HELICON INJECTED INERTIAL PLASMA ELECTROSTATIC ROCKET, HIIPER

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Introduction: This paper presents a radically new class of nuclear electric thrusters that has the advanced capabilities necessary to perform missions previously unfeasible. This light-weight propulsion system called HIIPER (**H**elicon **I**njected **I**nertial **P**lasma **E**lectrostatic **R**ocket) employs one of the highest density plasma sources (Helicon source) for plasma production and one of the most erosion-resistant accelerators (Inertial Electrostatic Confinement (IEC)) for plasma acceleration.

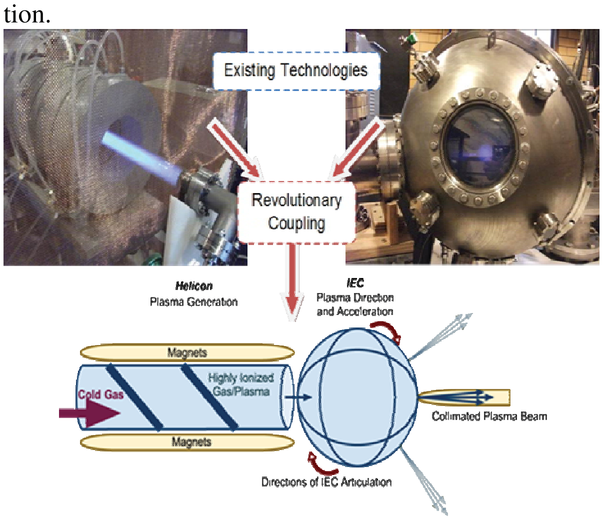

Fig 1: HIIPER concept

Although the helicon source and IEC have been used separately for space propulsion; issues of longevity, scalability and cost have always been a barrier in achieving more comprehensive interplanetary explorations. This is the first time that all these limitations have been overcome by using a Helicon stage to produce and inject very high density plasma into the IEC stage which accelerates ions to high energies (multi-kVs), forming an ultra high intensity, pencil-thin plasma jet exhaust that produces exceptional thrusting capability. The high ion energies plus the ability to use a wide variety of gases, e.g. nitrogen or argon as well as conventional xenon, provides high ISP, and with the addition of a heavier propellant gas in the nozzle, a variable power-ISP tradeoff. The HIIPER is also the only electric thrust system to date that can potentially be converted to a multi-role self-powered fusion spacecraft and propulsion system (e.g. presentation of the conceptual version with p-B11 fusion power, VIPER, for ultra fast deep space probe missions[1]). Indeed, the IEC part is already used to fuse deuterium in commercially available low level neutron generators for Neutron Activation Applications (NAA).

HIIPER allows for improved variable specific impulses and high thrust to power ratio by decoupling the ionization (helicon) and acceleration (IEC) stages of the plasma thruster. While VASIMR[2] uses decoupling with ICRH antenna heating, the IEC heating section allows unmatchable ion energies, power scaling and efficiency, with the added advantage of being simple and light-weight. The current 500-Watt HIIPER lab experiment is capable of specific impulses around 3,000 s, with a final multi-kilowatt device capable of around 276,000 s. The HIIPER provides low energy-per-ion cost and nearly complete ionization of the propellant thus reducing the neutral propellant loss and increasing the thruster efficiency. The geometry of the grid allows for minimal erosion rates of the grid and chamber by high energy plasma, thus increasing the operational lifetime enormously. In addition, HIIPER has demonstrated fuel versatility with propellants such as argon, xenon, as well as more massive molecular gases.

HIIPER can be employed to achieve highly challenging missions such as high speed round trip to Mars, non-stop cargo transport, and highly efficient long-term interplanetary explorations with an option of advanced directionality control using multiple programmable plasma jets for easy and accurate repositioning. HIIPER's unique features such as improved variable specific impulses, low specific mass, and low cost combined with longer operational lifetime makes it an enabler for future space missions.

Experimental Setup: HIIPER is an electric thruster composed of two main components; a helicon and a spherical Inertial Electrostatic Confinement (IEC) grid. The helicon is a device which generates high density plasma extremely efficiently using wave heating[3], the plasma from the helicon is fed to an asymmetric spherical IEC grid that accelerates the ions to produce thrust. The IEC[4] was originally devised as a plasma confinement technique for fusion plasmas.

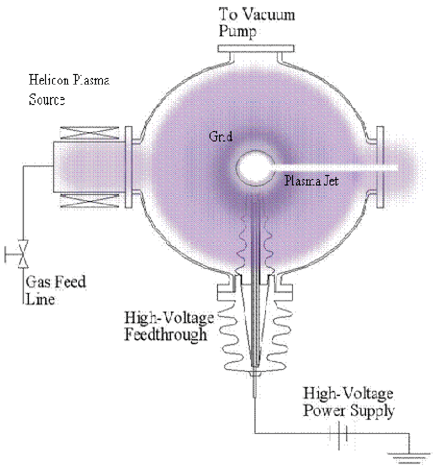

Fig 2: HIIPER experimental setup

However, the IEC section in HIIPER has been repurposed into a plasma acceleration stage. This is possible because of the way the IEC was originally used to confine the plasma, which was by having the ions in the plasma circulate back and forth in the radial direction. This ion circulation in the radial direction is caused by the spherically symmetric potential well created by the biased IEC grid. The ions are accelerated into the negatively biased center, and, because of their inertia, they will continue to move past the center to be decelerated by the increasing potential and eventually slow and stop and once again be accelerated back toward the center of the well.

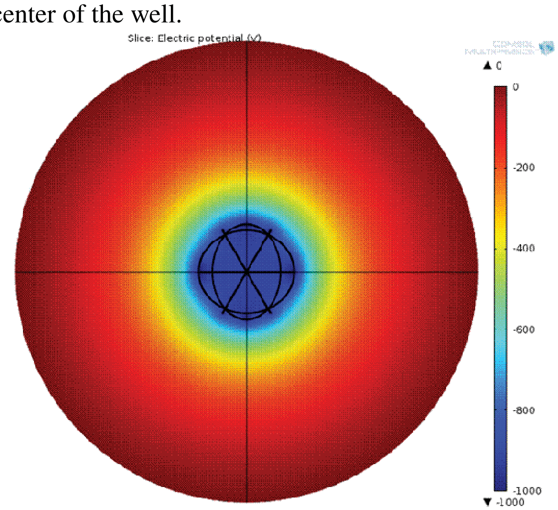

Fig 3: Spherically symmetric potential well created by the biased IEC grid (Simulation performed on COMSOL Multiphysics)

If there were an asymmetry in the spherical IEC grid, then ions would accelerate toward the center of the potential well, but because the potential well is no longer symmetric the ions deceleration at site of asymmetry would not be great enough to pull the ion back toward the center of the well allowing the ions to escape. These escaping ions form an exiting beam and by conservation of momentum the grid must gain momentum in the direction opposite of the beam.

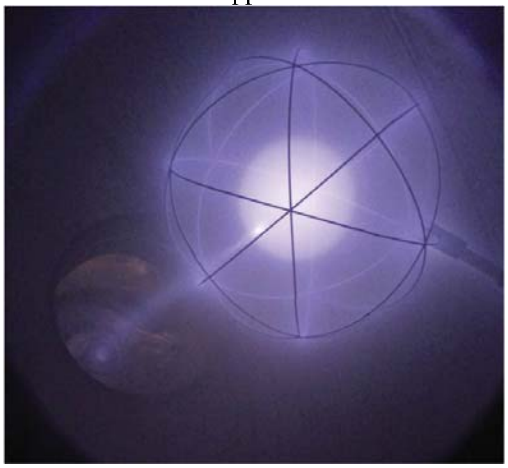

Fig 4: High energy plasma jet exiting the asymmetry in the IEC acceleration stage (Picture from the 500-W proof-of-concept HIIPER lab experiment)

The IEC is a DC discharge and like most other DC plasma discharges the ionization fraction is not that impressive so to compensate for this, a vastly superior plasma source known as a helicon is utilized to generate the plasma. Helicon plasma sources can create plasma with ionization fractions as high as ~90 %. This decoupling of plasma generation and plasma acceleration allows for a feature few electric thrusters possess which is variable specific impulse.

Conclusion: HIIPER's versatile operational characteristics opens the way to many new demanding space missions. HIIPER can switch between high specific impulse(low thrust) and low specific impulse(high trust) configurations increasing fuel economy and allowing more mission flexibility, which could allow for more complex deep space scientific missions. HIIPER also has the ability for vectored thrust; this is because the IEC grid can be rotated allowing control over beam direction. Vectored thrust can be extremely beneficial in lowering the overall weight of the spacecraft by reducing the number of maneuvering thrusters and other assisting components.

References: [1] John Orcutt et. al., (Sept. 2011) *DARPA 100-Year Starship Symposium.* [2] Franklin R. Chang-Diaz et al. (2001) *American Institute of Physics Conf. Proc.,* Vol. 595, 3-15. [3] Francis F. Chen (1991) *Plasma Physics and Controlled Fusion, 33,* 339-364. [4] Hirsch, Robert L. (1967) *Journal of Applied Physics*, 38, 4522-4534.