Experimental Advances and Next Steps in the Helicon Injected Inertial Plasma Electrostatic Rocket (HIIPER)

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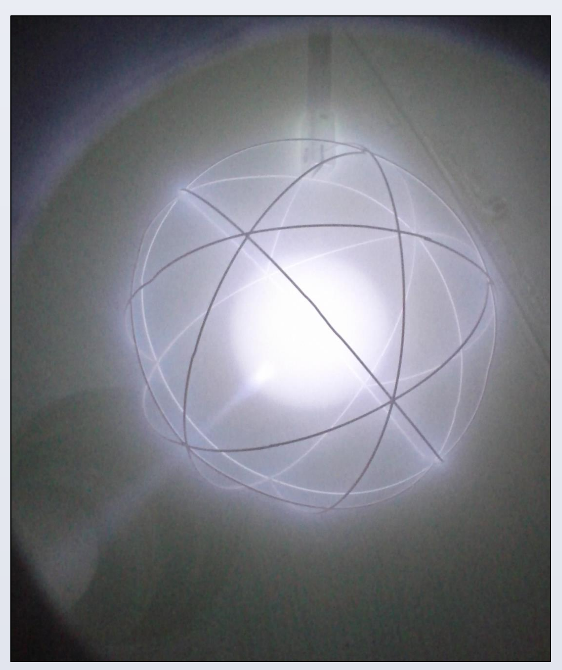
Introduction

- HIIPER: Helicon Injected Inertial Plasma Electrostatic Rocket
    - Consists of ion generation stage and ion acceleration stage
- Helicon device: generates ions (thus far, argon ions) through RF heating
- Ions then injected into IEC device
- IEC device: vacuum chamber (anode at ground potential) and IEC grid (cathode at approx. -4 kV)
- Core of ions forms at center of IEC grid
- IEC grid has asymmetry, which induces plasma jet to form



Asymmetric grid and plasma jet

- Hypothesis: ion acceleration/plasma jet → thrust force
- Potential uses: electric propulsion for deep-space exploration missions
- Advantages:
    - Design simplicity and low weight
    - High specific impulse
    - Separation of ion generation and acceleration stages results in variable performance
- Should IEC fusion be achieved, IEC devices on spacecraft could function as both power and propulsion methods

Recent Experiments

- Experimental analysis of plasma jet with several devices
    - Faraday cup: measures number of charged particles hitting it, yielding a value of total net current
    - Gridded energy analyzer (GEA): uses biased grids to filter particles of specific energies, resulting in a measurement of ion and electron energy distributions
    - Force sensor: measures the force produced by the jet
    - Spherical plasma probe: used in place of cathode, determines current from helicon
- Computational modeling of experiment with COMSOL Multiphysics software

- **Goal: determine whether jet is composed primarily of ions, which is necessary for a thrust force**

Experimental Setup

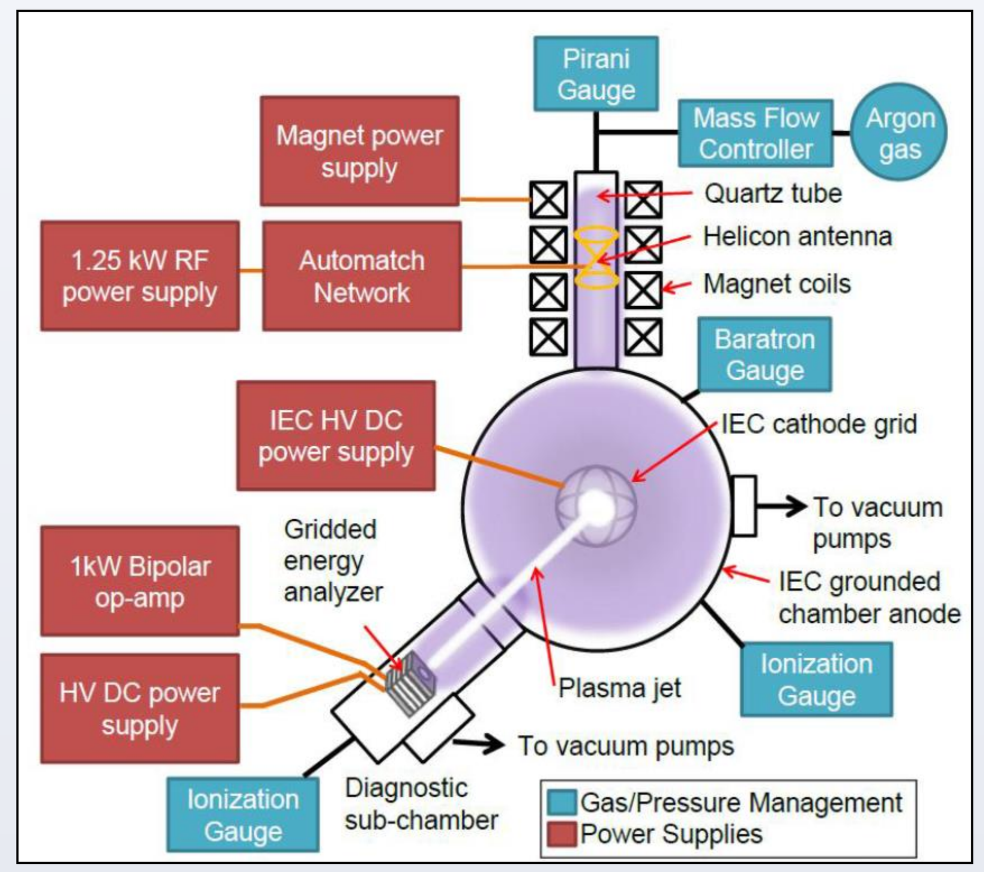
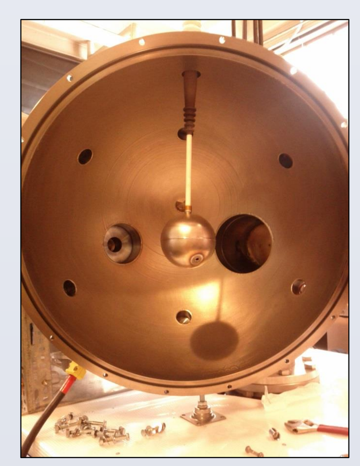
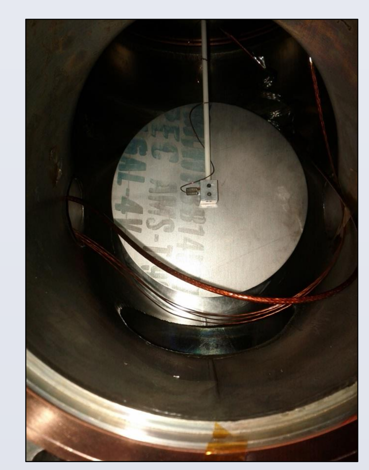


Diagram of experiment

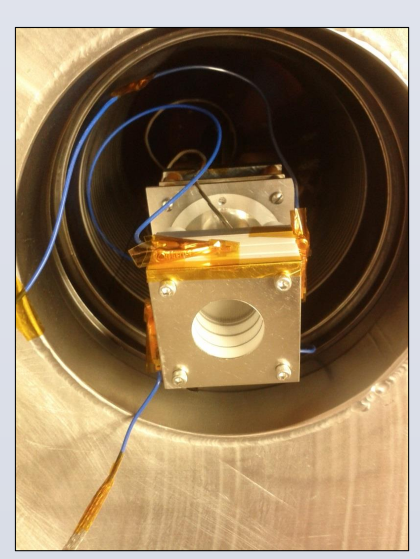
Faraday cup



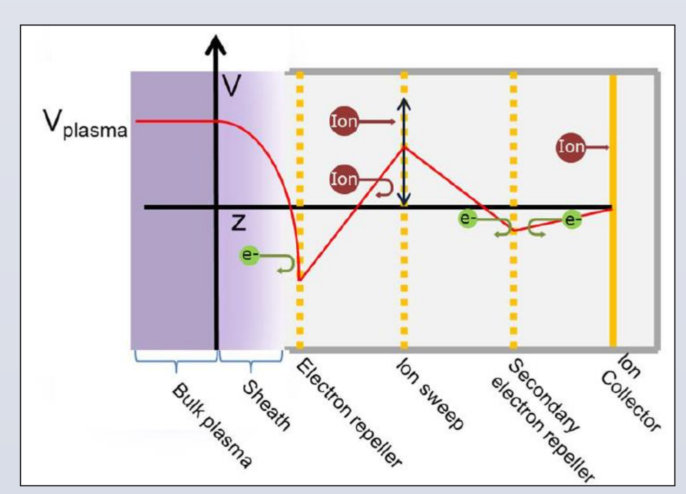
Spherical probe (inside vacuum chamber)



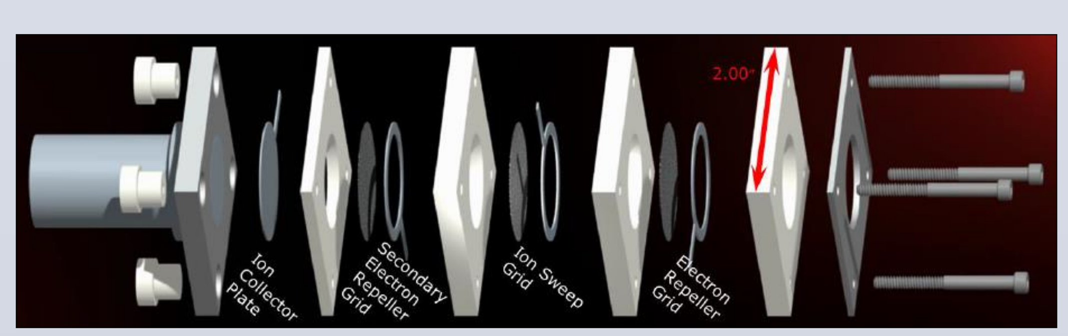
Force sensor



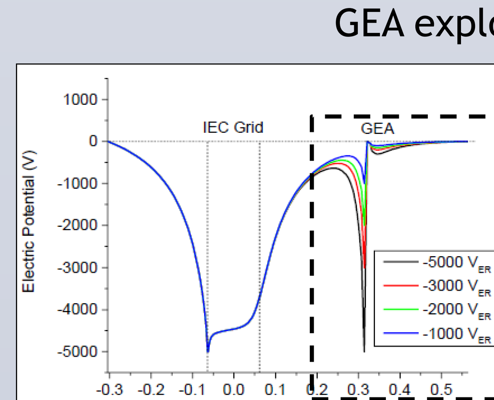
GEA



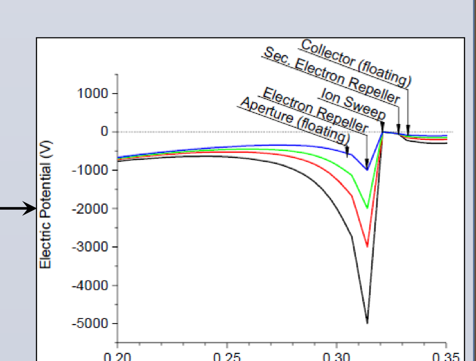
GEA illustration of grid effects on potential



GEA exploded view



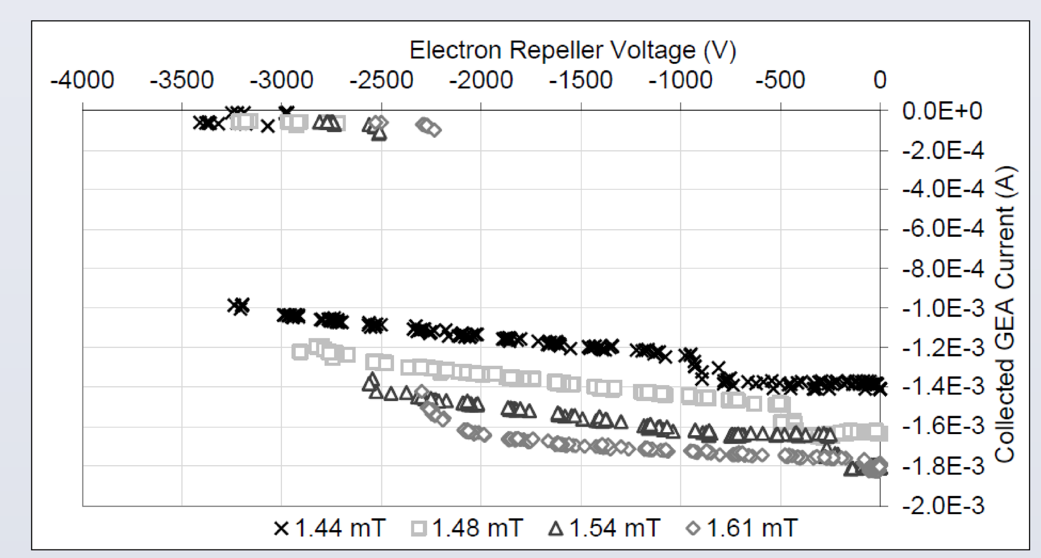
COMSOL: electric potential of experiment in radial direction (no plasma)



(zoomed in view)

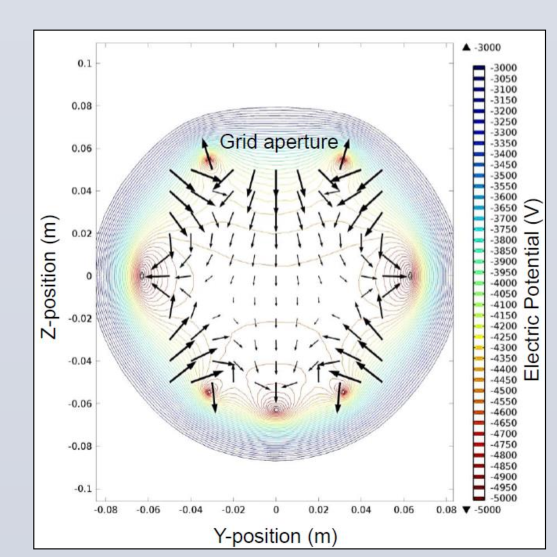
Results

- Plasma jet is only possible for argon pressures of 1.3 to 2.35 mTorr
    - If pressure too low → no breakdown
    - If pressure too high → shorter mean free path, and jet "fans out" into a spray
- Faraday cup: indicated a net negatively charged jet impinging the cup
- Faraday cup measurements also allowed computation of total efficiency (ratio of total jet power to total input power of all devices), equal to
    - ~20% with helicon off (glow discharge conditions)
    - ~1-2% with helicon on
- GEA: only electron energy spectra collected (not ion) - could not filter out high energy electrons sufficiently enough to see evidence of ions, and at a certain filter voltage, breakdown occurred between GEA grids



GEA results for several pressures

- Simple model for formation of plasma jet in IEC device:
    - Ions drawn toward negative cathode grid
    - Ions circulate through central core → collisional ionization w/background neutral atoms and secondary electron emission from grid collisions
    - Low KE electrons born through collisions experience strong potential gradient and are accelerated out of asymmetry
- Potential gradient simulated via COMSOL:



Electric field in cathode grid (no plasma)

- Comparing above simulation with electron energy spectra → electrons are born near aperture of IEC grid and then accelerate rapidly out

Results Continued

- Force sensor results inconclusive:
    - Piezoelectric strain gauges experienced interference from RF power supply
    - Thrust plate also was shown to move the wrong direction - due to possible heating/gas effect
- Spherical plasma probe: approximately 6% of helicon power went to ionizing, and 11% went to excitation

Conclusions

- Improved understanding of IEC jet-mode
- At present, plasma jet is composed primarily of electrons
- Need to study ways to make the jet have a significant ion component

Ongoing/Planned Work

- Methods to draw ions from IEC core are being investigated
    - Biased extractor grids (both experimental and computational studies)
    - Concentric grids to change electric potential well structure
    - Electromagnets to filter electrons from beam
- Set up differential pumping
    - Would reduce charge-exchange losses
- Use plasma potential probes to measure potential inside chamber
- Spectroscopy to measure plasma properties in ion core
- Modifications to current diagnostics:
    - Force sensor: investigate and fix incorrect behavior
    - GEA: modify design such that breakdown does not occur

Acknowledgements

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References

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