Collisional Losses in a VASIMR

Variable **S**pecific-**I**mpulse **M**agnetoplasma **R**ocket

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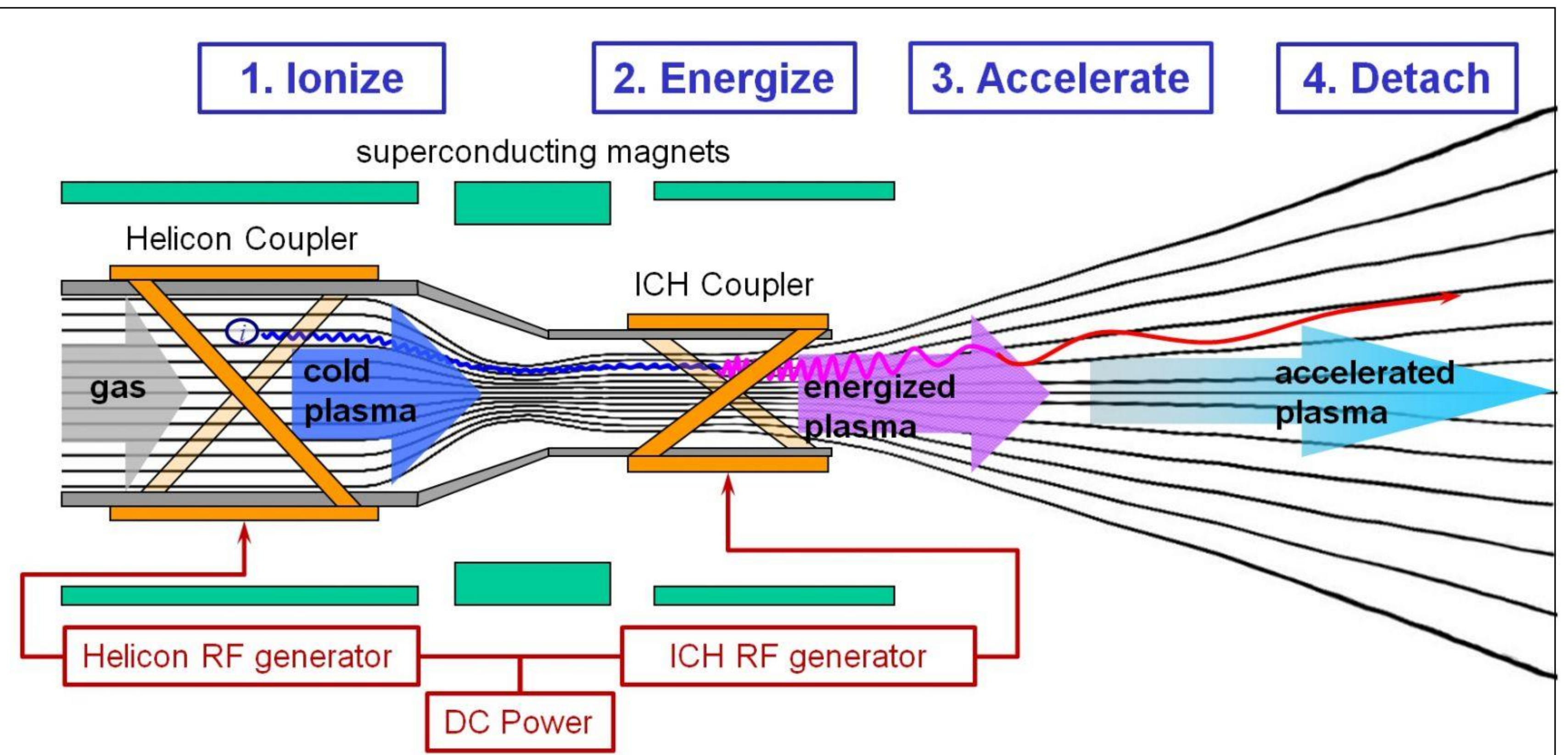
An Engine for Space Travel

A VASIMR (Variable Specific-Impulse Magnetoplasma Rocket) engine is an electrically-powered engine that uses plasma as a propellant for accelerating spacecraft in the vacuum of space. The VASIMR engine is designed to provide higher specific impulse and greater thrust efficiency compared to traditional chemical rockets. The engine works by ionizing a gas, such as argon or hydrogen, and heating it to extremely high temperatures to create a plasma. This plasma is then accelerated and ejected out of the engine at high speeds, producing thrust. VASIMR is seen as a promising technology for future deep space missions due to its potential to significantly reduce travel time and costs. However, there are still technical and engineering challenges that need to be overcome before the VASIMR engine can be used in space missions.

How Does it Work?

1. The neutral gas is ionized using radio waves or microwaves to strip electrons from the atoms. The resulting plasma is confined and contained by a strong magnetic field.
2. A process called ICH (Ion Cyclotron Heating) uses a rotating electric field to boost the perpendicular velocity of the ions. This results in a much hotter plasma (about 1 million degrees!).
3. As the plasma moves out the nozzle of the engine, the magnetic field diverges, which converts the perpendicular velocity of the ions into parallel velocity, generating thrust.
4. Eventually, the magnetic field weakens enough to allow the plasma to detach from the magnetic field of the engine, which prevents the plasma from hindering the engine's thrust.



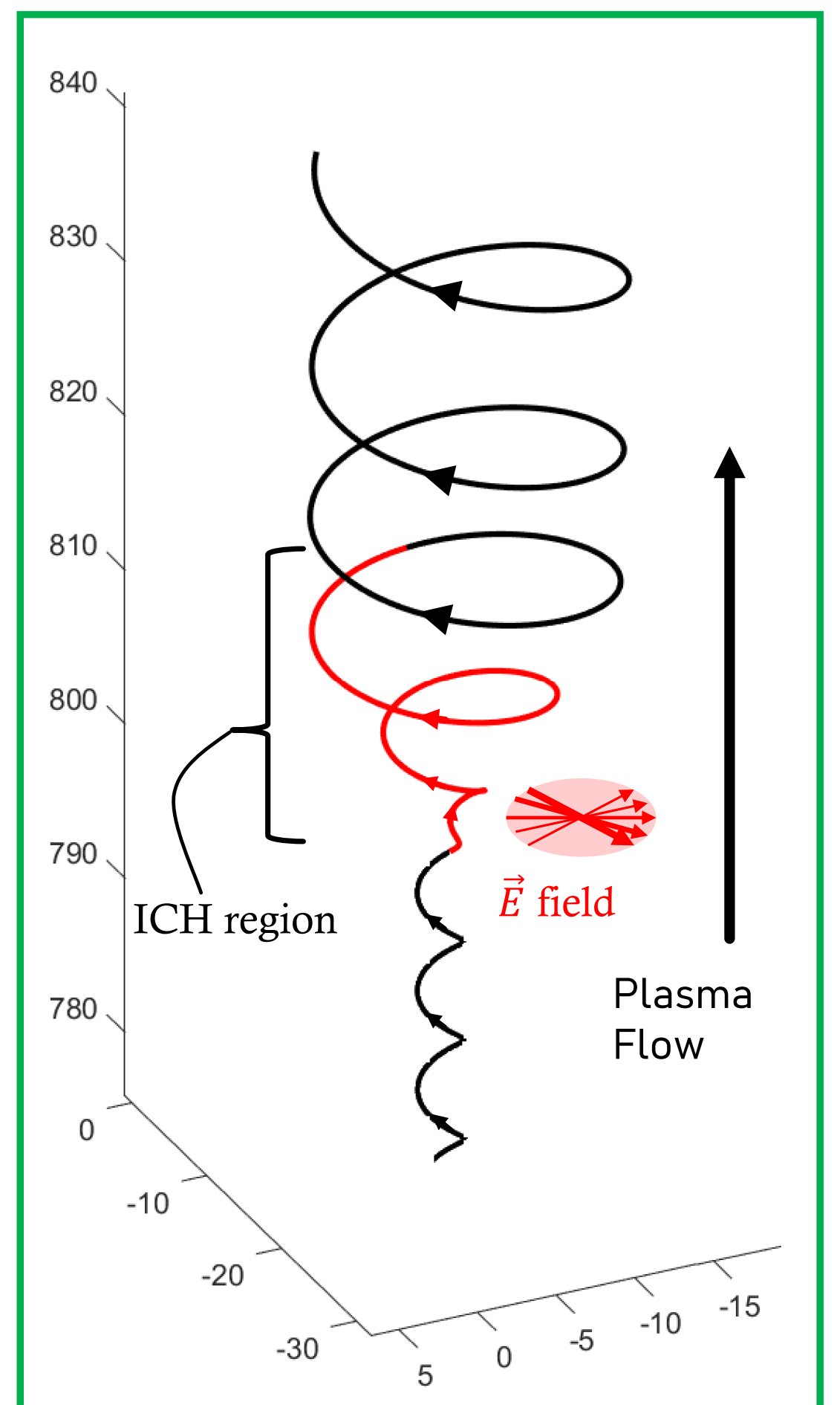
https://www.spaceflightinsider.com/wp-content/uploads/2017/07/VASIMR-operating-principles.jpg

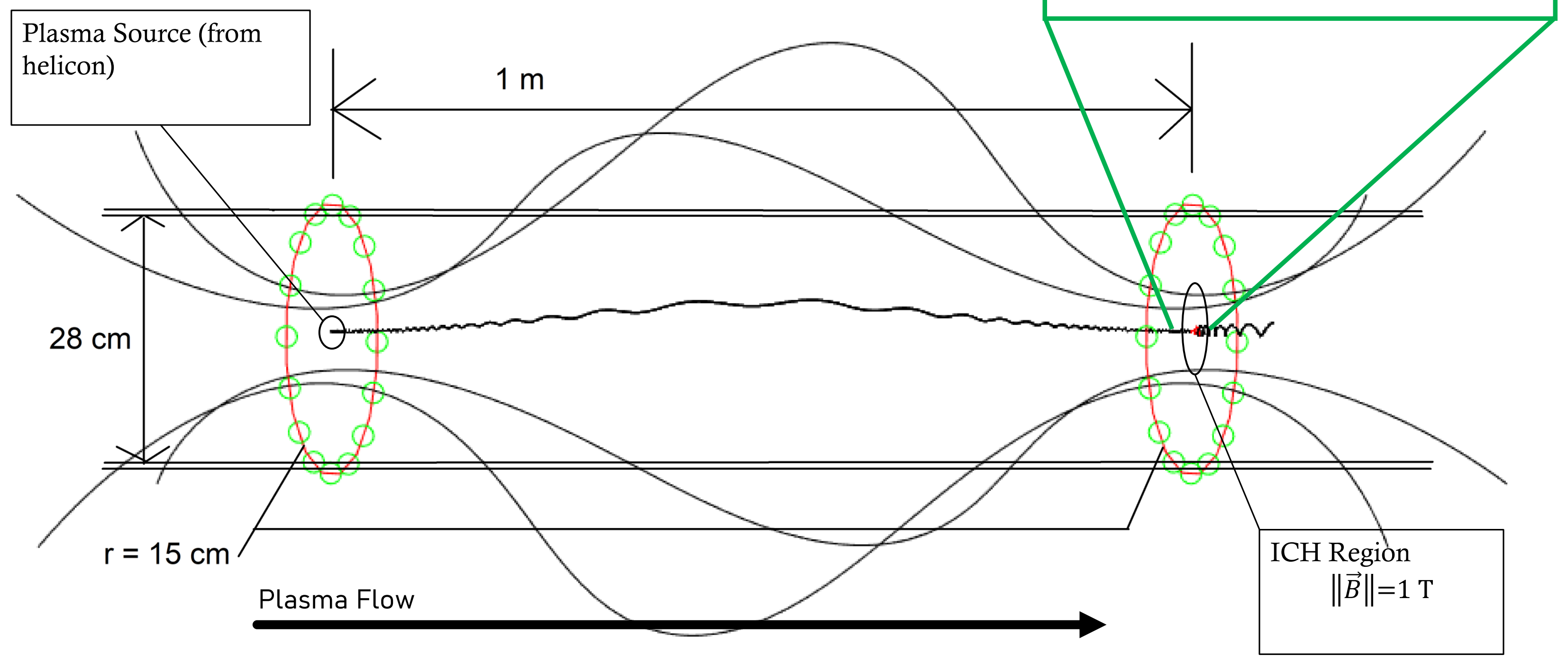
Producing a Simulation

We simulated individual ions passing through the engine. The engine was modeled by a cylindrical tube having two current loops at either end that represented the superconducting magnets, and a small ICH region just outside the exit loop (right side of figure below).

A thermal distribution of 1000 Argon ions was generated at the entrance (left side of figure below), and each was simulated passing through the engine using the Lorentz force law.

The ICH region is shown enlarged in the figure to the right. During ICH, an electric field rotates in resonance with the cyclotron motion of ions in a magnetic field. This has the effect of increasing in the ions' perpendicular velocity, which in turn increases their gyration radius, as seen in the figure to the right. In practice, the shape of the ICH region would be smooth and complicated, however our model uses a simplified 1 cm long ICH region with hard boundaries, and constant 1 kV/m magnitude rotating electric field.



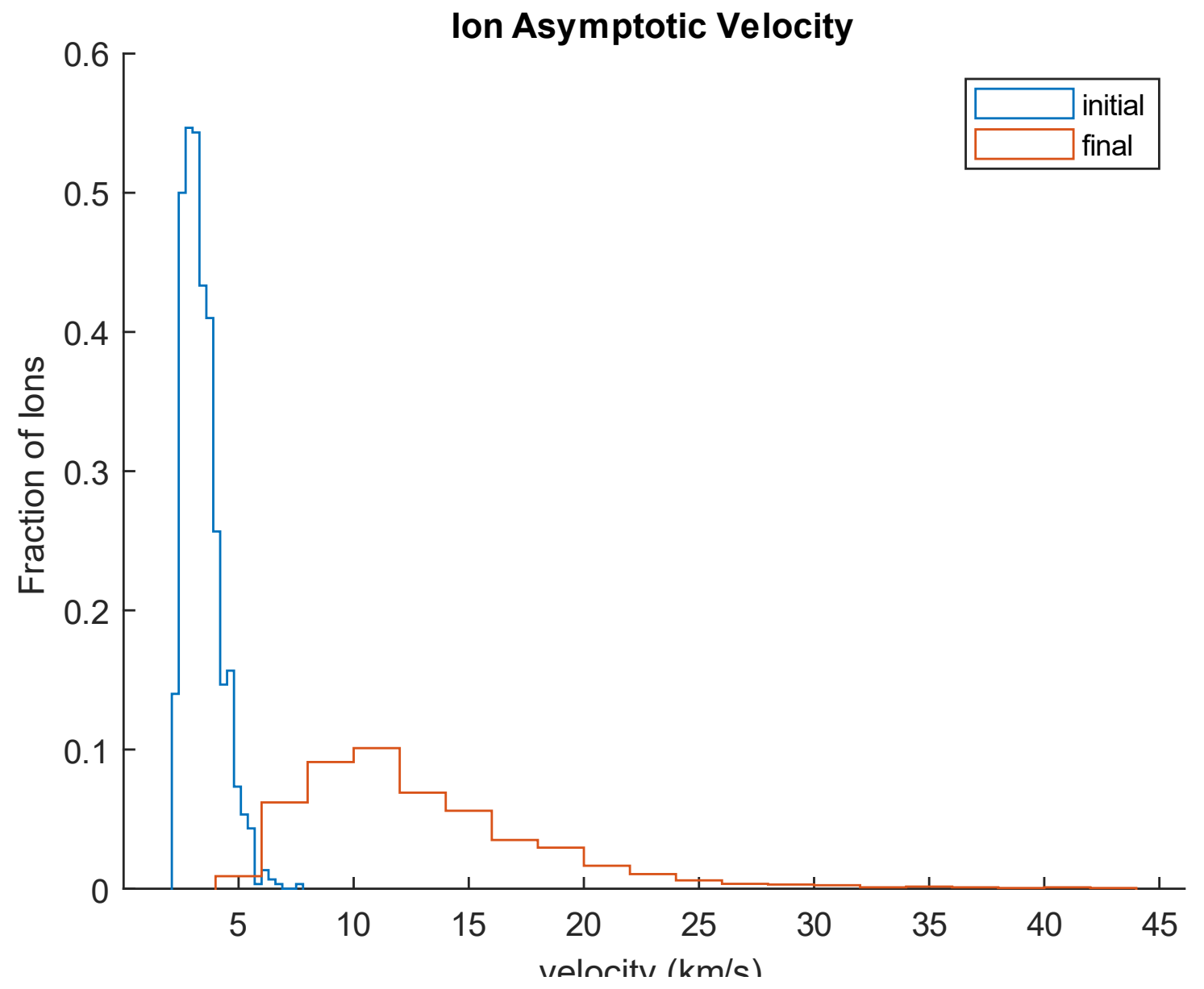


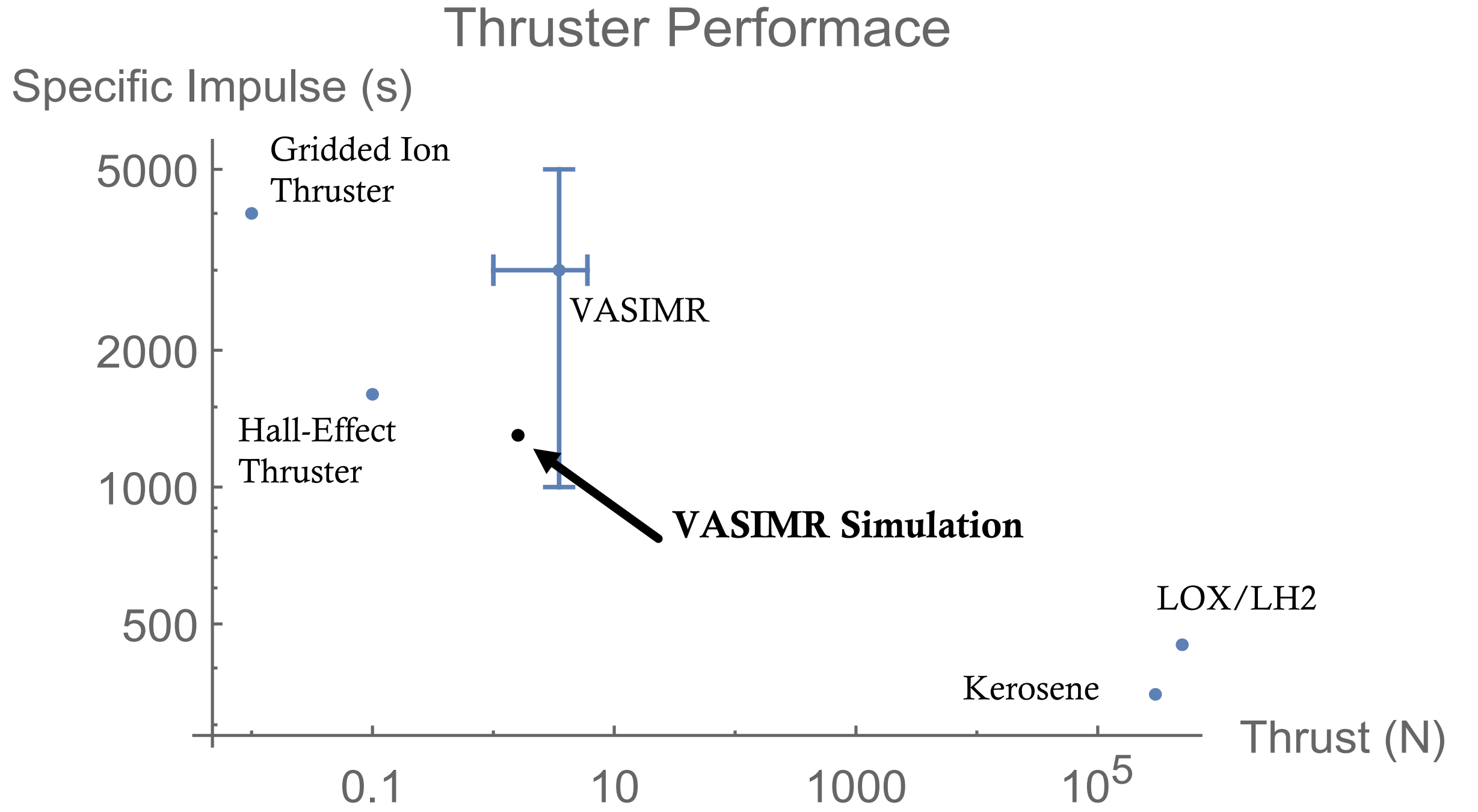
Simulation Results

Without accounting for collisions or other many-particle interactions within the engine, we observed an operating specific impulse of approximately 1300 seconds, a thrust of 1.6 Newtons, and a thruster jet power of 10 kW at a mass flow rate of 120 mg/s. Despite minimal assumptions, these parameters agree with observed operating parameters of the VASIMR prototype VX-200 [1].

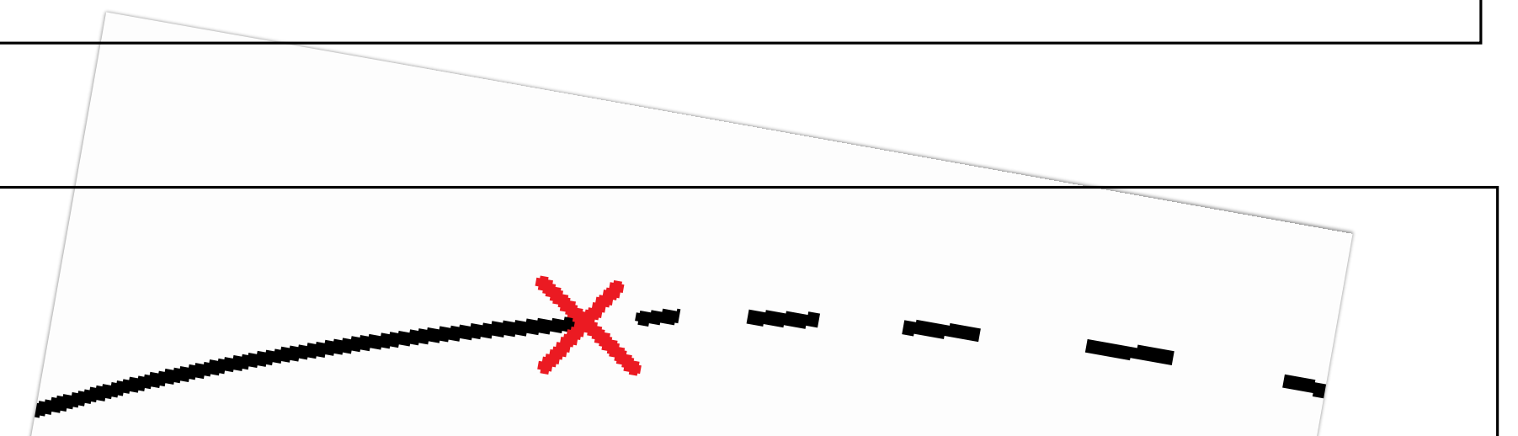
The ICH process in our model was observed to produce heating from 30,000 K to 500,000 K.

The figure to the right shows the change in the velocity distribution of the ions after passing through the engine. The figure below shows the VASIMR operating parameters in comparison to other propulsion technologies, including our simulation results.





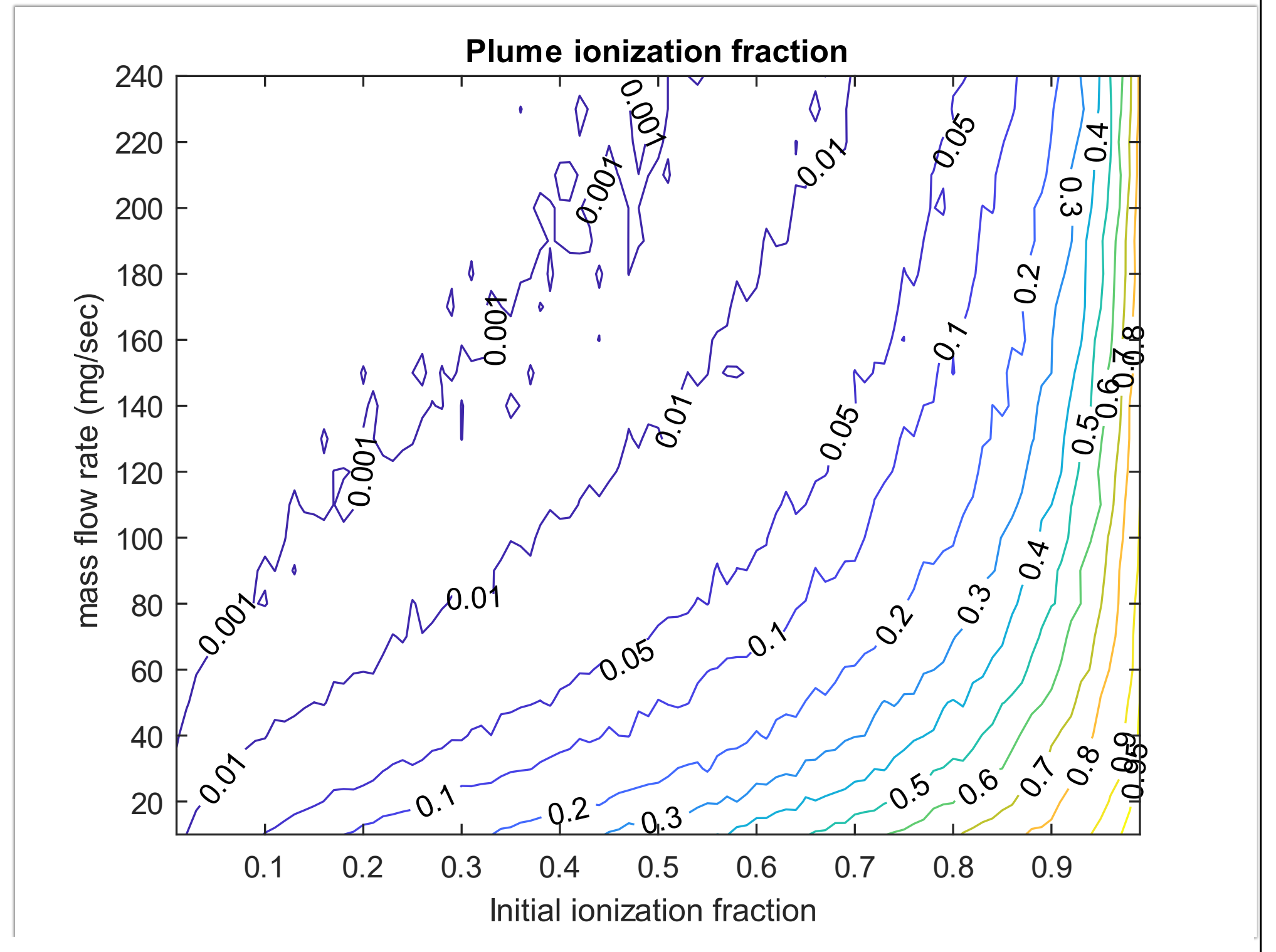
Collisional Losses

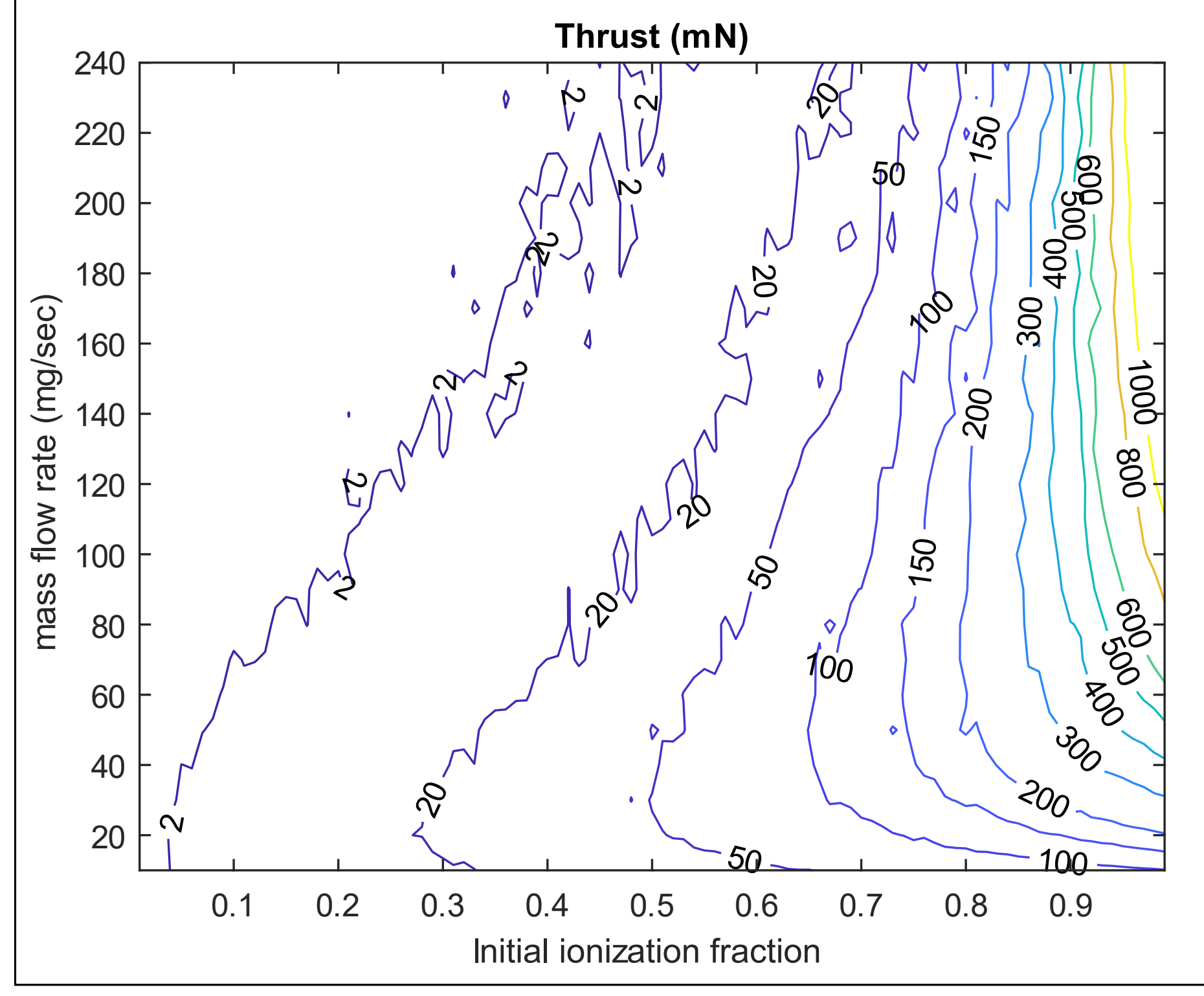


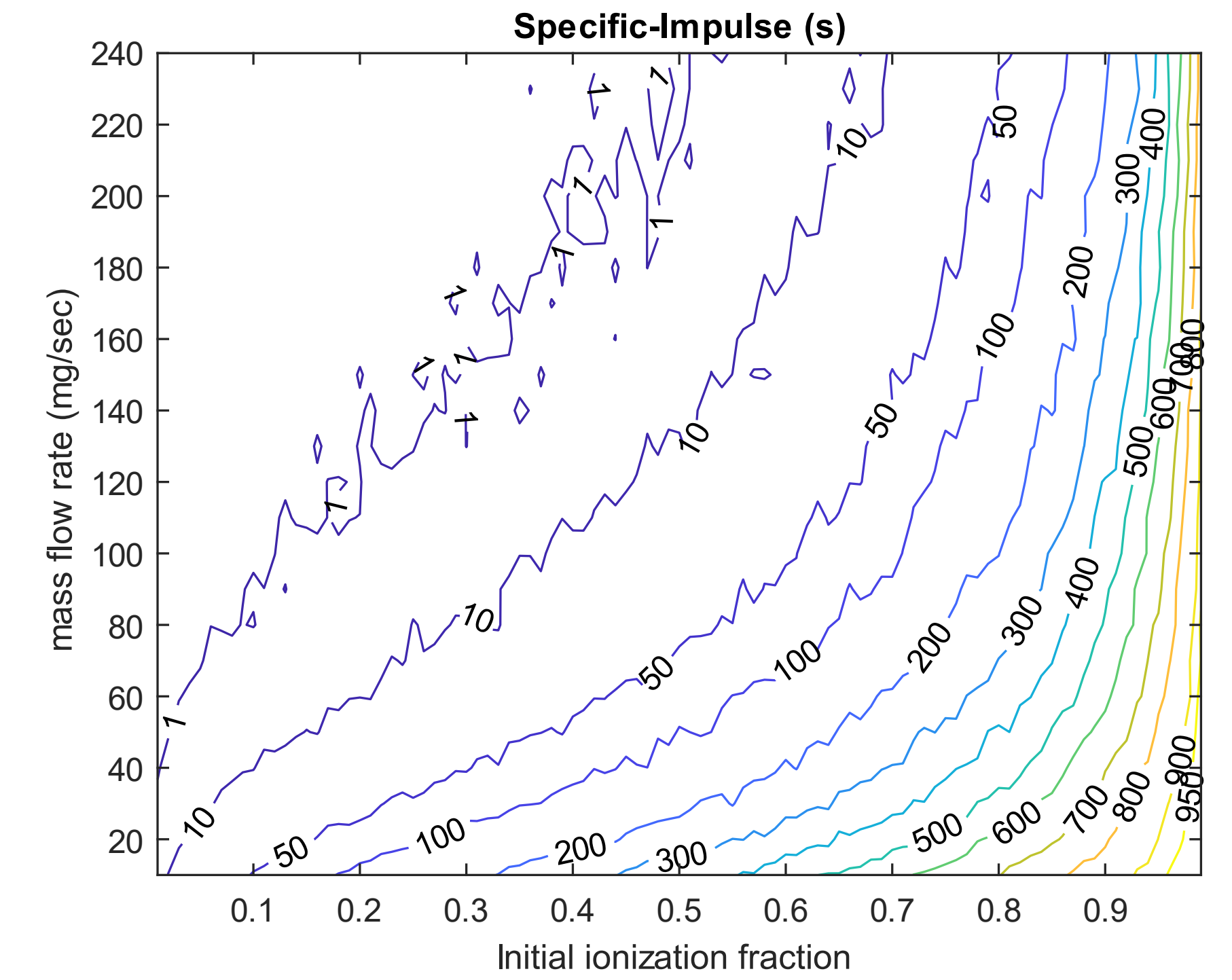
For a more realistic model, we accounted for collision phenomena in the form of ion-neutral collisions. Collisions of any sort would tend to reduce the performance of the engine, and ion-neutral collisions are assumed to be the greatest contributor to performance loss. We generated a new set of 1000 ions and used Monte-Carlo methods to discard ions which experienced a collision under 2376 different combinations of the engine's mass flow rate and initial ionization fraction values.

The resulting engine operating parameters are shown here. We see that collisional losses are overwhelming, except at high initial ionization fractions and low mass flow rates.

For the VX-200 to have the observed efficiency that it does [1], we suspect that its helicon must have a high efficiency on the order of 95% initial ionization or more.







[1] Longmier, Benjamin W, et al. "Improved Efficiency and Throttling Range of the VX-200 Magnetoplasma Thruster". Journal of Propulsion and Power, vol. 30, No. 1, January-February 2014. DOI: 10.2514/1.B34801