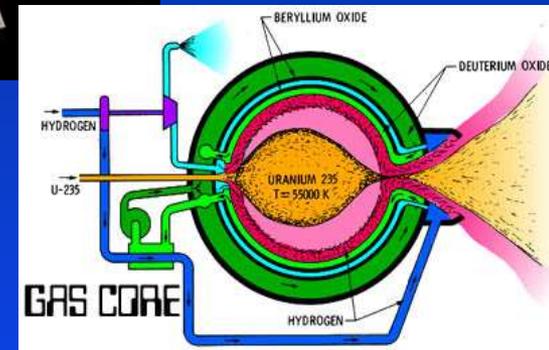
# Gas-Core Nuclear Fission

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



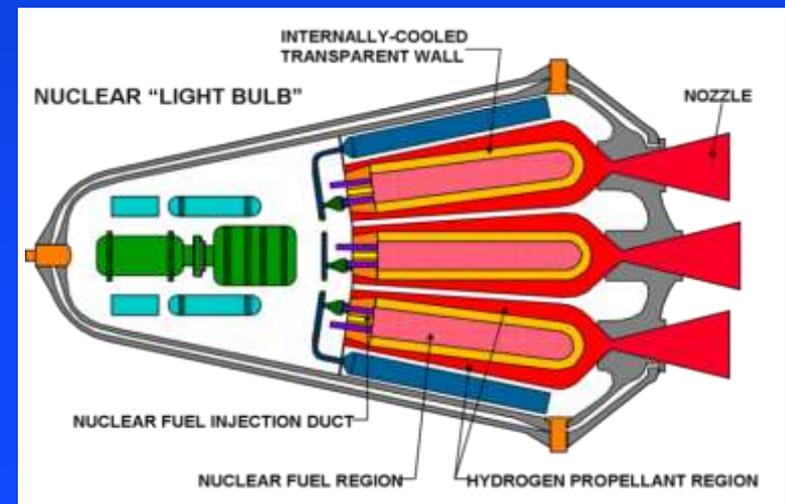
## Open-Cycle Gas Core

- 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 (off) state



## Closed-Cycle Gas Core

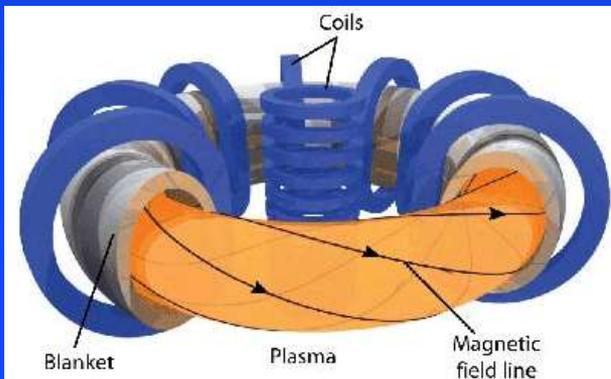
- Gaseous fission process contained in ablatable transparent vessels (quartz)
- Hydrogen used to cool vessel walls while absorbing heat
- Plasma temps around 55,000°K
- $I_{sp}$ : 1,500 – 2,400 sec
- Thrust: 45 – 450 kN (101 klbf)



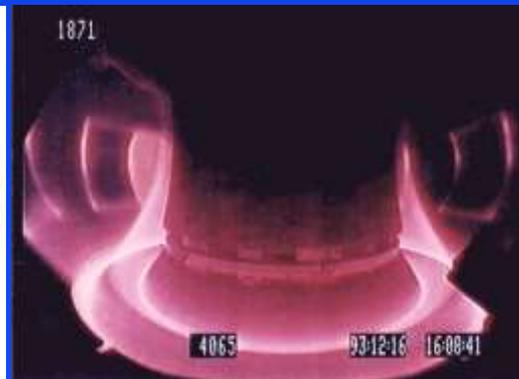
# Nuclear Fusion

- Bonds atomic nuclei by overpowering their **electrostatic repulsion**
- **Energy release** and fusion products are contained within a **plasma**
  - ▄ Plasma cannot contact containment vessel walls or it will cool and neutralize, thus stopping the fusion process
  - ▄ Primary technical challenges are plasma **containment** and **sustainment**
- 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 fusion products directly
- Three main approaches:
  - ▄ **Magnetic Confinement (MCF)**
    - Uses strong magnetic fields and magnetic gas dynamic “mirrors” in a **Tokamak reactor** or linear device

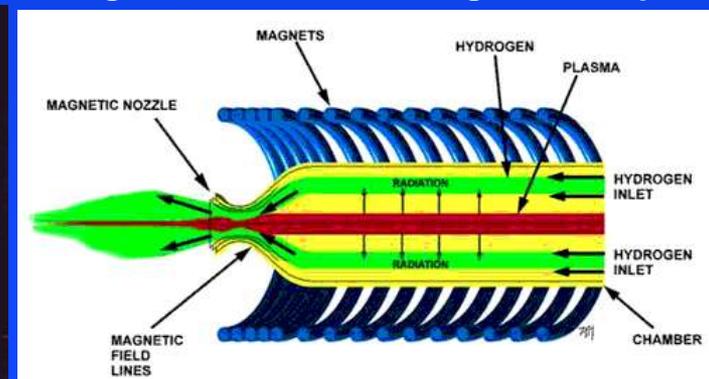
Tokamak Fields



Fusion Plasma

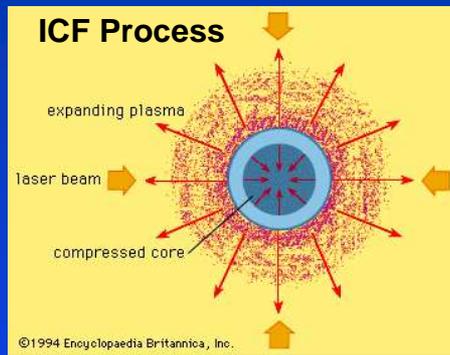


Magnetic Mirror Fusion Engine Concept

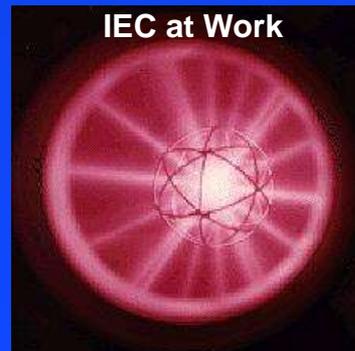
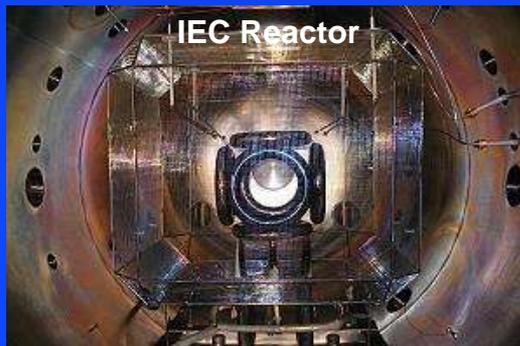


# Nuclear Fusion

- /// **Inertial Confinement (ICF) and Magnetic Inertial Confinement (MIC)**
  - ICF: Pellets of fusible material blasted by petawatt-powered laser pulses will implode/fuse at nearly **100 million degrees**
  - MIC: Metallic liners driven inwards by huge magnetic forces collapse around a fusible plasma and initiate fusion

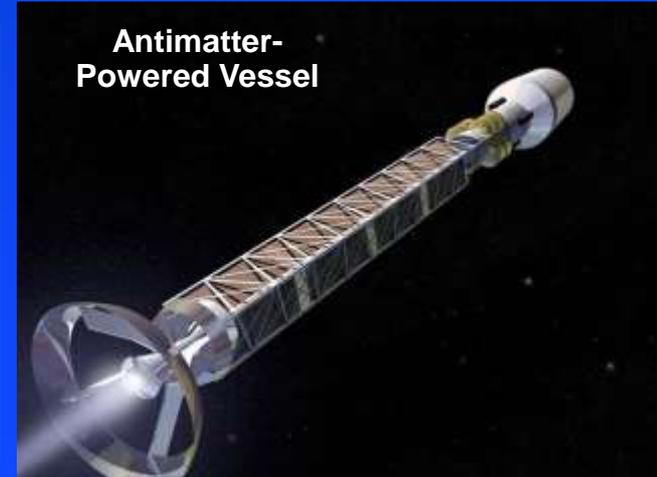
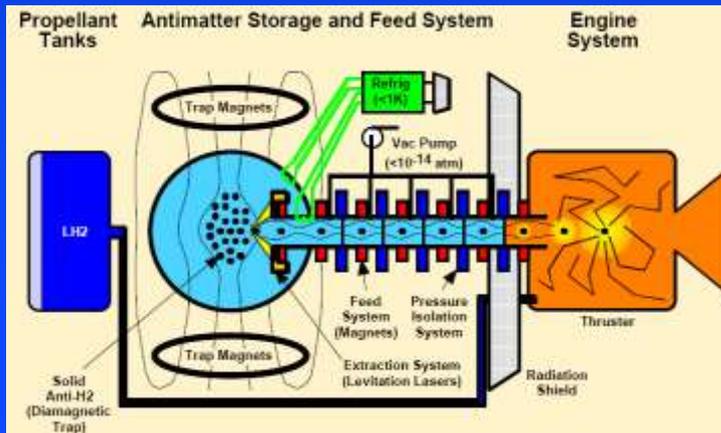
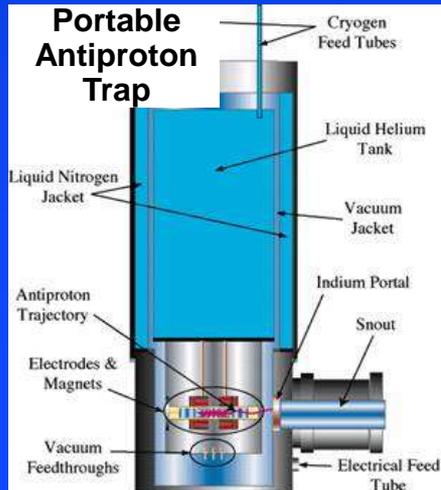


- /// **Inertial Electrostatic Confinement (IEC)**
  - Bombards fusion plasma with ions to hold it in place
  - Ions generated by 100 kV potential have enough energy to initiate fusion



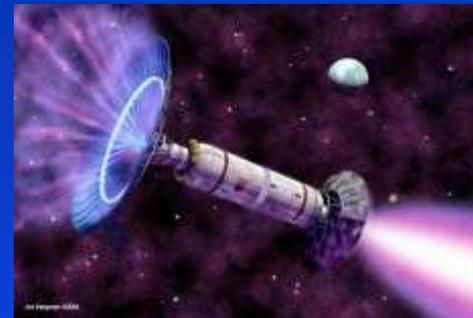
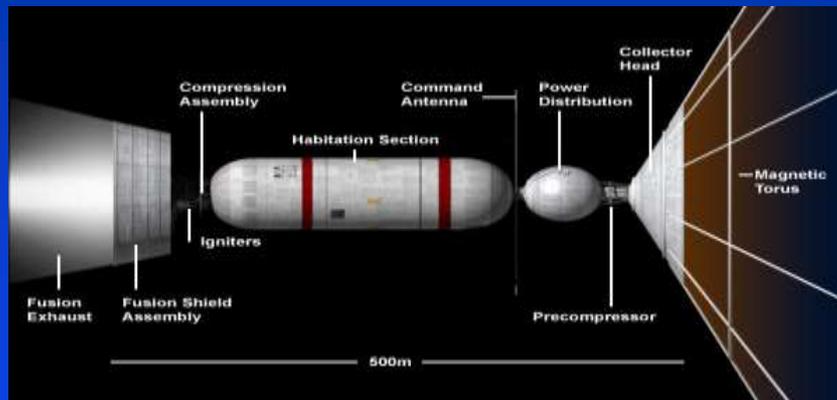
# Matter/Antimatter Annihilation

- Elementary particles have counterparts of opposite charge, but same mass
  - Electron (-) → **Positron (+)**      Proton (+) → **Antiproton (-)**
- M/AM reactions yield the **highest energy density** process in nature:
  - 1 kg matter + 1 kg AM =  **$1.8 \times 10^{17}$  J!**
  - AM must be stored and handled using magnetic fields. It can not contact normal matter
- Very inefficient capture process: Global production is **2-20 nanograms/yr** at a cost of between **\$25B-300B per milligram!**
  - Grams** of AM could propel a spacecraft to Mars in one month, but capturing that much would take **millions of years!**
- Engine concept: Inject AM into working fluid to augment heat release
  - Example: use antiprotons to initiate fusion (antiproton catalyzed fusion)
- $I_{sp}$  between 5,000 - 10,000,000 sec** - Viable for multi-decade, robotic interstellar missions, but not for shorter, human missions

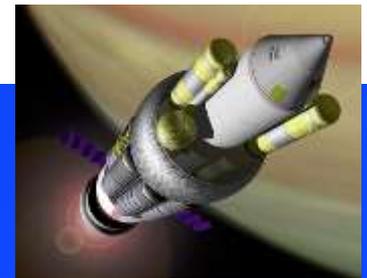
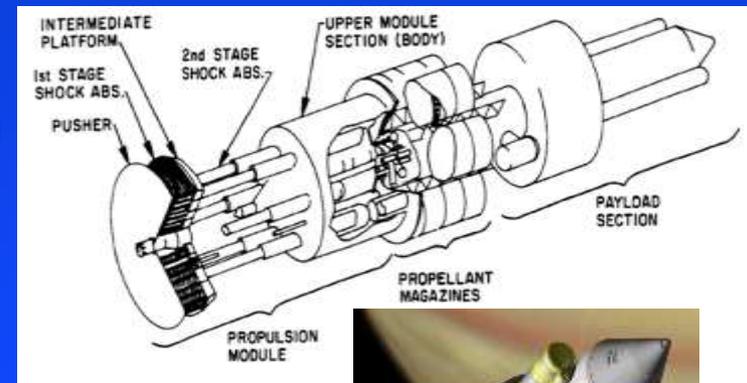


# Other Alternative Mass Ejection Systems

- Interstellar Ramjet / Bussard Hydrogen Ramjet (c.1960)
  - ⌘ Uses strong magnetic fields to scoop interstellar hydrogen into a collector, heats it (conventionally) and expels it
  - ⌘ **Infinite  $I_{sp}$**  since hydrogen fuel collected in-situ
  - ⌘ Fields must sweep  **$10^{18}$  cu. meters** of space to collect **1 gram** of hydrogen!



- Nuclear Pulse Propulsion (Orion - c.1947)
  - ⌘ Uses nuclear detonations (fission, fusion or antimatter) to propel a vessel
  - ⌘ Extensively studied with many variants (e.g. Mag-Orion, Mini Mag-Orion)
  - ⌘ Many technical issues to resolve
  - ⌘  $I_{sp}$ : 6,000 – 100,000 sec.
  - ⌘ Theoretical velocities of 0.1c



# Propulsion System Comparison

Generalized comparison of  $\Delta v$ , Thrust and  $I_{sp}$  for Mass Ejection propulsion systems:

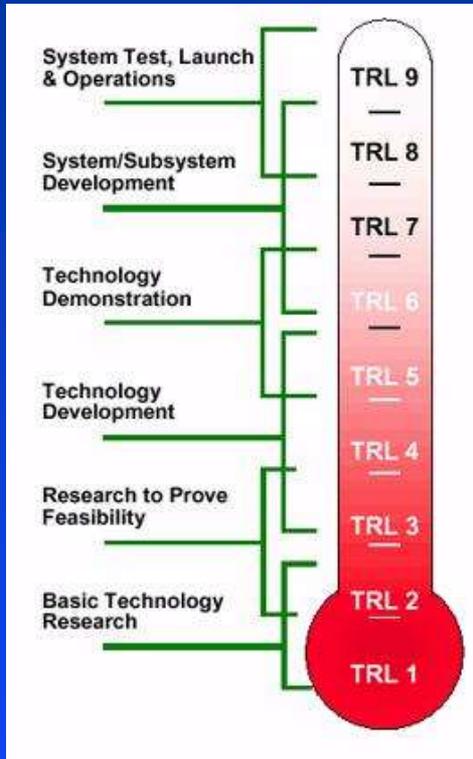
**WE ARE HERE**  
State-of-the-Art

Propulsion System	Subclass	$\Delta v^*$ (km/s)	Thrust (lbf)	$I_{sp}$ (s)
Chemical	Solid	5.7-7.1	Up to 3.0M	200-310
	Liquid	6.9-11.5	Up to 1.5M	300-470
Nuclear	Solid Core Fission	11.5-20.7	25-250k	600-1100
	Gas Core Fission	N/A	~100k	1500-7000
	Fusion	230-2300	~25k	10k-100k
	Antimatter	~2000	N/A	5k-10M
Alternative	Bussard Ramjet	Infinite	N/A	Infinite
	Orion	N/A	N/A	6k-100k

\* Assumes 90% of vehicle is propellant ( $m_1/m_0 = 0.1$ )

# Current Status of Mass Ejection Systems

## NASA Technical Readiness Level (TRL) Guide



Concept	NASA TRL*	Notes
Chemical	9	Interstellar applications impractical
Solid-Core Fission	5	Extensive history, NERVA, systems well-understood
Fusion	3	Significant R&D work on terrestrial systems
Gas-Core Fission	3	Critical proof-of-concept work performed
Orion	2	Concept and formulation work, major technology issues to be addressed
Interstellar Ramjet	2	
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: Mass ejection propulsion is **NOT VIABLE** for interstellar missions within a human lifetime.**

Good for **interplanetary exploration** within a "reasonable" time, but **won't work** for interstellar travel.

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



***Chapter 7:***  
***Physics-Based Concepts***

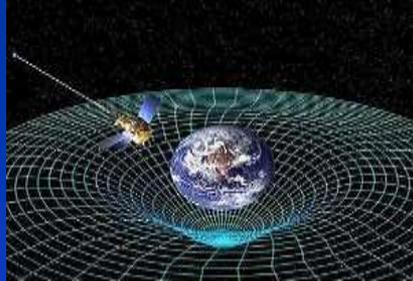
# Physics-Based Concepts

- What's different about these concepts compared to the others?
  - ⚡ **No mass ejection** ("propellantless")!
    - **Eliminates** the necessity to carry fuel or propellant
    - Terms like " $I_{sp}$ " and " $\Delta v$ " become meaningless
  - ⚡ Use the **space-time medium** as the energy source or "working fluid"
  - ⚡ Propulsive forces derived from **fluidic space, quantum physics, string theory, gravito-electromagnetism**, and many others.
  - ⚡ Some employ aspects of cosmological genres like **dark matter, dark energy, black holes, gravity waves, alternate dimensions** and **universal expansion**
  - ⚡ Most 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 ( $\sim 70\text{-}99\% c$ ), but at **the speed of light or beyond!**
- **Necessary for truly feasible, human interstellar missions!**

**And now for something completely different...**

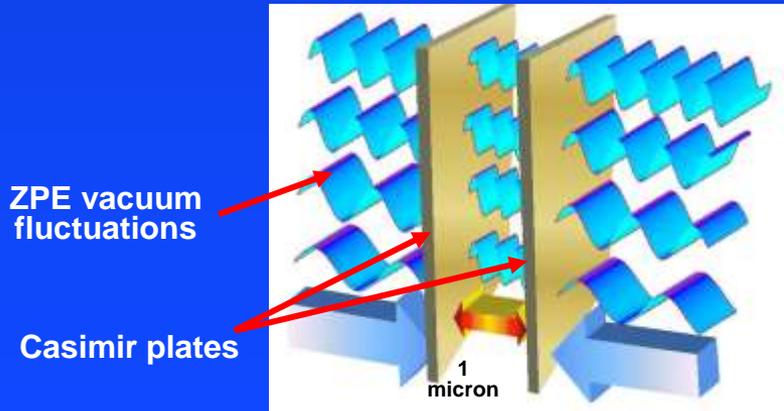
# ...But First, Some Important Definitions

- Space-time Medium – The 3 spatial +1 temporal dimensional continuum in which all physical things exist. The medium through which electromagnetic energy propagates.



Space-time distortion from Newtonian gravity (Minkowski space-time)

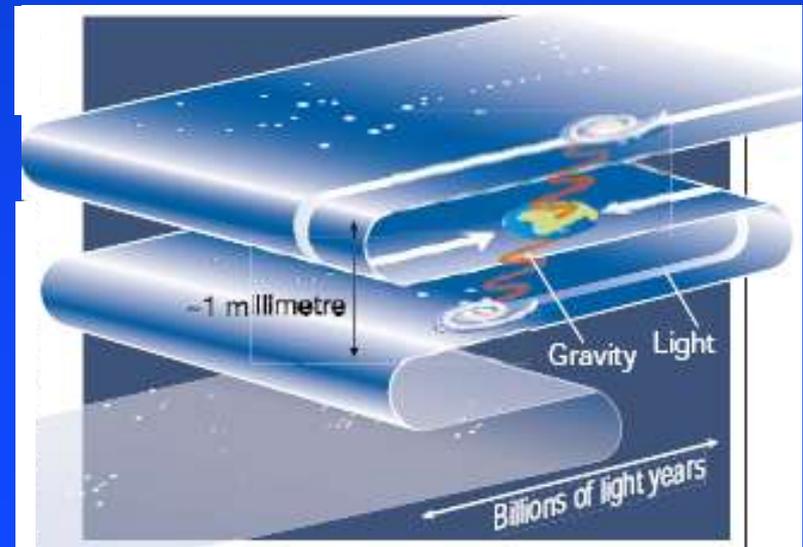
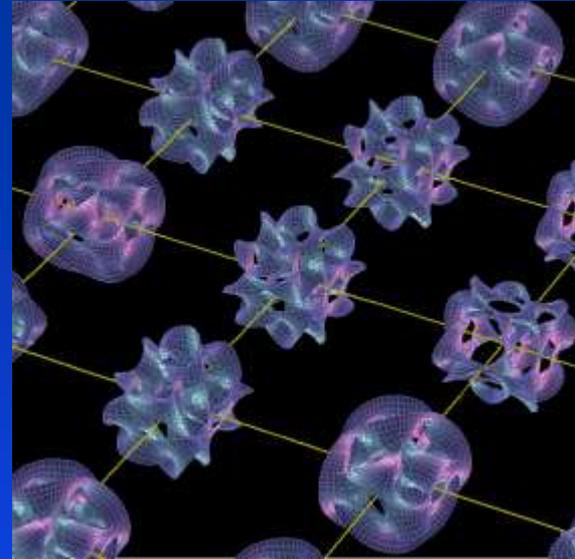
- Negative Mass/Matter – Matter that produces negative (or repulsive) gravity contrary to normal, “positive” matter. Sometimes called “exotic” matter. Antimatter is not negative matter.
- Zero-Point Energy/Field (ZPE/ZPF) - Quantum mechanical, random, instantaneous energy fluctuations within a volume of empty space (vacuum). The smaller the observed volume (approaching the “zero point”), the larger the fluctuations. 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 generate  $10^{-7}\text{N}$ !

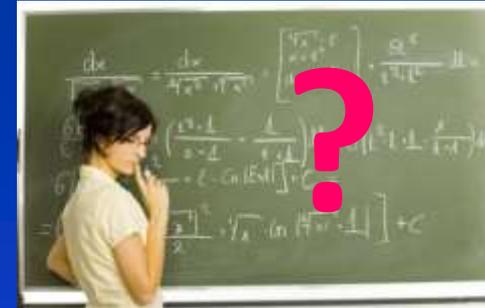
# More Important Definitions

- **String Theory** – A universe model in which space-time is composed of fundamental entities called “strings”. Strings are thought to exist at Planck lengths ( $1.6 \times 10^{-35}$  m or  $\sim 10^{-20}$ x smaller than a proton) or smaller. Strings randomly interact to produce elementary particles, EM fields and gravity.
- **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.



# Things to Remember...

- We (humans) don't understand 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?
- We don't know the true **nature of mass**
  - /// Created by Higgs particles and fields?
  - /// Formed by knotted strings and quantum filaments?
- We don't 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?
- We don't know the nature of **Dark Matter & Dark Energy**
  - /// Can it be synthesized?
  - /// Can it be used for propulsion?
- Einstein's field equations, quantum field theory and both Special and General Relativity **do not discount FTL travel!**



# 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.

**1) Space-Time Warp Systems** – Modify the space-time continuum to mitigate relativistic effects and allow for travel.

- /// **Alcubierre Warp Drive (and Experiments)**
- /// **Traversable Wormholes**

**2) Fundamental Force Coupling** – Mitigate, reduce or artificially create gravity, inertia or propulsive effects through novel electromagnetic interactions with fundamental forces or through quantum mechanics.

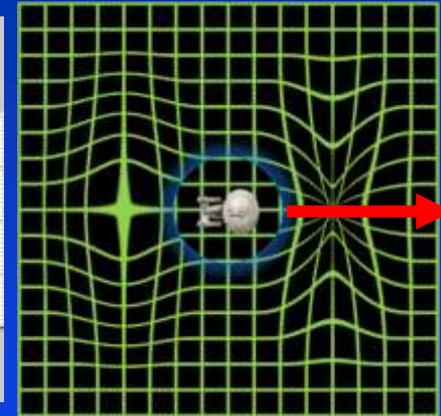
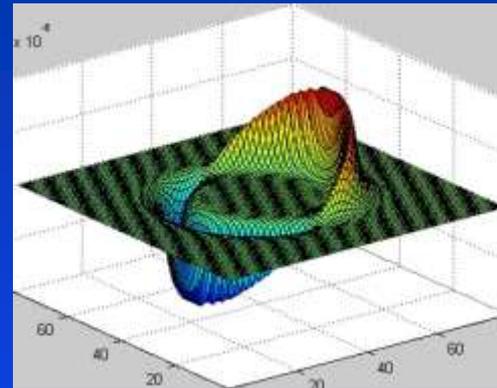
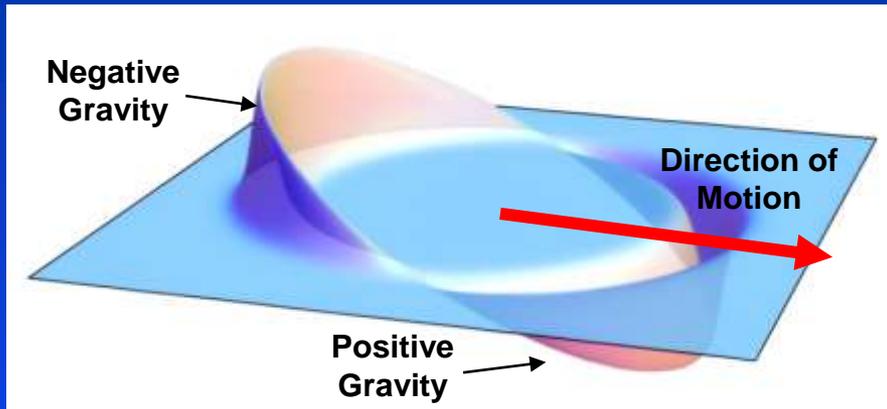
- /// **Resonant Energy Devices (and Experiments)**
- /// **Mach’s Principle and Mass Fluctuations (and Experiments)**
- /// **Gravito-Electromagnetism (GEM)** (see Supplemental Info)
- /// **Extended Heim Theory (EHT)** (see Supplemental Info)

**3) Alternate Dimensions / “Hyperspace”** – Enter an alternate space-time where relativistic effects are circumvented and faster-than-light travel is naturally possible.

- /// **Brane-Based Alcubierre Drive**
- /// **Tri-Space and Fluidic Space-Time**
- /// **Hyperspace in General Relativity** (see Supplemental Info)

# 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 unaffected by relativistic effects.
- An elegant approach for a vehicle to “ride a gravity wave”.



## ▪ Pros:

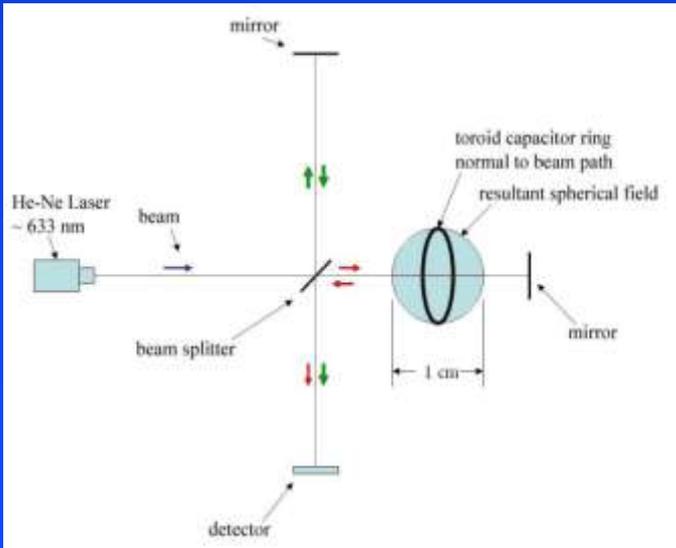
- /// Simple and makes sense. A sound theory.
- /// Many variants explored by many theoretical physicists.
- /// The mathematics have been contrived and solved (general relativity).
- /// Negative energy may be possible through the **Casimir effect and ZPE.**

## ▪ Cons:

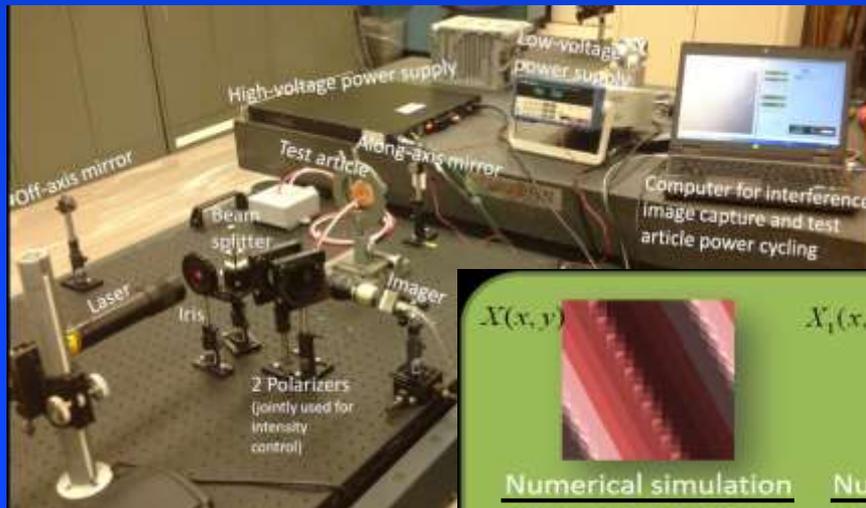
- /// Requires **controllable, negative mass** to create repulsive gravity, possibly as much as  **$10^{67}$  grams**. Some approaches claim only a few milligrams are required.
- /// Not guaranteed to propagate at  $c$  or FTL.
- /// Real-time navigation difficult or impossible.

# Warp Field Interferometry Experiments

- Dr. H. S. White (EagleWorks at NASA/Johnson) attempting to **artificially produce and detect space warping** using laser interferometry
  - ⌘ Uses toroidal capacitor rings to supposedly change the “optics” of spacetime
  - ⌘ Compares path length of laser beams through distortion, if present
  - ⌘ Setup similar to Michelson-Morley aether detection experiment of 1887
- Goal is to quantify energy required to create the Alcubierre warp metric
  - ⌘ Challenge is to create a positively-detectable distortion
- To date, **non-null results** from two separate interferometers using three different analysis techniques
- Results are **far from conclusive** and could be noise or false positives
  - ⌘ Lab may construct a high-fidelity test article for independent testing

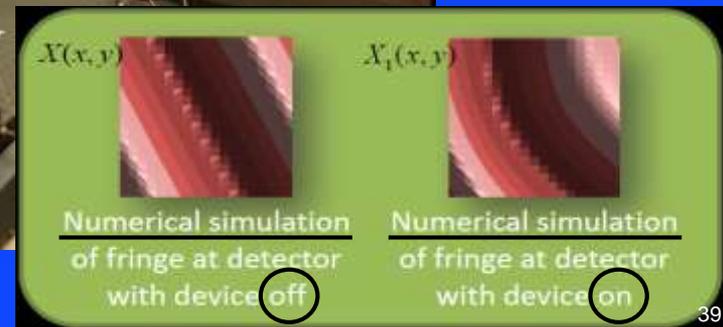


Interferometer Schematic



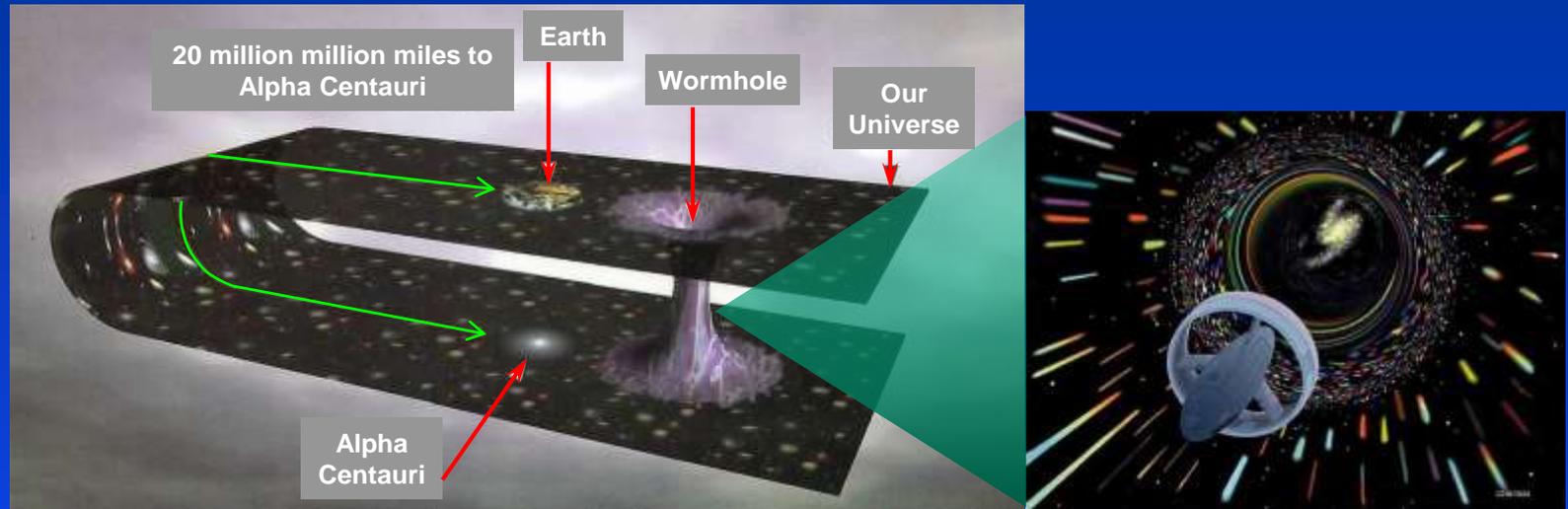
EagleWorks Setup

Predicted Results



# 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** (e.g. neutron star equivalent) of both negative and positive matter 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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The concepts listed below are some of the “more popular” ones in their genre and have **many variants** beyond those presented.

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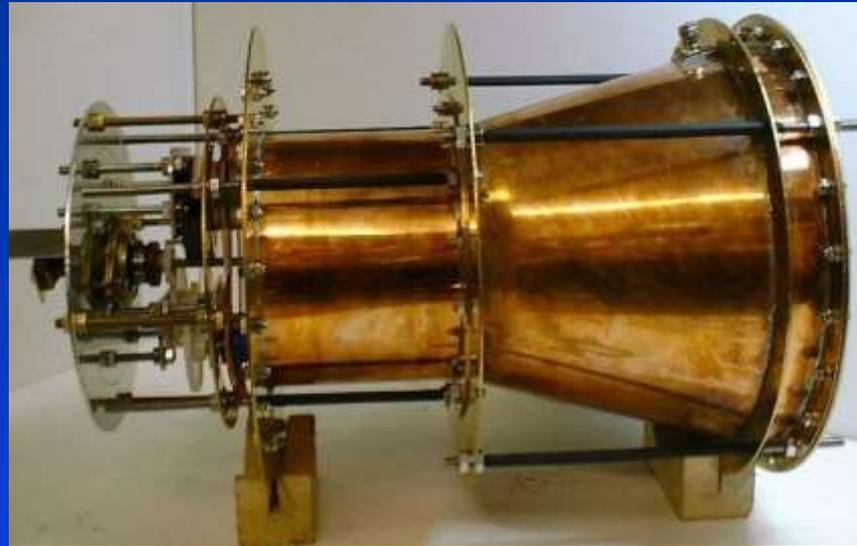
# Resonant Energy Devices (1)

- Create propulsive forces through precise control of EM fields and/or quantum fluctuations confined within a **specialty-designed cavity or container**.
  - ⚡ Usually involve antennae, coils or special materials (dielectrics).
  - ⚡ **Theoretically** works by creating a differential “radiation”, “quantum” or “field pressures” inside the cavity that reacts with ambient space-time.
- Numerous concepts exist based on a variety of theories:
  - ⚡ Q-Thruster (NASA Johnson) – Based on quantum fluctuations
  - ⚡ Cannae Device (Cannae Company) – Based on EM/RF energy
  - ⚡ EmDrive (Shawyer, U.K.) – Based on microwave energy
  - ⚡ Serrano (Gravitec, Inc.) – Based on electric field shaping
- Thrust levels (unverified) in the **micro- to millinewton range**.
- **Pros:**
  - ⚡ For over 100 years, similar concepts have been thoroughly examined.
  - ⚡ Many “engineering” approaches exist, some patented.
  - ⚡ May be scalable, if real.
  - ⚡ **Experiments in progress.**
- **Cons:**
  - ⚡ For over 100 years, has **never been successfully demonstrated!**
  - ⚡ Theories of operation are often based on alternative, usually incorrect interpretations of well-known, proven physics.
  - ⚡ **Initial** experimental characterization methods remain questionable and have been verified to produce unsubstantiated results.
  - ⚡ **Rigorous** experimentation shows **zero thrust** and/or benign alignment with earth’s magnetic field.

# Resonant Energy Devices (2)



Q-Thruster (2004 version)  
NASA Johnson/Eagleworks



EmDrive  
Shawyer  
Q-Thruster  
(2015 version)

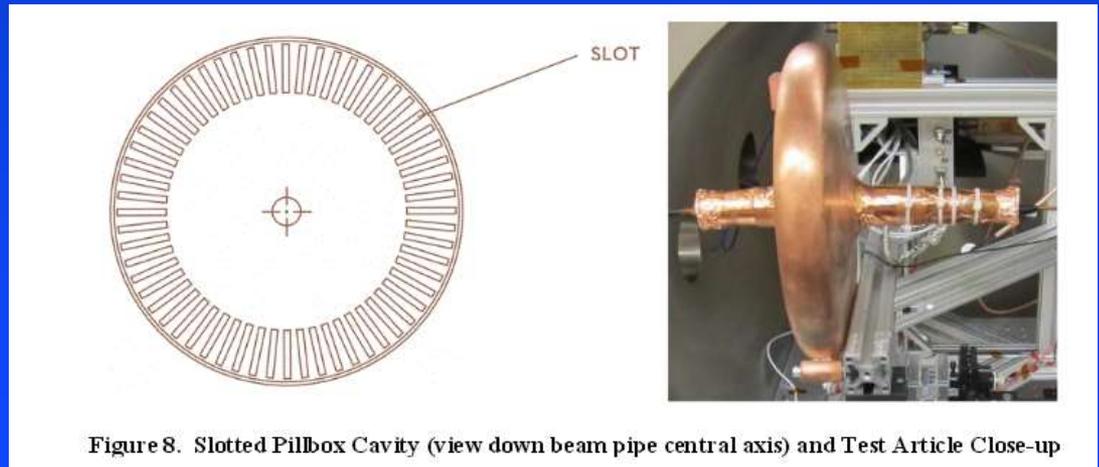


Figure 8. Slotted Pillbox Cavity (view down beam pipe central axis) and Test Article Close-up

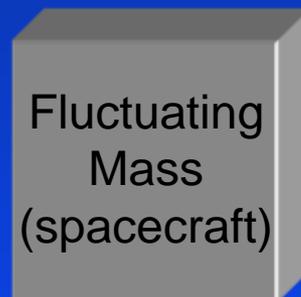
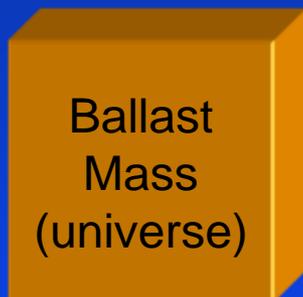
Cannae Drive  
Cannae

# 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.

- Induce **mass fluctuations** which the distant matter in the universe (ballast) will react upon to develop a net force (the Mach Effect).
  - ⚡ The time-averaged "push-pull" may result in a **directional force**.



## ▪ Pros:

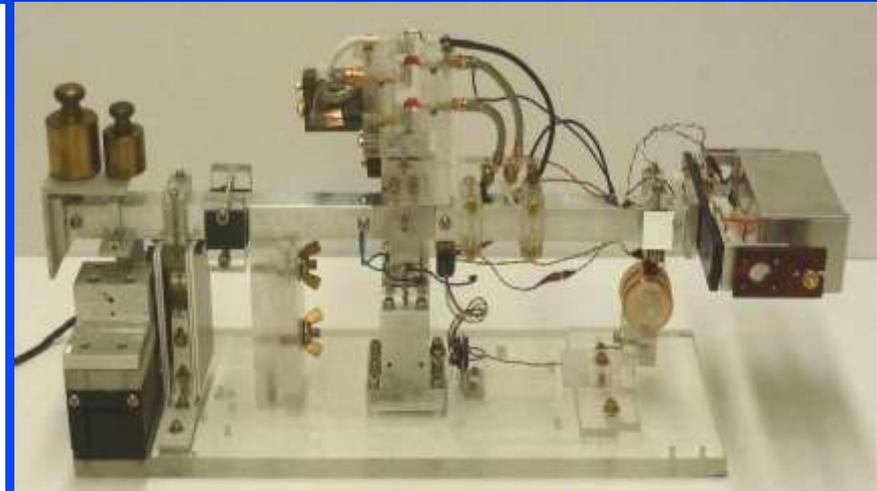
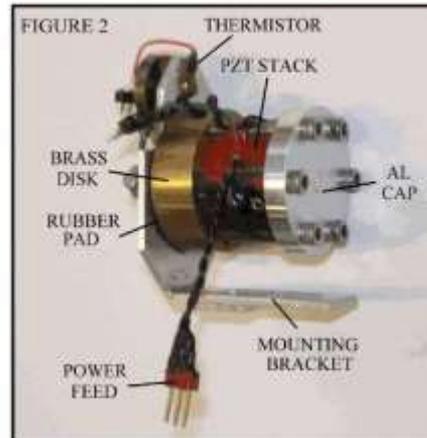
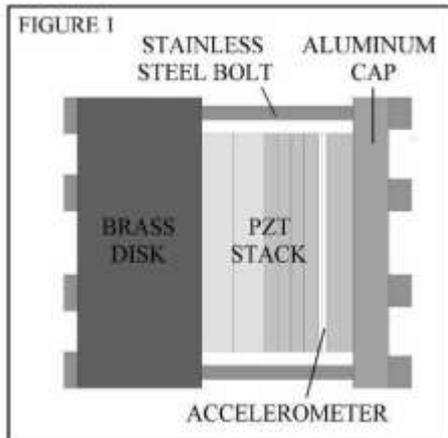
- ⚡ **Experiments in progress around the world** (US, Ger, Ital, Can)
- ⚡ Operational theory **may** be contained within General Relativity and other well-known, proven, accepted conventions.
- ⚡ May **produce negative energies** required for other exotic concepts.
- ⚡ Testable at reasonable power levels and with simple hardware.
- ⚡ Relatively simple engine application: **Mach Effect Gravity Assist (MEGA)**

## ▪ Cons:

- ⚡ **Difficult to measure** and quantify "thrust": signal-to-noise issues, test apparatus effects, sensitivity of device to experimental conditions.
- ⚡ Operational theory has been shown to be based on critical misinterpretations
- ⚡ Scaling effects unexplored.
- ⚡ Propulsive performance of MEGAs not yet quantified (may sublight only).

# Mach Effect Experiments (1)

- CalState University Fullerton (CSUF) experimenting with Mach Effect Propulsion using **piezoelectric** wafer stacks.
  - ⚡ Careful applications of AC voltages induces internal energy changes to the stack, simulating a fluctuating mass.
  - ⚡ This produces a periodic acceleration of one end of the stack while its internal energy fluctuates at twice the applied frequency.
  - ⚡ Mass fluctuation is “rectified” by the application of a second harmonic voltage signal that results in a net force on the device.
- **$\mu\text{N}$  thrust levels** purportedly detected with current experimental setup.
  - ⚡ Higher thrust levels possible if effects can be scaled – **millinewtons??**
- Claims to demonstrate sustained (non-pulsed) thrust in both directions.
- CSUF experiments spanning over 15 years **show interesting results!**

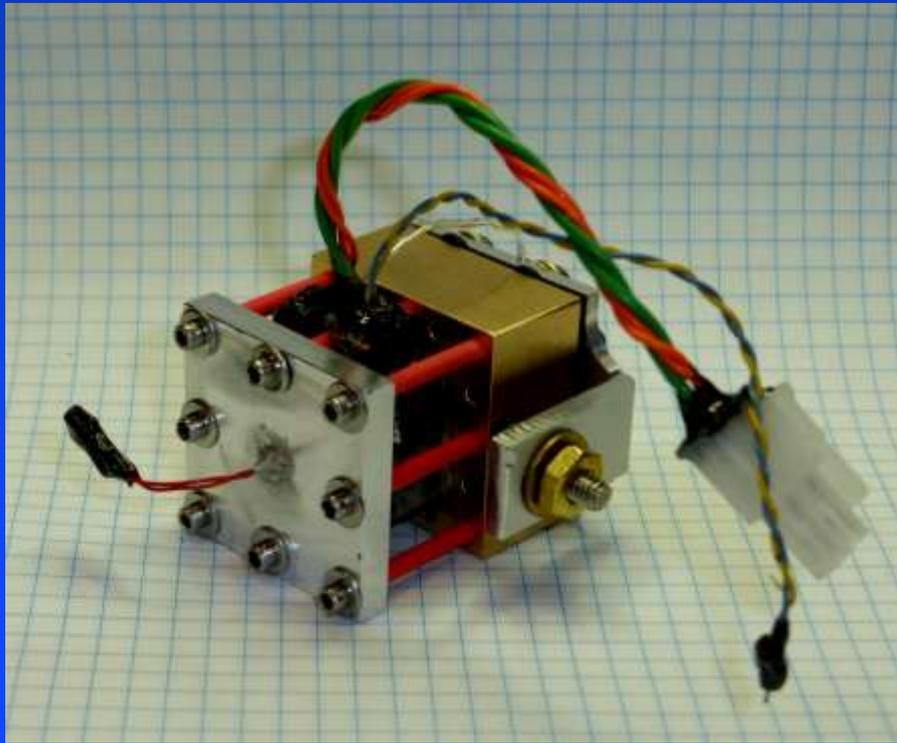


Woodward's PZT Module (mid-2000's to 2018)

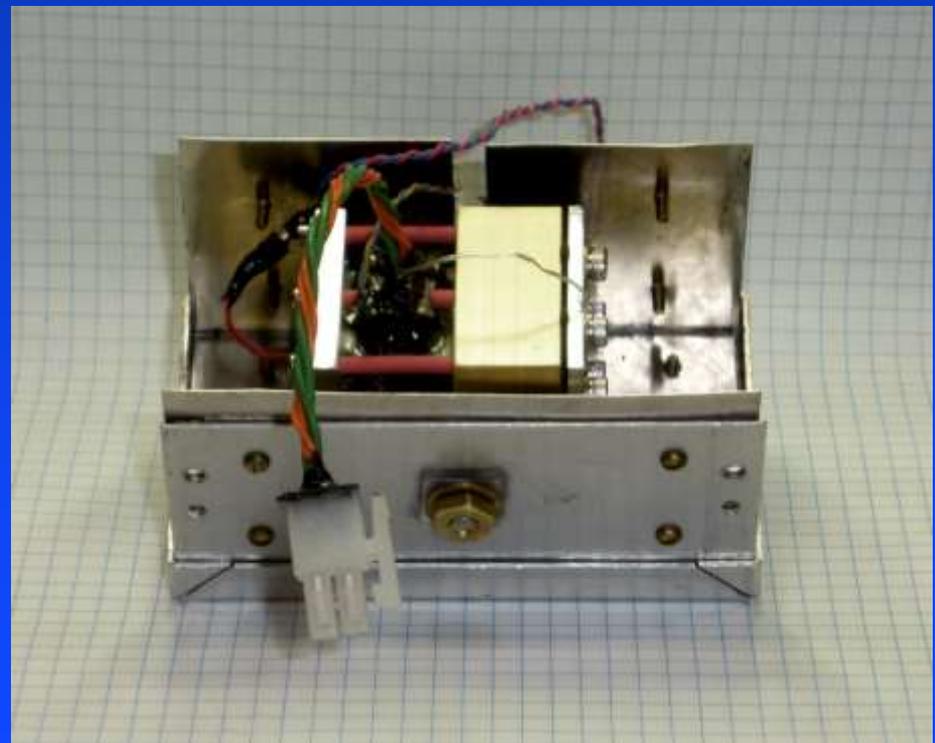
MLT Thrust Balance (ARC Lite) at CSUF

# Mach Effect Experiments (2)

- Rigorous testing in Germany (2017-2019) shows that signals are likely caused by **thermal and/or mechanical effects**, not Mach Effect.
  - Final conclusions to be published in 2020.
- Signals can also be reproduced from **mechanical modeling** of device acting like an anharmonic oscillator.
- MEGA operational theory from CSUF does not hold up to scientific rigor and convention.



Larger cube configuration w/ different wafer material (present)



Mounted in Faraday box

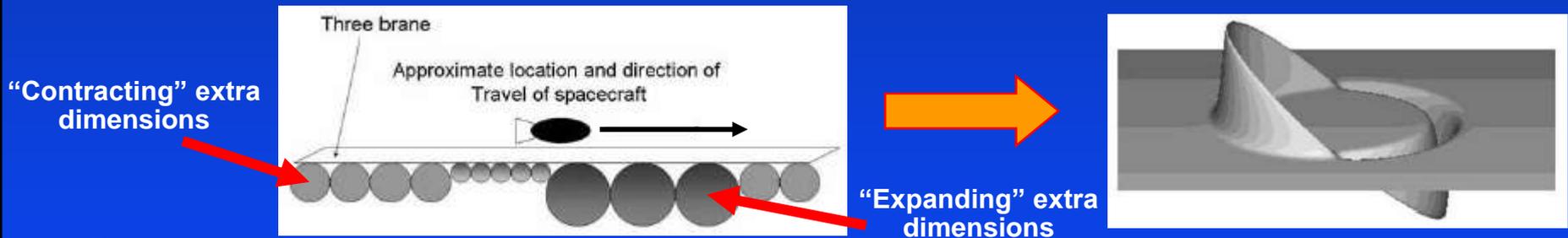
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  - ⚡ Hyperspace in General Relativity (see Supplemental Info)

# Brane-Based Alcubierre Drive

- Adjust the radii of **extra dimensions** within our own to affect changes in the local cosmological constant.
  - Develops an Alcubierre-like space-time distortion. Relates the cosmological constant to the **Casimir energy** of Planck-scale, compactified dimensions from **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.



- **Pros:**
  - No relativistic effects (similar to Alcubierre Drive).
  - Does not directly use negative mass.
  - **Faster than light travel is possible with upper limit of  $10^{32}c$ !**
  - Originated at Baylor University (R. Obousy/G. Cleaver)
- **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

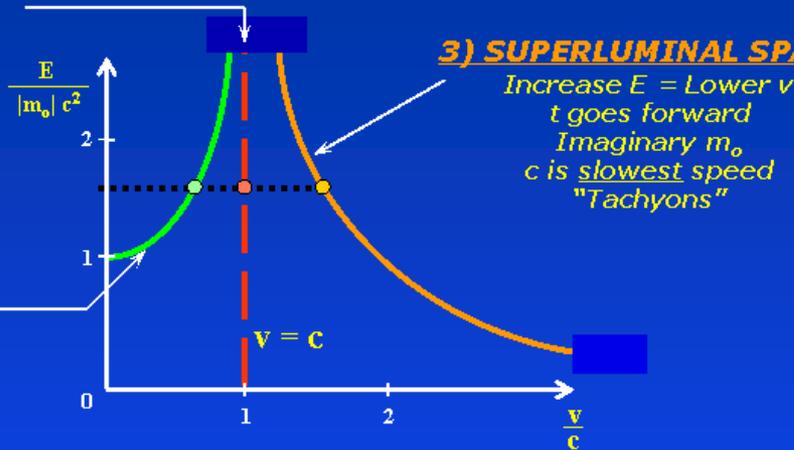
- Proposes that the universe consists of **three, co-located space-times**: subluminal ( $v < c$ ), luminal ( $v = c$ ) and **superluminal ( $v > c$ )**, hence "Tri-space".

## 2) LUMINAL SPACETIME:

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

## 1) SUBLUMINAL SPACE:

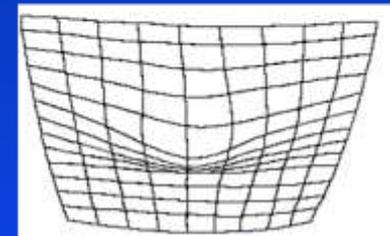
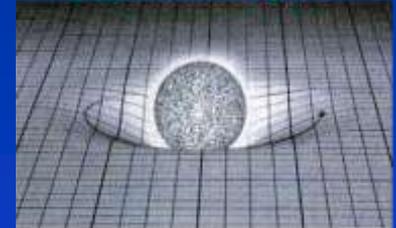
Increase  $E$  = Higher  $v$   
Real  $m_0$   
 $t$  goes forward  
 $c$  is fastest speed  
"Tardyons"



## 3) SUPERLUMINAL SPACE:

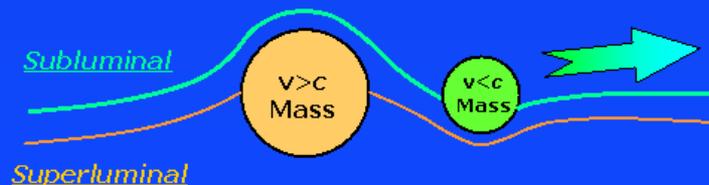
Increase  $E$  = Lower  $v$   
 $t$  goes forward  
Imaginary  $m_0$   
 $c$  is slowest speed  
"Tachyons"

Subluminal Space



Superluminal Space

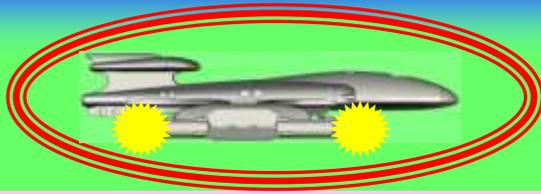
- Energy **extraction** results in **higher** velocities.
- Real, positive mass** energy can exist in only one space at a time.
- In superluminal space, **rest mass becomes imaginary** and only velocities **greater than  $c$**  exist.
- Superluminal mass is made of **tachyon equivalents** of subluminal particles.
- Either space is unobservable from the other, but gravity acts across each.



- Superluminal mass has a **repulsive gravitational effect** in subluminal space.

# Tri-Space and Trans-Space FTL Travel

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



Subluminal Space ( $v < c$ )

Luminal Spacetime ( $v = c$ )



Superluminal Space ( $v > c$ )

- **Pros:**

- ⚡ **Velocities always greater than light speed** (theoretical infinite velocity)
- ⚡ **No relativistic effects.** Causality or relativity not violated in either space
- ⚡ **Navigation possible**
- ⚡ No negative matter required
- ⚡ **Several plausible theories exist for entering superluminal space**
- ⚡ Tri-Space model consistent with current scientific discoveries
- ⚡ Evidence suggests existence of **superluminal space & fluidic space-time**

- **Cons:**

- ⚡ **Assumes** existence of superluminal space (possibly dark matter/energy)
- ⚡ Mathematics partially understood, requires analysis of **fluidic space-time**
- ⚡ Characteristics of superluminal space need to be understood
- ⚡ Difficult to model in 3-D

# Comparison of FTL Concepts

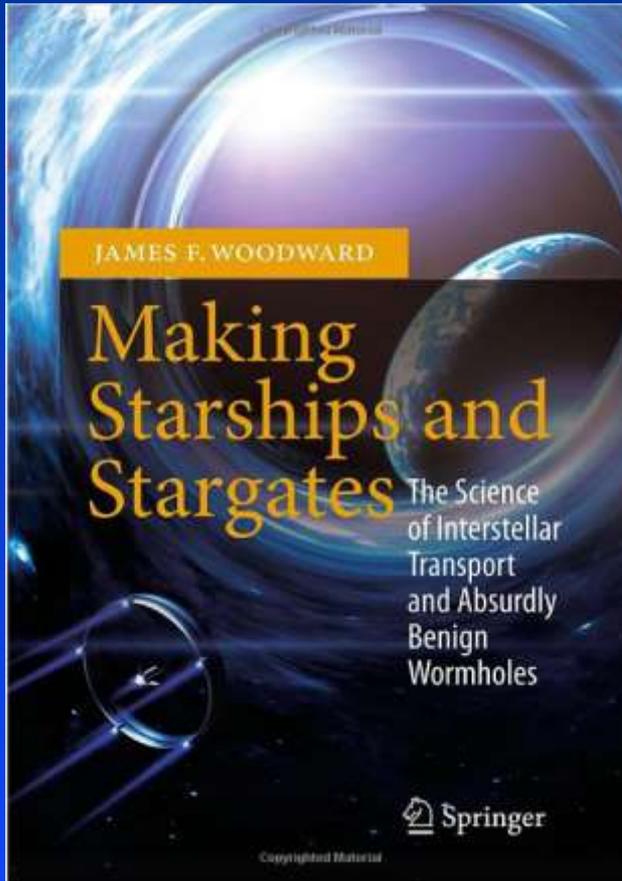
Trans-Space FTL Travel has many advantages over other FTL concepts...

## Trans-Space FTL Travel

## Other FTL Travel Concepts

	Trans-Space FTL Travel	Other FTL Travel Concepts
Basic Concept	Matter energy transferred from one space to another through spacetime medium	<ul style="list-style-type: none"> <li>- Disturbance created in spacetime via holes, warps, folds, etc.</li> <li>- Access to multi-dimensional spaces/branes</li> </ul>
Mass	Vessel traverses <i>subluminal</i> space by traveling through <i>superluminal</i> space	Vessel travels through holes, warps, folds, or hidden dimensions in spacetime
Energy	<ul style="list-style-type: none"> <li>- Absolute throughout tri-space</li> <li>- Conserved between all spaces</li> </ul>	<ul style="list-style-type: none"> <li>- Large amounts required</li> <li>- 'Negative' energy required (?)</li> </ul>
Time	<ul style="list-style-type: none"> <li>- No causality effects</li> <li>- Time travel not possible</li> </ul>	<ul style="list-style-type: none"> <li>- <i>Sometimes</i> instantaneous - no causal effects</li> <li>- 'Negative' energy may pose temporal issues</li> </ul>
Navigation/Control	<ul style="list-style-type: none"> <li>- Possible in superluminal space (similar to subluminal space)</li> <li>- Detection/Interaction using gravity wells</li> <li>- 'Stationary' EM energies for attitude control</li> </ul>	<ul style="list-style-type: none"> <li>- Unknown, difficult or impossible</li> <li>- Destination must sometimes be known beforehand</li> </ul>
Other	<ul style="list-style-type: none"> <li>- No 'negative' quantities required</li> <li>- Transition to FTL state at subatomic level</li> <li>- No initial velocity required to transition</li> </ul>	<ul style="list-style-type: none"> <li>- No guarantee of FTL velocities</li> <li>- Quantum effects not defined</li> <li>- "Brute force" to get to near-c velocities</li> </ul>

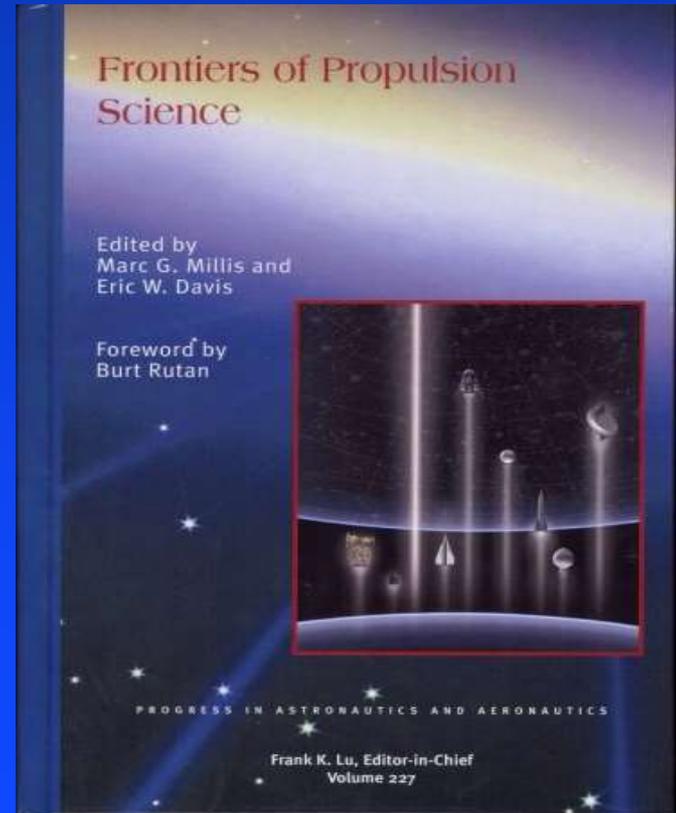
# The Only **Books on Credible Advanced Propulsion**



James F. Woodward

## **Making Starships and Stargates: The Science of Interstellar Transport and Absurdly Benign Wormholes**

Available through Amazon.com



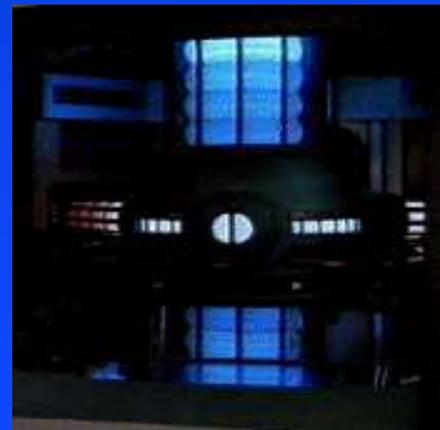
Marc Millis, Eric Davis

## **Frontiers of Propulsion Science**

Now in 2<sup>nd</sup> Printing, Available through AIAA

# Summary of Propellantless Ideas

- All “back of the napkin” concepts, so **NASA TRL is about 0 or 1**
- Of the concepts described, only these few appear to offer the possibility of **light speed or FTL travel**:
  - ⚡ Alcubierre Warp Drive
  - ⚡ Traversable Wormholes
  - ⚡ Brane-Based Alcubierre
  - ⚡ Trans-Space FTL Travel
  - ⚡ Hyperspace in GR (see Supporting Info)
- Subsystems required to support these concepts are still being conceived, as are the actual “engines”
- **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)!

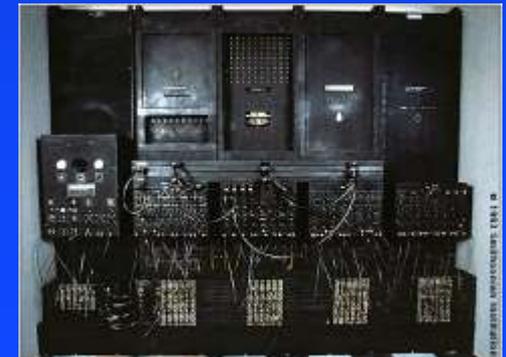
**Where do we go from here?**



***Chapter 8:***  
***Closing Statements***

# *There Will ALWAYS be Skeptics (a good thing!)*

- “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, 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.”
  - A Yale University management professor in response to Fred Smith’s paper proposing reliable overnight delivery service.  
Smith went on to create 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.



# ***There Will ALWAYS be Skeptics***

From the October 9th, 1903 edition of the **The New York Times**

*“[A] flying machine which will really fly might be evolved by the combined and continuous efforts of mathematicians and mechanics in from one million to ten million years.”*

From the October 9<sup>th</sup>, 1903 entry in Orville Wright’s diary:



*“We started assembly today.”*

# ***Final Thoughts on Interstellar Travel***

- Mankind **needs** to venture out into the universe to seek the answers to questions about our evolution and our fate
  - ⚡ Terrestrial-based and robotic exploration have extreme limitations.
- Current propulsion technology and near-term advancements **will not** facilitate rapid, human exploration of the solar system or local stars
- Contrary to popular belief, the speed of light is **NOT** the speed limit!
  - ⚡ Einstein and others have shown this to be true
- A **paradigm shift** in propulsion technology **must happen** if we are ever to become a thriving, space-faring civilization
  - ⚡ Depart from conventional systems into **physics-based** concepts that enable travel at **superluminal speeds!**
- Some of these concepts 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.**

## ***And Lastly....***

---

“So many of our dreams at first seem impossible, then they seem improbable, and then when we summon the will, they soon become inevitable.”

- Christopher Reeve, Actor

“You have kindled a fire, and we shall not let it die out, but will bend every effort to make the greatest dream of mankind come true.”

- Prof. Hermann Oberth to Tsiolkovskii, 1929, describing putting a human in space

***Thank You for Your Attention!***

# THANK YOU!



For a copy, contact:  
Greg Meholic at  
[orionstar2209@yahoo.com](mailto:orionstar2209@yahoo.com)

Interstellar Exploration Vessel  
*Orion Star*  
© Greg Meholic, 2005  
(No...This isn't from Star Trek)



# Photo/Graphics Credits (1) (may not be in order)

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# ***Supplemental Information:***

*Antimatter Information*

*Gravito-Electromagnetism (GEM)*

*Extended Heim Theory*

*Hyperspace in GR*

*MLT Fluctuation Experiments*

*NASA Breakthrough Propulsion Physics Project (BPP)*

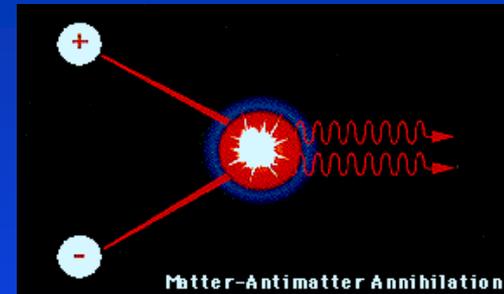
*BPP Details and Experiments*

*Anomalous Acceleration Field (Tajmar)*

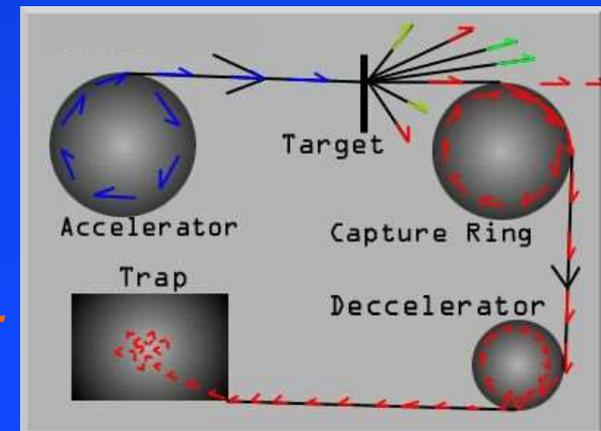
*Potential Acceleration Field Applications*

# Matter/Antimatter Annihilation

- Every elementary particle has a counterpart that is of opposite charge, but same mass.
  - ⚡ Electron (-) → **Positron (+)**
  - ⚡ Proton (+) → **Antiproton (-)** (*preferred for propulsion – more mass*)
- When two similar mass particles collide, the two masses are annihilated and **completely converted to energy**.
  - ⚡ Antimatter can be sustained indefinitely as long as it does not contact normal matter.
  - ⚡ Process yields the **highest energy density** in nature: 1 kg matter + 1 kg AM =  **$1.8 \times 10^{17}$  J!**



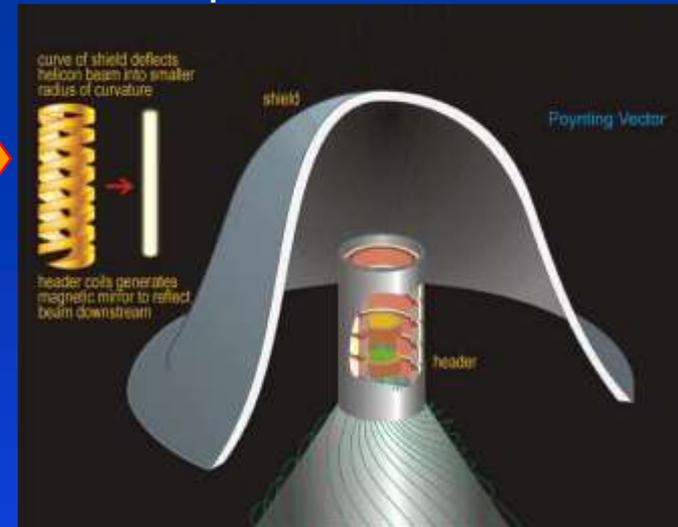
- Antimatter is created by colliding a highly-accelerated matter stream with a stationary target.
  - ⚡ Antimatter must be quickly and carefully captured during the process - inefficient.
  - ⚡ Trapping and storing antimatter requires high vacuum conditions at very low temps.
  - ⚡ *Global annual production: 2-20 nanograms/yr*
  - ⚡ *Production cost: \$300B per milligram*
  - ⚡ Able to make **Anti-hydrogen?**



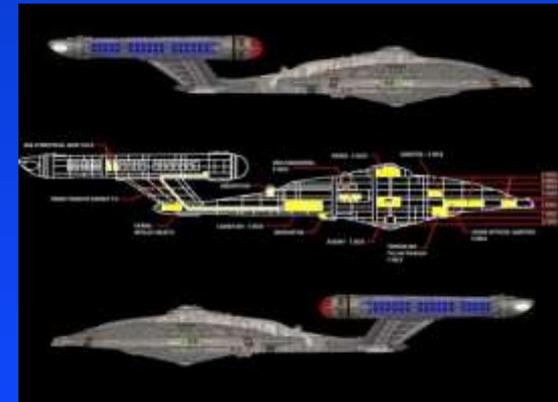
# Gravito-Electromagnetism (GEM)

- **Create or manipulate gravity** through precise control of EM forces
  - ⚡ Usually involves antennae, coils, toroidal inductors, various other hardware
- Generate an “anti-inertial” field to protect vehicle from rapid accelerations - “**inertial dampeners**”
- Attempts to merge the physics of **gravity** & **inertia** with those of **electromagnetism**
  - ⚡ Heavy math: Einstein Field equations, stress-energy tensors, torsion fields, etc.
  - ⚡ Involves both particle and quantum physics.

Example: Potter “Onion” drive



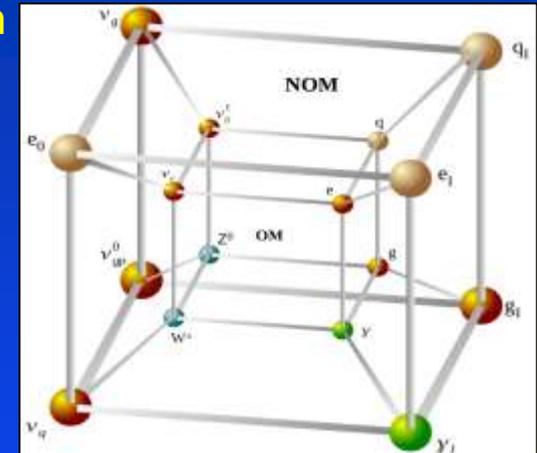
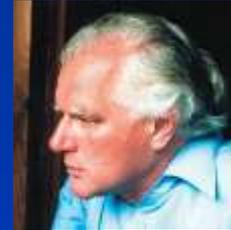
- **Pros:**
  - ⚡ Has been thoroughly examined for over 100 years
  - ⚡ Many “engineering” approaches exist, some patented
  - ⚡ J. Brandenburg & P. Murad (Morningstar) (among many) actively pursuing theory development for propulsion applications



- **Cons:**
  - ⚡ Has **never been successfully demonstrated** - in over 100 years!
  - ⚡ Very few concepts have been experimentally tested, all with null, unfavorable or questionable results
  - ⚡ Travel at speeds at or near  $c$  is unknown

# Extended Heim Theory (EHT)

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



## ■ Pros:

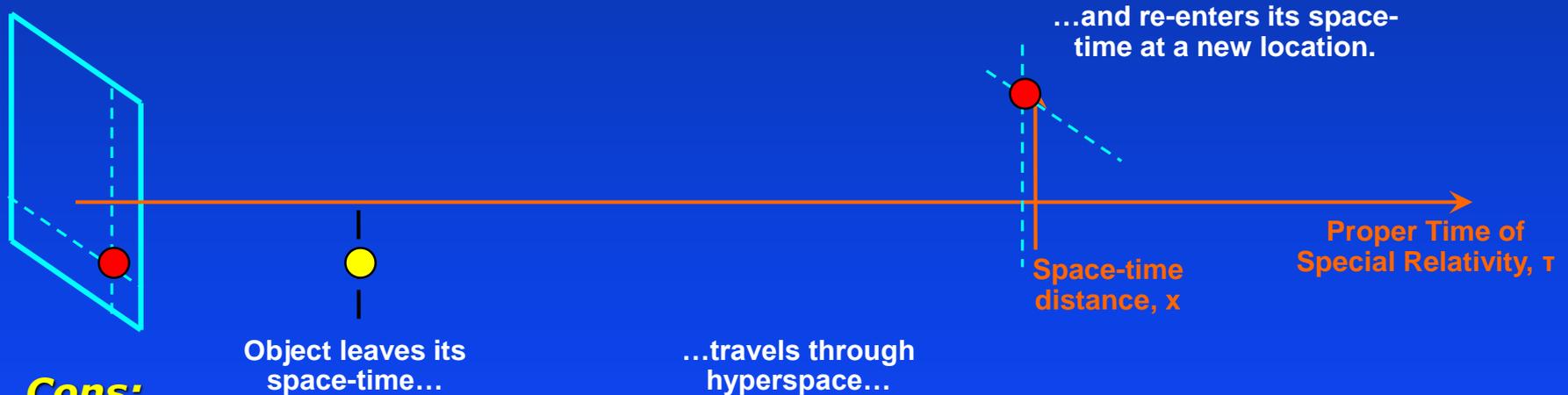
- ⚡ W. Dröscher and J. Häuser (Germany) are using EHT to facilitate propulsion concepts.
- ⚡ Beginning to gain recognition as a viable alternative to Standard Models of modern physics and quantum mechanics.

## ■ Cons:

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

# Hyperspace in General Relativity

- Shift or “rotate” a spacecraft into a **hyperspace** where time is measured differently, but where travel at  $c$  or greater is allowed.
- 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.
  - ⚡ Particles in hyperspace move at  $c$ .
  - ⚡ Hyperspace topology may also help to explain universal expansion.



## ■ **Cons:**

- ⚡ Highly mathematical and somewhat esoteric.

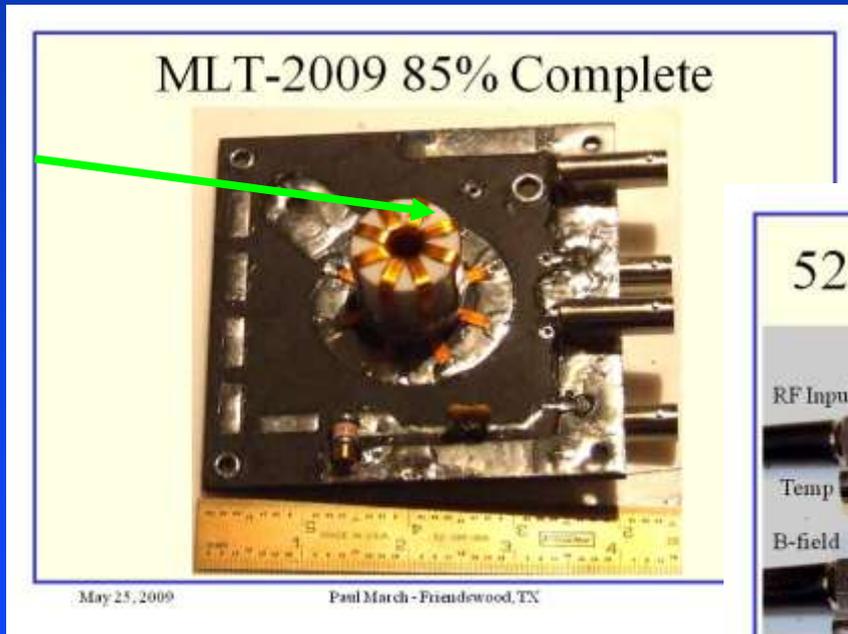
## ■ **Pros:**

- ⚡ 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.
- ⚡ Hyperspace only exists in a mathematical sense – may be untestable.

# MLT Mass Fluctuation Experiments

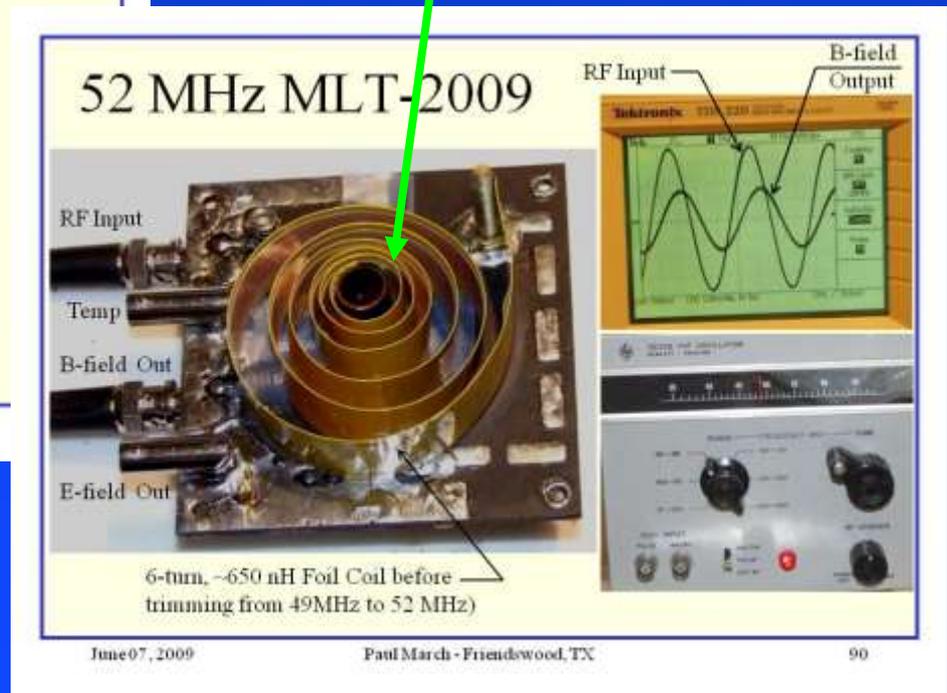
- Paul March (ret. Lockheed, Barrios) and H. Sonny White (IAS) using a circular ring of capacitors subject to an oscillating magnetic field.
  - Force measured on custom-designed pendulum.
- All experiments are **in progress and continuing!**

Capacitor ring



March/White MLT and Testing

Electric field coil

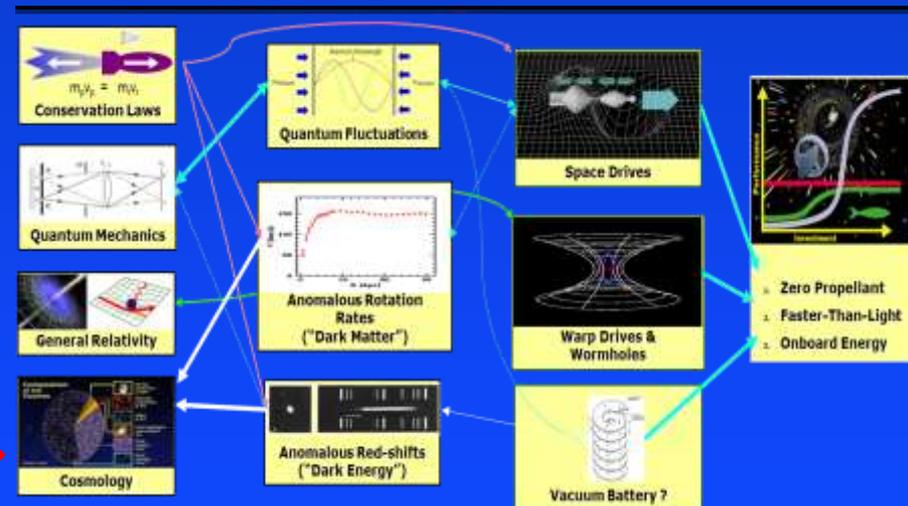


# Breakthrough Propulsion Physics (BPP) Program

- **First dedicated effort to experimentally explore fundamentals of physics-based propulsion concepts**
  - ⌘ Developed a rigorous process for determining the **scientific credibility and validity** of unique propulsion ideas involving "new" or "breakthrough" physics.
- Operated out of NASA Glenn Research Center by Marc Millis between 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.

- **Summary of BPP Program:**

- ⌘ \$1.55M spread over 6 years
- ⌘ **16 experiments funded**
  - **5 not viable (null)**
  - **7 unresolved**
  - **4 open for continued study**
- ⌘ **16 AIAA journal publications**
- ⌘ See **Supporting Information** for the categories explored



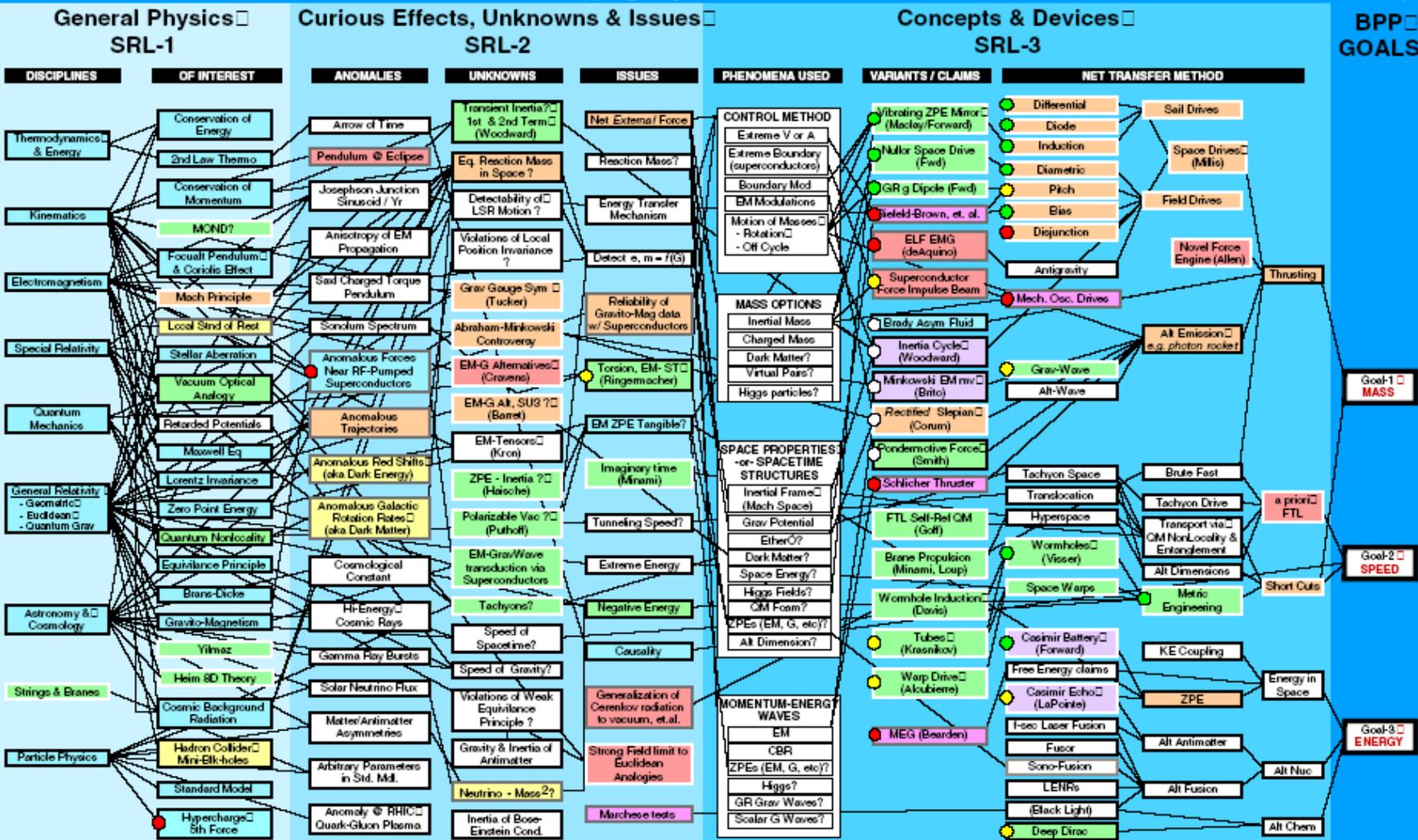
- ⌘ **Book: *Frontiers of Propulsion Science* - Available thru AIAA**
  - 23 chapters from 18 contributing authors (including editors)

# BPP Detailed Topics

Marc G. Millis

Mapping Physics to BPP Goals

Draft Ver. 2004-10-08\_BPP\_Map

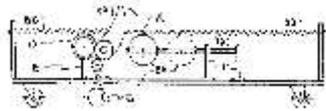
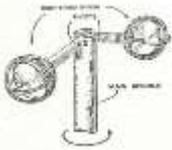


**COLOR KEY:** [Place-Holder] [SRL-n.0 (Noticed)] [SRL-n.1 (Problem Defn)] [SRL-n.2 (Collect Data)] [SRL-n.3 (Hypothesis)] [SRL-n.4 (Tested)] = TRL-1 (Op Principles) | TRL-2 (Concept Design) | TRL-3 (Design Tested)

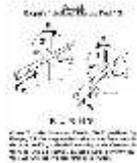
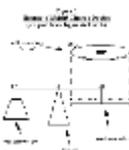
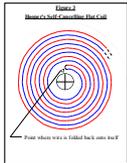
● = Dismissed   ● = Caution   ● = Continue Study   ○ = TBD   ▲ = Info Included

[Blk Frame] = Title or Empirical+Theoretical   [Gry Frame] = Empirical   [Wht Frame] = Theoretical

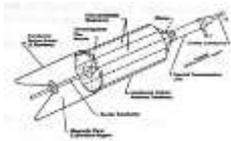
# BPP Null Research Findings



- **Mechanical “Antigravity” (AIAA-2006-4913)**  
Gyroscopes, Sticktion oscillators



- **Hooper “antigravity” coils (NASA TM-106963)**



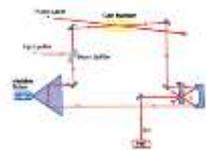
- **Schlicher thrusting antenna (AIAA-2001-3657)**



- **Podkletnov gravity shield (Hathaway, *Physica C* 385 p.488)**

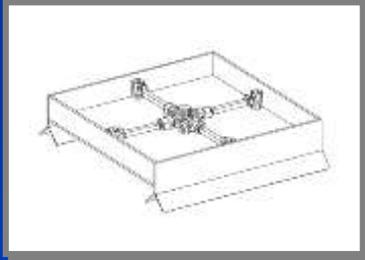


- **Corona blowers (NASA CR-2004-213312)**  
“Biefeld-Brown,” “Electrogravitics,” “Lifters,” “ACTs”

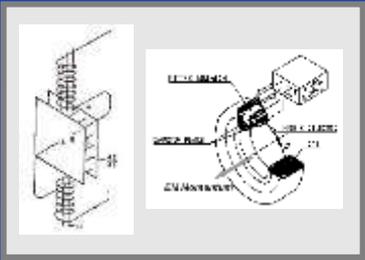


- **Quantum tunneling as FTL venue**

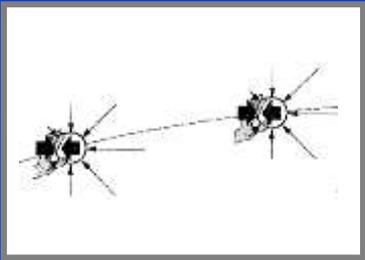
# BPP Unresolved Research Approaches



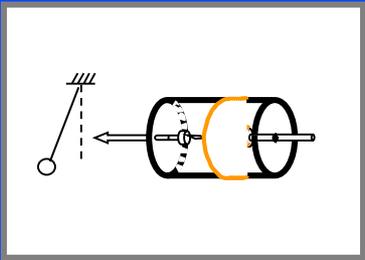
- Woodward's **inertial oscillation** theory & experiments
- If genuine, assess propulsive implications



- Abraham vs. Minkowski **electromagnetic momentum** (1909)
- If Minkowski correct, assess propulsive implications



- **Inertia & gravity** interpreted as quantum vacuum effects
- If viable, assess propulsive implications



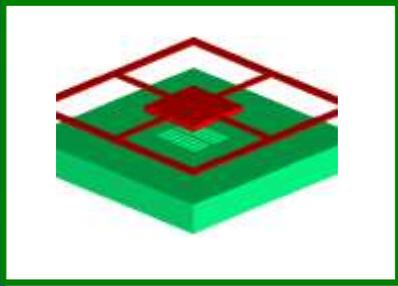
- Podkletnov latest claim: “**force-beam**”
- Superconductors as a new generic exploration tool

# BPP Open Research Approaches



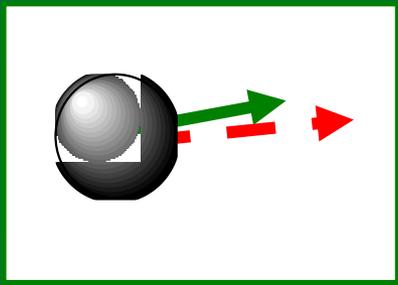
## Space Drives

- Seek reaction mass from space (revisit cosmological anomalies)
- Revisit Mach's Principle (inertial frame physics)
- Seek *Asymmetric* Coupling of the Fundamental Forces



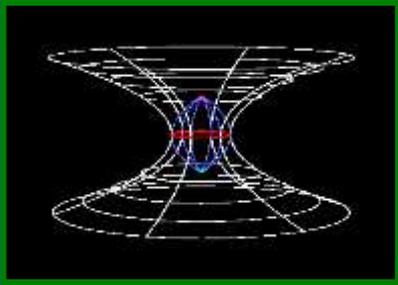
## Quantum Vacuum Energy Experiments (NASA CR-2004-213311)

- As a window to studying fundamental space properties
- Asses magnitude of *tangible* forces or energy
- Note: Although propulsion possible in principle, still too feeble



## Provocative Questions

- Resolve anomalous spacecraft trajectories
- Look for violations of Equivalence Principle in free-fall

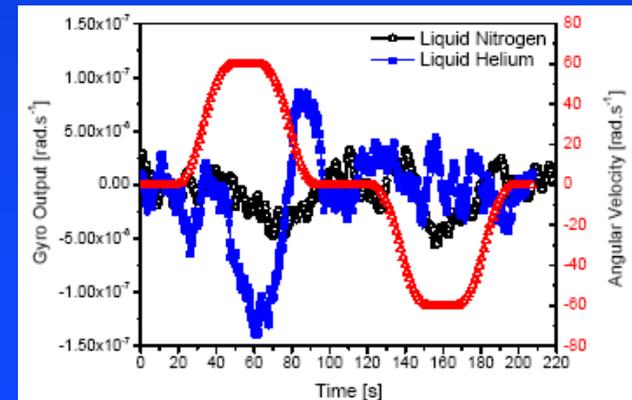
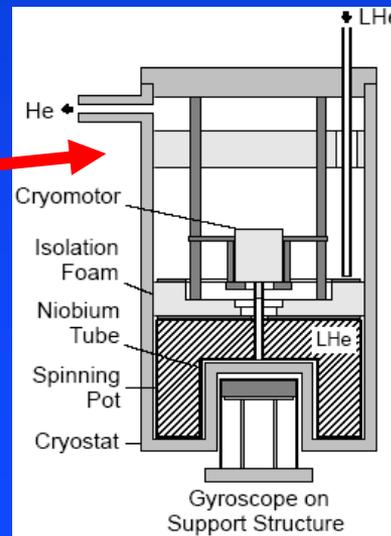
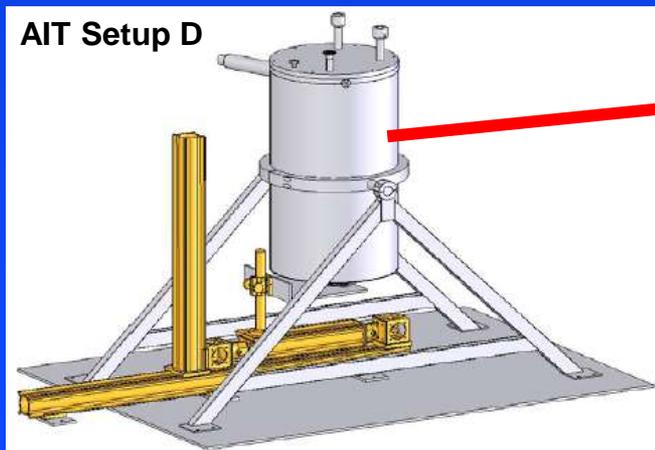


## Faster-Than-Light Inquiries

- Average null energy conditions
- Quantum fluctuations in topology
- Causality questions

# Anomalous Acceleration Field (2004-2012)

- Dr. M. Tajmar (Austria) had **experimentally observed** what was described as a “gravity-like” anomalous acceleration field generated within the vicinity of rotating, liquid helium
  - ⚡ Anomalous signals detected by stationary gyroscopes and accelerometers
  - ⚡ Dipole field exhibited an unusual rotational parity violation
- Observed effect was **16-18 orders of magnitude greater** than prediction by General Relativity (GR)
  - ⚡ Observed field was in the  **$10^{-5}$  G** range
  - ⚡ **No known theory in physics** could readily explain the field’s strength or observations
- Careful examination determined effect was caused by some sort of acoustical mechanical resonance. **It was not an anomalous acceleration field**
- Possible ties to Gravity Probe B data anomalies



# Potential Acceleration Field Applications

If a Mach Effect or anomalous acceleration field can be amplified, controlled, directed, and efficiently produced, **remote force generation technology** may potentially be possible for..



## Gravity Gradients

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

## Object Deflection

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

## Vehicle Control

- "Propellantless" satellite or upper stage RCS
- De-orbit capability

## Propellantless propulsion?

...Plus a myriad of other medical & manufacturing possibilities!