Inertial Electrostatic Confinement Fusion for Spacecraft

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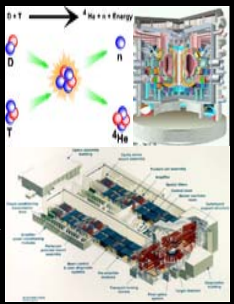
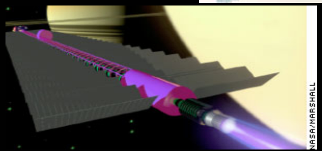
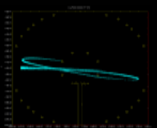
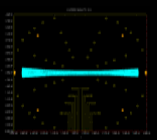
BACKGROUND

Nuclear fusion has been identified as a potentially abundant and useful source of energy for both Earth-based and space-based power systems. This hypothetical functionality is a result of the extraordinary energy density of the relevant fusion reactions in combination with the relative abundance of potential fuels. The development of the national experimental fusion programs to date has focused on very large, very heavy reactors for ground power applications. Specifically, the push for fusion energy is focused on two primary means of achieving fusion energy: magnetically confined fusion and inertial confinement fusion. Both of these approaches show promise for future sources of energy on the Earth, but due to their extraordinary mass, use of such reactors in spacecraft would require many launches of the biggest heavy-lift launch vehicles in combination with an in-space assembly that would surpass the International Space Station in its scale and complexity. The MIT Space Systems Laboratory Fusion Power and Propulsion Group (FPPG) views the probability of this sort of space activity as quite low in the foreseeable future. Consequently, we are investigating a very low-mass alternative type of fusion reactor known as an inertial electrostatic confinement (IEC) fusion reactor.









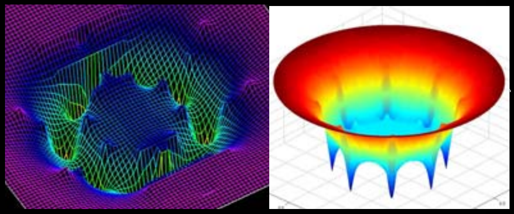
IEC fusion reactors use electric fields to confine the fusion ions at sufficiently high energy for a sufficient time to fuse. The electric field is often generated by a high voltage power supply connected to two highly transparent, concentric, spherical, wire grids. Positive ions are introduced near the outer (anode) grid. They are accelerated by the electric field in towards the central cathode grid. Ideally, these ions pass through the cathode grid (because it is not a solid metal sphere but rather a wire grid with many large holes) and fuse in the center of the device. Those ions that do not fuse pass out the other side of the cathode and are turned around by the electric field on the other side of the device for another pass. These experimental fusion reactors can be fabricated inexpensively and on a laboratory scale. Many amateur scientists have built such reactors in their garages or basements and have reported measurements of fusion products. The groundwork in this field was laid by Farnsworth, Hirsch, and Bussard (among many others). The biggest shortcoming of IEC fusion is the relative inefficiency of the reactors. Ions are lost when they impact grid wires, and electrons stream out from the center of these devices and heat the anode wall. The FPPG has developed a multi-grid IEC device which allows the ions to be focused away from the grid wires thereby improving the confinement time and theoretically improving the efficiency of the reactor.

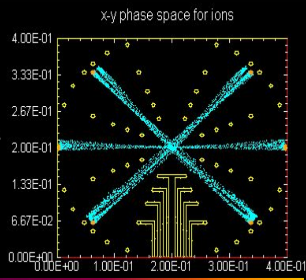
GOALS OF THE RESEARCH

1. Improve the efficiency of IEC Fusion reactors for space power and propulsion applications
2. Model and explore the fundamental physics of IEC reactors in the space environment
3. Experimentally investigate theoretical efficiency improvements

MULTI-GRID IEC DEVICES

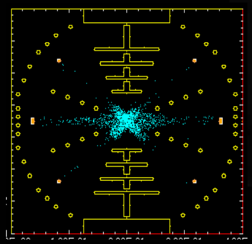
- Hypothesis: Multiple-grid IEC devices allow fusion ions to be focused and confined for longer times than conventional, 2-grid IEC devices
- Focusing grids create "channels" in vacuum potential structure → limit non-radial ion motion
- Longer ion lifetime → higher efficiency IEC reactor

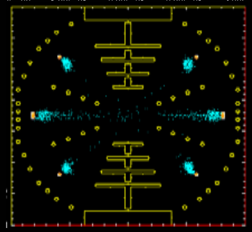


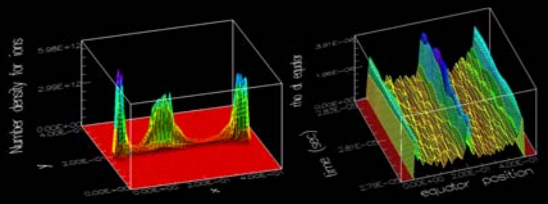


DISCOVERY OF SELF-ORGANIZATION

- Spontaneous Ion bunching observed in Particle-In-Cell modeling
- Bunches "resonate" at the device bounce frequency
- Synchronization between crossing beams also observed
- Hypothesis: Bunching is a saturated electrostatic streaming instability in spherical potential well structure







EXPERIMENT DEVELOPMENT

Experimental hardware is being assembled in the MIT Space Systems Laboratory in order to investigate the predicted improvements in ion confinement and to investigate the computationally predicted ion bunching phenomenon. Hardware consists of a 2' diameter, 3' long cylindrical stainless steel vacuum chamber with UHV capability, multiple high-voltage power supplies, a custom-built ion gun, and a 2GHz oscilloscope-based digital DAQ system. The chamber has many ports available for future diagnostics.

OPTICAL DISCHARGES

Early experimental runs in air at low vacuum were conducted in a 2-grid configuration. These experiments qualitatively reproduced the types of discharges seen in other IEC devices in the published literature. Slight asymmetries in the cathode grid wires result in a "jet-mode" discharge. It has been postulated by Miley at UIUC that this type of discharge might be useful for propulsion. Because this high-pressure regime of operation is subject to ion loss mechanisms that do not exist at lower pressure (charge exchange etc.), this mode of operation is not being investigated in depth by the FPPG.

At lower pressures (1.5e-3 mbar), the IEC "star-mode" has been observed in our experiment. In this mode, the discharge appears qualitatively more symmetric based on optical measurement. At still lower pressures, the background density is too low to detect any optical discharge with existing hardware. This UHV "accelerator regime" is where the device will be operated to evaluate the expected increase in ion confinement time due to the addition of focusing grids. Confinement time will be extrapolated from measurements of electrical current to the grid wires and charge count during destructive dumping of the trap.