Engines for the Cosmos

Galactic forces spiral across the cosmos fueled by nuclear fission and fusion and atoms in plasmatic states with throes of constraints of gravitational forces and magnetic fields. In their wanderings these galaxies spew light, radiation, atomic and subatomic particles throughout the universe. Throughout the ages of man visions of journeying through the stars have been wondered. If humans and human devices from Earth are to go beyond the Moon and journey into deep space, it must be accomplished with like forces of the cosmos such as electrical fields, magnetic fields, ions, electrons and energies generated from the manipulation of subatomic and atomic particles. Forms of electromagnetic waves such as light, radio waves and lasers must control deep space engines. We won't get far on our Earth accustomed hydrocarbon fuels.

Deep Space Propulsion

Rocket propulsion to explore deep space is different than launch propulsion on Earth. On Earth high thrust is required to escape Earth's gravitation pull. Vehicles in deep space are only faintly affected by Earth's gravity. Consequently, high thrust engines are not required. To explore the outer planets in a reasonable time, cosmos engines must generate either high exhaust velocity or high specific impulse (Isp). Specific impulse is a measure in seconds of propulsion system efficiency in converting fuel energy into momentum. Chemical propulsion can provide high thrust but is limited in the specific impulse (<500sec). This is because chemical propellants carry all of the energy that can be generated within the chemical composition of the propellant and there is a fundamental limit this energy and consequently to the specific impulse generated. To achieve higher specific impulses we must look to other energy sources including fission and fusion. With the very high energies from these sources perhaps sub atomic particles of light gases can be manipulated to efficiently generate low thrust energy using electron guns, electrical fields, magnetic fields, electric currents, lasers, radio waves and combinations thereof.

This was known by some early 20th century chemical rocketeers. In 1947 Wernher von Braun asked Ernst Stuhlinger to research Herman Oberth's concept of electric propulsion as written in his book, "Possibilities of Space Flight", published in 1939 in Berlin. As Stuhlinger recalls, von Braun said "I wouldn't be a bit surprised if we flew to Mars electrically". Stuhlinger immerged himself in studying electric propulsion possibilities and in 1955 presented a paper to the International Astronautical Congress in Vienna entitled, "Possibilities of Electrical Space Ship Propulsion". In 1952 von Braun presented his first plan for a journey to Mars. This plan using chemical propulsion required 5,320,000 metric tons of fuel for 10 spaceships and the assemblage of 37,200 tons in Earth orbit. Stuhlinger's plan for a Mars journey with electric propulsion required putting only 2,788 tons into Earth orbit. Von Braun then (1952) wrote "The small thrust (from electric propulsion) is effective for missions to the more distant parts of the solar system".

Stuhlinger immerged himself in the development of electric ion propulsion development. On September 27, 1961, Stuhlinger and Hughes Research technicians working under a NASA Marshall Space Flight Center contract, demonstrated the operation of a low-thrust (0.1 lb.), high specific impulse ion propulsion engine in a vacuum chamber simulating outer space. This was the first firing of a non-chemical rocket of the order that is destined to take man beyond the Moon and into deep space. By 1962 the nuclear-electric propulsion research work at Marshall Space Flight Center was transferred to NASA's Lewis Center as the Marshall Center focused on the mission of developing the Saturn rockets that would overtake Soviet space superiority and land Americans on the Moon.

In June 1996 a prototype xenon ion engine built at Lewis began long-duration tests in a vacuum chamber at JPL and recorded more than 8,000 hours of operation. On October 24, 1998, Deep Space1 was launched, the first spacecraft to reach another planetary body.

Ion Propulsion

In electric ion propulsion systems, the electric energy is deposited into the propellant flowing into the engine. Whereas chemical propulsion systems use heat to eject combusting propellants, ion propulsion systems have an electrical field that ejects propellant ions into space thereby transferring momentum to the spacecraft. Cesium or xenon gas is injected with ions from an electron gun. The electric field from the voltage on a pair of metal grids extracts the charged ions and expels them into space. A cathode located toward the end of the engine injects electrons into the charged exhaust so that the spacecraft body does not build up a negative charge. The ion drive is powered by solar panels but could be powered by a nuclear reactor for more powerful and deeper space missions. The electrical grids physically limit the flow of the ion beam and therefore the power generated.

In the Deep Space 1 ion engine electrons are emitted from a hollow tube cathode and enter a magnetic-ringed chamber where they strike xenon atoms. This impact knocks away a xenon electron causing the xenon to become ionized. As the ionized gas flows to the rear of the engine, it encounters a 1,280-volt electrical field from a pair of metal grids that forces the xenon ions to shoot from the engine body at speeds of 100,000 km/h (60,000 mph). This engine develops $1/50^{th}$ of a pound of thrust, much less than chemical rockets but with it's high specific impulse (a measure of propulsion energy output per fuel mass) it can journey in space for years.

Ion thrusters emit beams of positive ions and have high Isp values. Ion thrusters are still powering the Deep Space 1 probe.

Hall-Effect Thrusters – Russian Space Engines

The Russians have built Hall-effect thrusters and flown them on more than 100 satellites since the early 1970s. The Russian Hall-effect thruster engines also have an electric field that ejects high temperature charged xenon gas particles. The electric field is not created by electrical grids but by a ring of magnets around the perimeter of the chamber with a magnetic core rod running axially down the center so as to generate a radial magnetic field. This radial magnetic field causes the xenon electrons to circle the chamber interior thereby inducing an axial electrical field without grids and a Hall current that ejects the charged particles out into space. The Hall current derives from differing behavior of electrons and heavier ions in field induced spiral pathways. The Hall-effect flow of particles out into space is not impeded by grids, however the engines are less efficient than ion engines because electrical energy is not injected into the gas as in the ion engine. The energy comes from the gas that carries the energy only. The Russian thruster SPT 140 is a 5 kW engine with a thrust of 250mN (Steve put this in fractions of Newtons), exhaust velocity of 22.5 km/s and is 57% efficient.

Magnetoplasmadynamic Engines

Magnetoplasmadynamic (MPD) engines accelerate charged particles in plasmatic states out of the engine with magnetic fields rather than electrical fields. Hydrogen, argon or lithium are used as the gas propellant. The converging shaped outer configuration of the engine chamber serves as an anode with a rod in the center of the chamber being the cathode. A voltage between the anode and cathode creates an electric current that flows radially through the gas and also down the cathode. The current flow in the gas ionizes it. The current in the cathode generates a circular magnetic field that encounters the radial electrical field thrusting the ions out into space. The magnetic field is self induced Lorentz force on the plasma particles. MPD engine is capable of continuos thrusting and can operate at higher power than other deep space engines. Various configurations of magnetoplasmadynamic engines are being developed in the U.S., Russia, Germany and Japan. MPD configurations being experimented with in the U.S. include first ionizing and heating the hydrogen with radio waves of certain frequencies. The radio waves can heat the gas to plasma states of over 10 million degrees. Magnets are used to control the plasma during the process and in certain configurations as a variable choke for the exhaust. Improved controls of propulsion parameters such as thrust, Isp, and exhaust speed are being developed for magnetoplasmadynamic rockets that will make them more promising for deep space missions.
(talk fusion)
(fusion, sttr) (Steve, add to this)

Deep Space Engines Energy Sources

Electric propulsion devices require an energy source and electric generation method in order to operate. Many concepts have been examined including solar photovoltaic, thermoelectric, thermionic, electrochemical, and the Brayton, Rankine, and Sterling thermodynamic conversion cycles. Typically these systems will provide power for the entire spacecraft as well as the propulsion device. Batteries, photovoltaic cells, isotope thermoelectric generation units, and fuel cells have been used in space flight operation. So far the power output capacity for operational systems has been low (tens of watts).

Much higher power levels will be needed for space travel to the outer planets in reasonable time frames or for manned space travel. The energy sources considered most practical for spacecraft applications are chemical (batteries or fuel cells), solar, isotope radiation from decay, and nuclear fission. . Chemical fuel cells can supply up to 1 kW of power for a few weeks. Solar cells have supplied most of the power for longer duration space missions. Power levels from solar cells have upper limits of around 15 kW at 8-10 W/ft^2 and are about 8-12% efficient. Nuclear processes show the most potential for providing the large amounts of power needed for timely deep space missions or for powering large spacecraft.

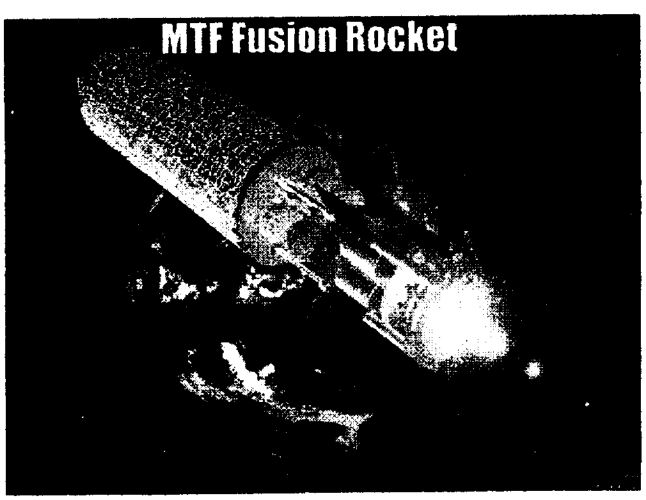
Nuclear propulsion concepts have concentrated in three main areas: radio isotope generators, nuclear thermal, and nuclear electric propulsion. Radioisotope generators (RTGs) have been used on satellites since the early 60's to provide on board power for satellite functions. They have a remarkable record of reliability and have been a true enabling technology. Their drawbacks are high cost for the fuel (plutonium-238) and the relatively low power available (just a few kiliowatts-electric are available for each RTG). Nuclear fission processes offer the potential of much higher power generation for propulsion. Nuclear reactors provide heat that can be used to directly heat a working fluid (typically hydrogen) and provide thrust through an expansion similar to other thermal rockets. The performance limits of this system are dictated by material properties and are about 3000C, producing a specific impulse between 500 and 800 sec. The United States recognized early the benefit that nuclear propulsion could provide for interplanetary exploration and ran an extensive research and development program in nuclear propulsion called the Rover Program. The bulk of the United States efforts came to a close in the early 70's but the Russians continued development and have flown over thirty nuclear reactor powered systems while the United States has flown but one in the mid-sixties, the Snap-10A.

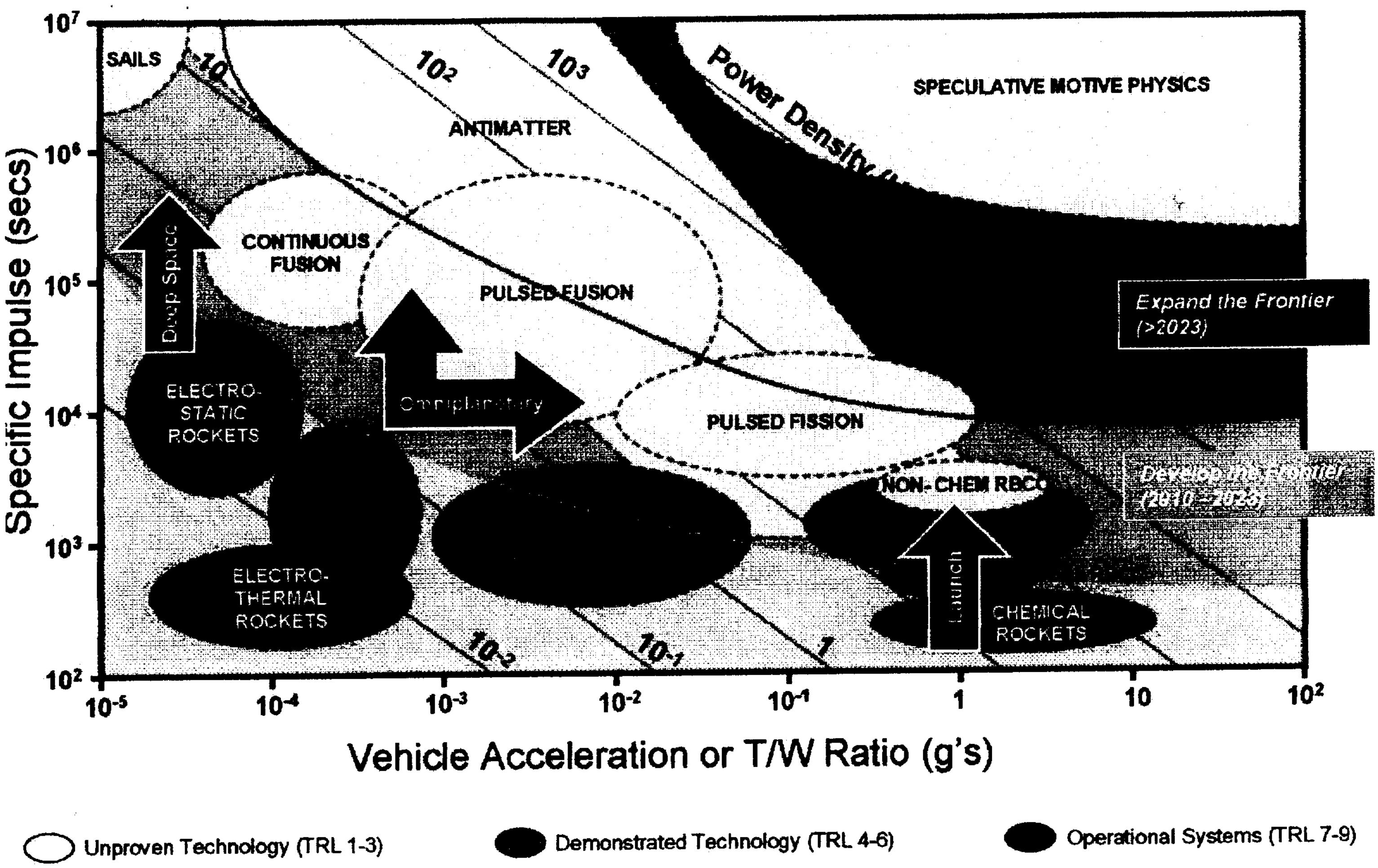
Nuclear electric propulsion schemes involve converting the heat from a reactor to electrical energy by way of a power conversion device. These devices may be dynamic, such as the Brayton or Stirling engines, or be thermoelectric. The electricity generated can then be used in conjunction with an electric propulsion thruster. The power available for propulsion is limited simply by the reactor size and efficiencies of each device. Reactor and power conversion technologies are available today to accomplish a space demonstration with only some thruster development needed to be able to take advantage of the power available from such a nuclear propulsion system.

Further out on the horizon, fusion propulsion may play a role for very large deep-space going spacecraft. Fusion, which derives its energy from the fusing of two atomic nuclei, offers a potential advantage for propulsion in that the plasma produced in the fusion reaction could be used directly for momentum transfer and not have to be converted to electrical energy. A magnetic nozzle would be used to direct the plasma flow. Fusion propulsion devices are necessarily large (80MT and above) in order to achieve a scaling fusion. Though we have over forty years of fusion research and technology to draw on, significant breakthroughs in fusion system efficiencies have to be accomplished before a propulsion device can be accomplished. The fusion process must return much more energy than used in the reaction and the current state of the art is around breakeven. Still, propulsion, having different and less strenuous economical requirements than terrestrial based fusion for power, may be the first practical application for fusion devices.

Deep Space Engines, Potentials and Opportunities

Engines being engineered for deep space missions are out of necessity are fueled by clean energy from light gas atoms. The fuels are brought to certain states and subjected to electric and/or magnetic fields that accelerate and eject fuel charged particles out of the engine thereby giving momentum to the spacecraft. These new deep space engines promise to enable us to send missions to the far reaches of the solar system and beyond cosmos exploratory instruments and possible even manned missions in the future. From these exploratory missions we will expand our intellect and knowledge of the universe we live in to a higher extent. Even more than exploring the universe, these engines potentially can be reconfigured to provide clean cheap abundant power on Earth. So in developing these engines to explore deep space we have opportunities to develop new clean power systems on Earth. Engineering systems that sent men to the Moon during the 1960s, was a catalyst for improving life systems on Earth. Hydrogen was proven to be a clean efficient source of power. Fuel cells and solar photo-voltaic cells were proved practical and have been used increasing in other life systems. The Apollo began the popular use of computers and lasers. To learn more about ourselves and our role in the universe, we must go deep into the cosmos. For to provide clean abundant energy for life on Earth we must engineer the use of the energy of atoms and stars for life on Earth. It can be said that this is the engineering challenge of this new millennium.





SAILS
10
10^2
10^3
Power Density
SPECULATIVE MOTIVE PHYSICS
ANTIMATTER
CONTINUOUS FUSION
PULSED FUSION
Deep Space
ELECTRO-STATIC ROCKETS
PULSED FISSION
NON-CHEM RBCC
Expand the Frontier (>2023)
ELECTRO-THERMAL ROCKETS
Launch
CHEMICAL ROCKETS
10^{-2}
10^{-1}
1
Specific Impulse (secs)
10^7
10^6
10^5
10^4
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10^2
10^{-5}
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10^{-3}
10^{-2}
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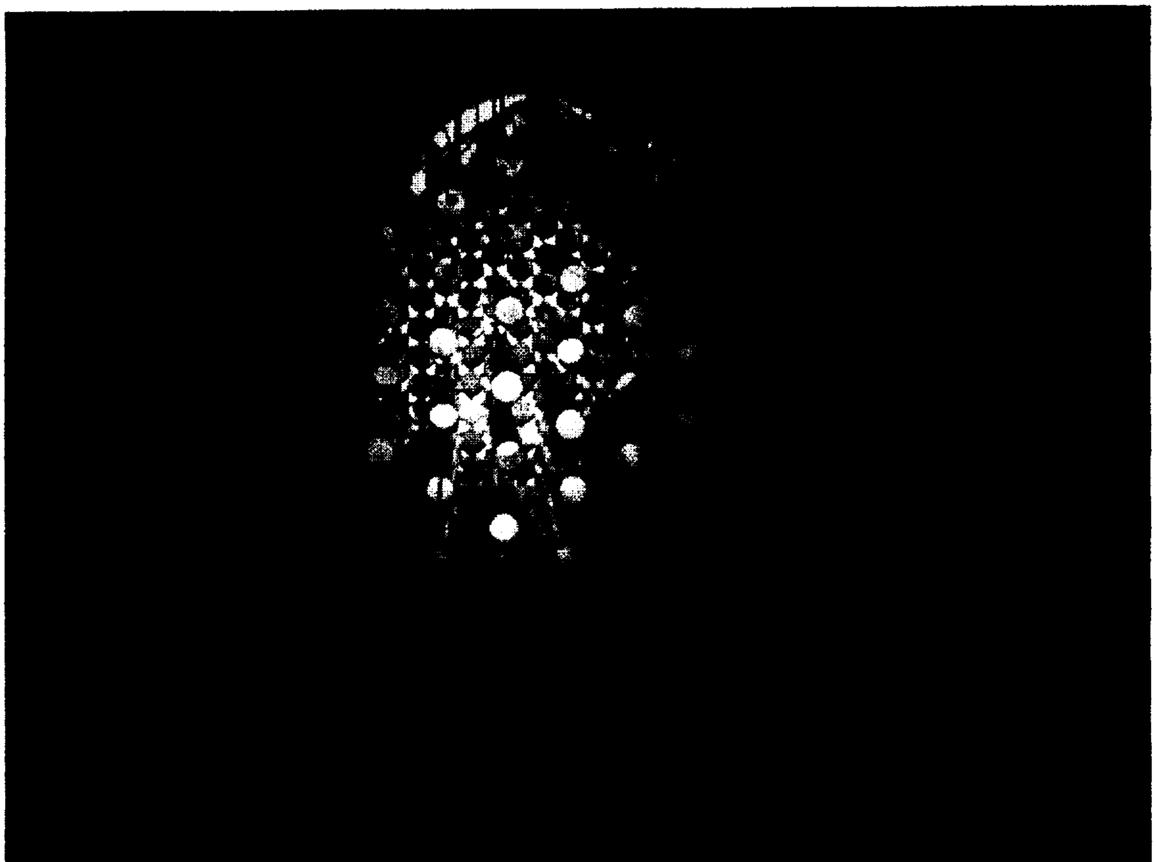
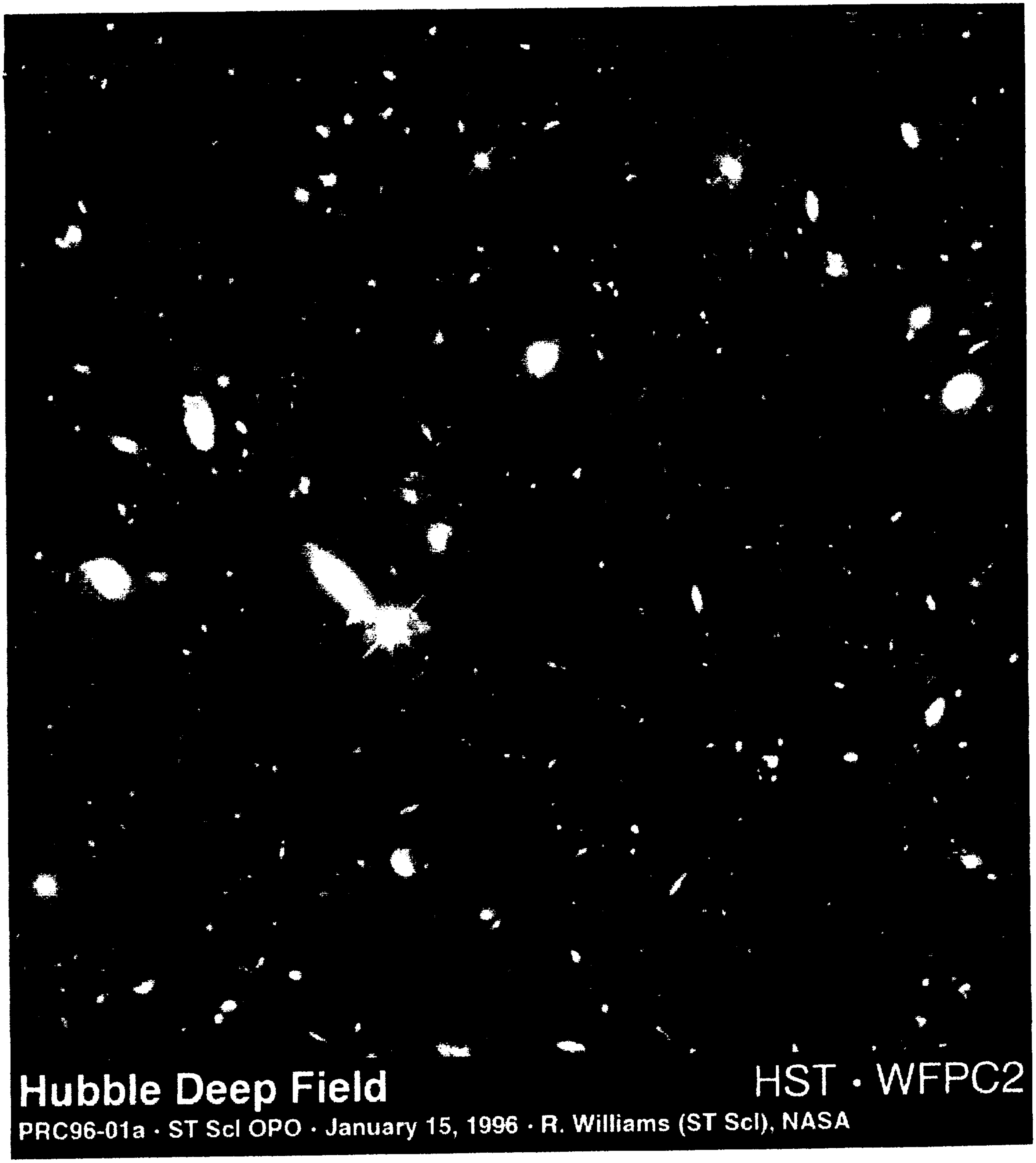
1
10
10^2
Vehicle Acceleration or T/W Ratio (g's)
Unproven Technology (TRL 1-3)
Demonstrated Technology (TRL 4-6)
Operational Systems (TRL 7-9)



"[1]Non-Nuclear Test of a Full-Scale 100 KWt Reactor Core Mockup at Marshall Space Flight Center"[2]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