Ion Acceleration Mechanism in a Quad Confinement Thruster

March 3rd, 2017

Andrea Lucca Fabris, Aaron Knoll
Surrey Space Centre, University of Surrey, UK

Christopher V. Young, Mark A. Cappelli
Stanford Plasma Physics Laboratory, USA

Outline

1. **Surrey Space Centre Propulsion Activities Overview**

2. **Quad Confinement Thruster (QCT) Development History**

3. **Laser-Induced Fluorescence Measurement of the Ion Velocity Field in the QCT plasma plume**

4. **Conclusions**

1. SSC Propulsion Activities

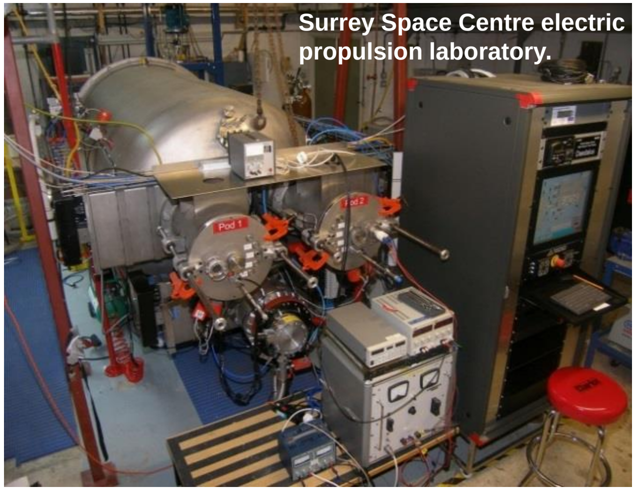
- The **Surrey Space Centre (SSC)** is a world leading Centre of Excellence in Space Engineering, and has multiple spacecraft design facilities **satellite design labs and propulsion test facilities** for thruster design and testing

- **More than 60 academic and graduate researchers** within SSC

- The **plasma propulsion group** includes 1 lecturer, 1 postdoc researcher, 4 graduate researchers, 6-10 undergraduate students

- The propulsion test facilities assigned for Electric Propulsion (EP) development consist of two large vacuum chambers and three smaller chambers with cryogenic and/or turbomolecular pumping

Picture taken from the Alsat Nano cubesat designed and built at the Surrey Space Centre (2016). The image was taken by the Open University wide field camera .

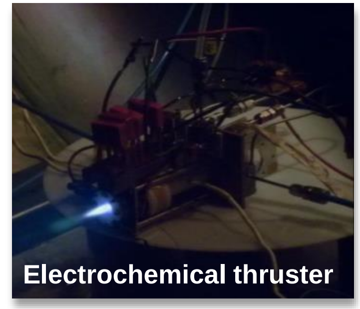


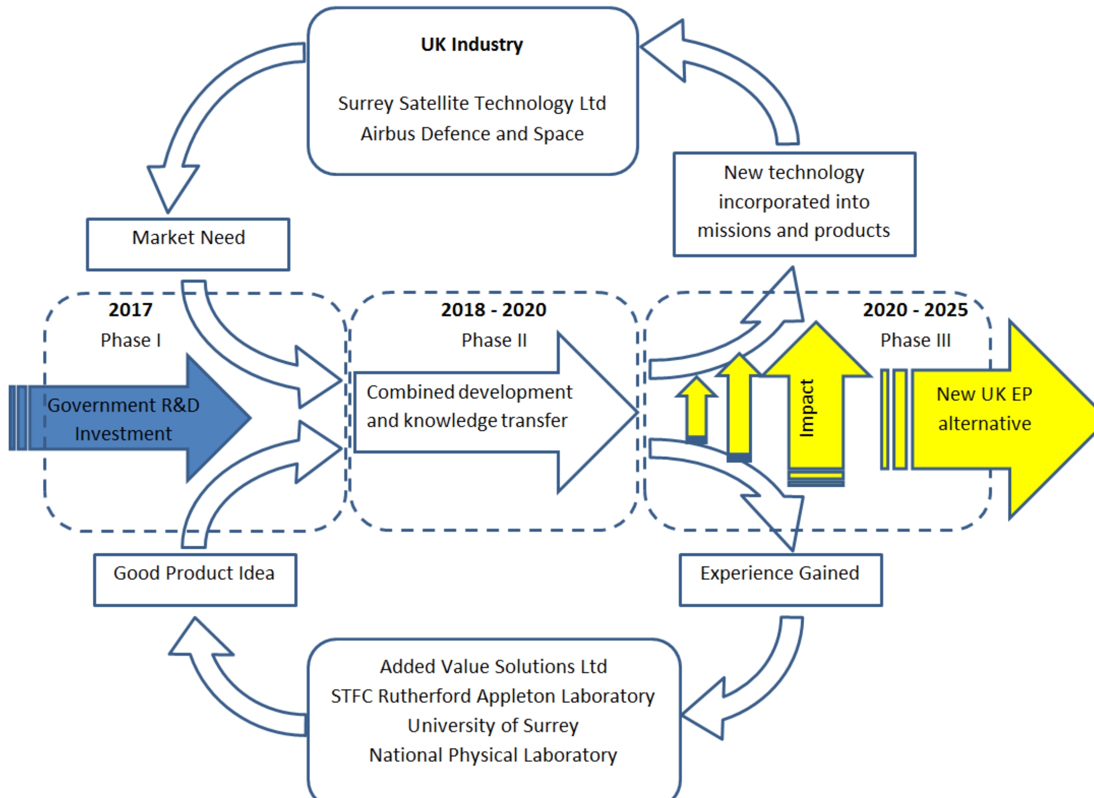
Surrey Space Centre electric propulsion laboratory.

1. SSC Propulsion Activities

Technologies

- **Plasma thrusters**
  - Quad Confinement Thruster
  - Halo Thruster
- **Hollow Cathode Neutralizers**
- **Alternative ion beam neutralization techniques**
  - Radio Frequency neutralizer
  - DC magnetized plasma neutralizer
- **Hybrid electrochemical thruster**





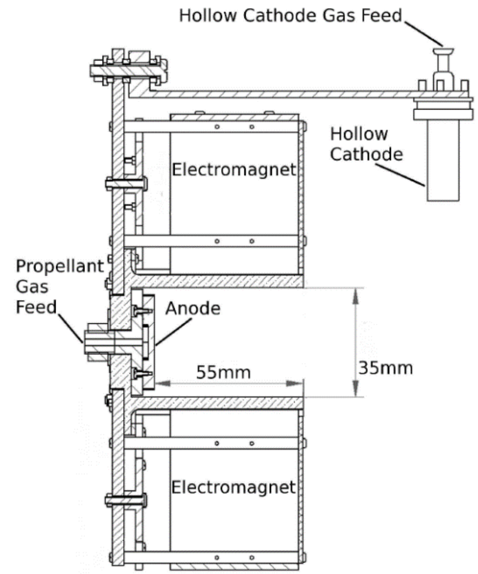
Direct route to commercialization/flight demo through the collaboration with industrial partners

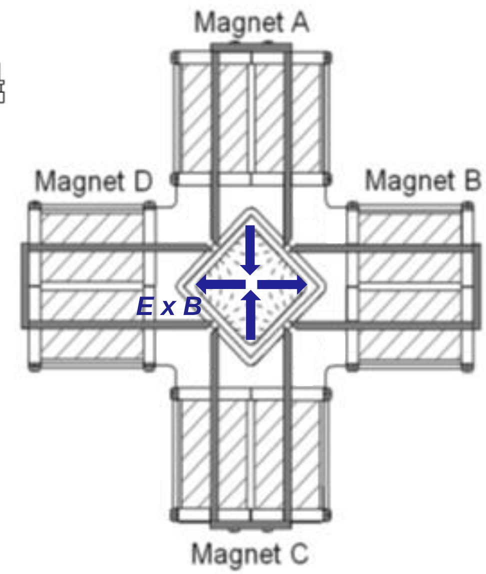
Project costumers/sponsors

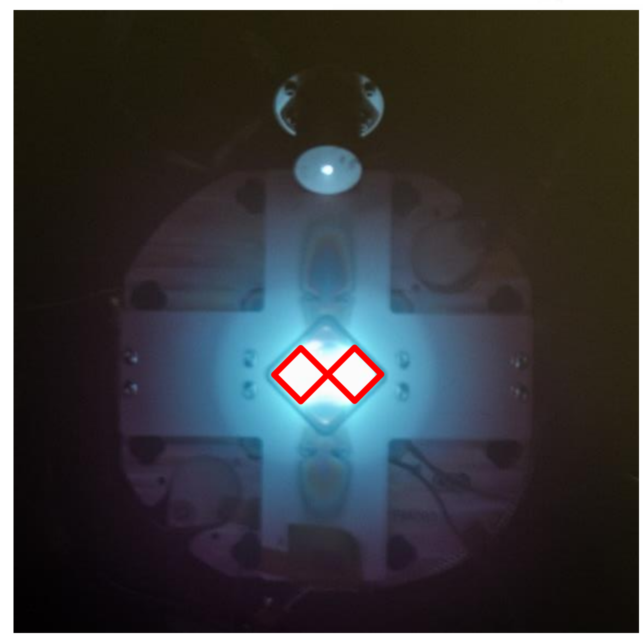
- **Industry:** Airbus Defence & Space, SSTL
- **Government institutions:** ESA, UK Space Agency, UK government

2. QCT Development History

- The QCT is based on a **magnetized DC plasma discharge** enclosed in a square discharge channel
- The anode is located at the closed, upstream end
- Neutral gas enters the channel around the periphery of the anode plate
- An **external hollow cathode** provides primary electrons for ionization and neutralizes the ejected ion beam
- The **magnetic field contains four cusps located at the channel walls**
- The magnetic and electric fields establish an **open E x B electron drift**
- The magnetic field topology is manipulated using four independent electromagnets on each edge of the channel, tuning the properties of the generated plasma



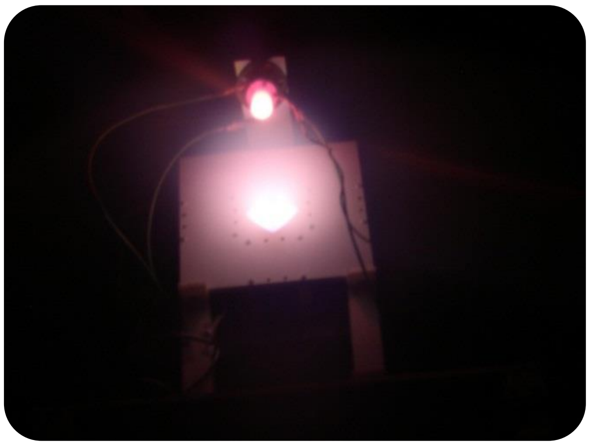


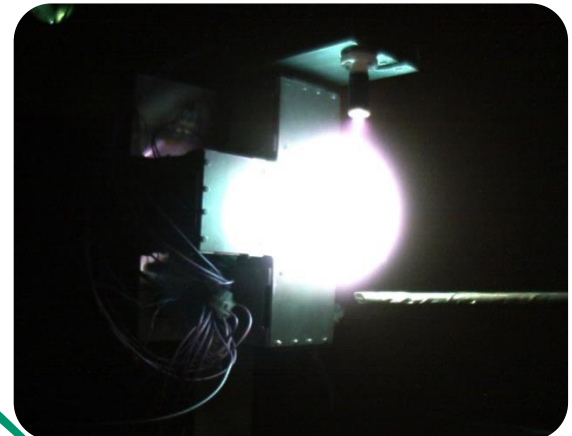


2. QCT Development History

2010

First laboratory prototype





Typical performance metrics (200 W)
Thrust 2.5 mN
Isp 400 s

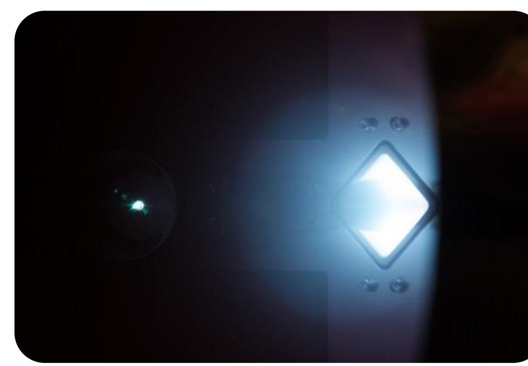
2014 *Advanced Engineering Model*

Current Status (2016-2017)

- Technological development and flight demo led by industry (SSTL)
- SSC supports performance characterization of flight standard unit, acceptance tests of the Flight Model and qualification campaign
- SSC carries out physical investigation and thruster optimization activities

Flight Model ***2016***

Space Demo ***2017***



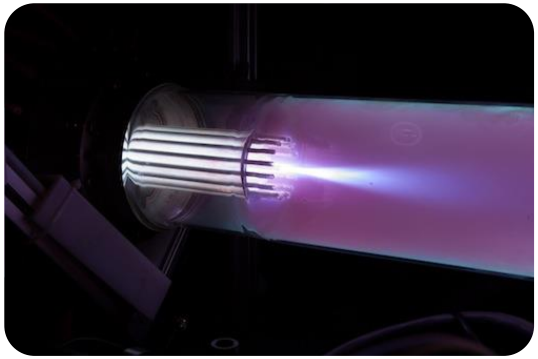
SURREY SPACE CENTRE

3. QCT LIF Velocimetry

UNIVERSITY OF SURREY

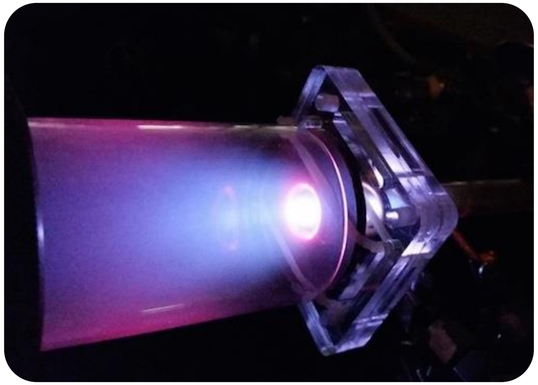
- Collaboration with **Stanford University** aimed to highlight the **ion acceleration mechanism** in a QCT and verify the **steering of ion trajectories** under different magnetic field topologies
- **Non-intrusive local laser-induced fluorescence measurements** have mapped the ion velocity field downstream a 200 W QCT laboratory model
- Accurate (200 m/s uncertainty) and nonintrusive
- High spatial resolution (~1 mm) of the 2-D ion velocity vector (plus velocity distribution functions)

Pulsed plasma coaxial accelerator



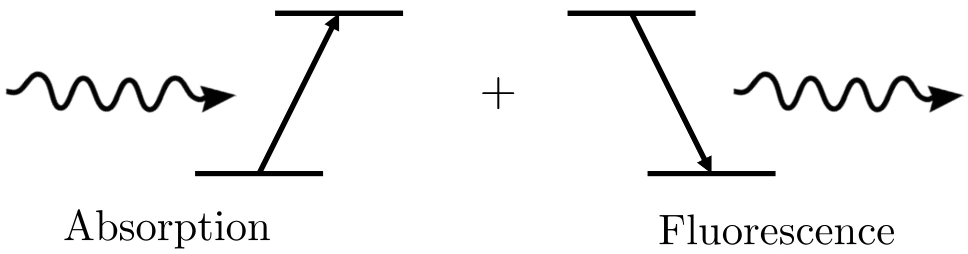
STANFORD PLASMA PHYSICS LABORATORY

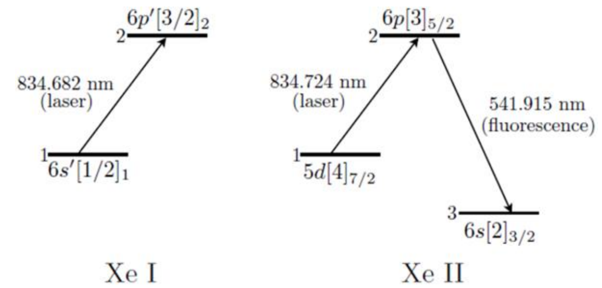
Cold plasma physics and diagnostics



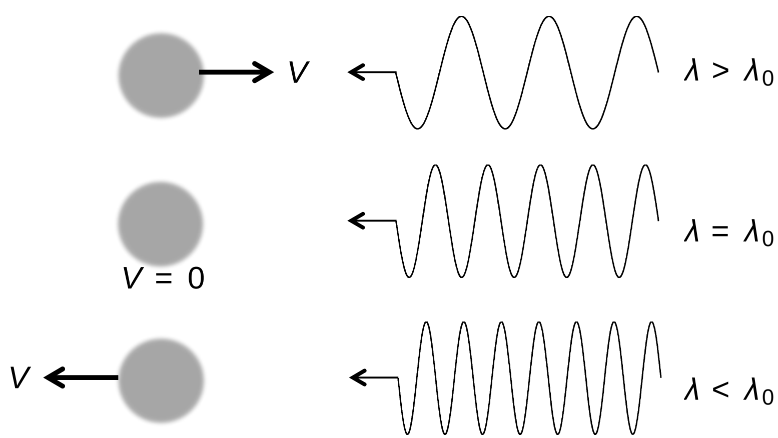
Plasma propulsion

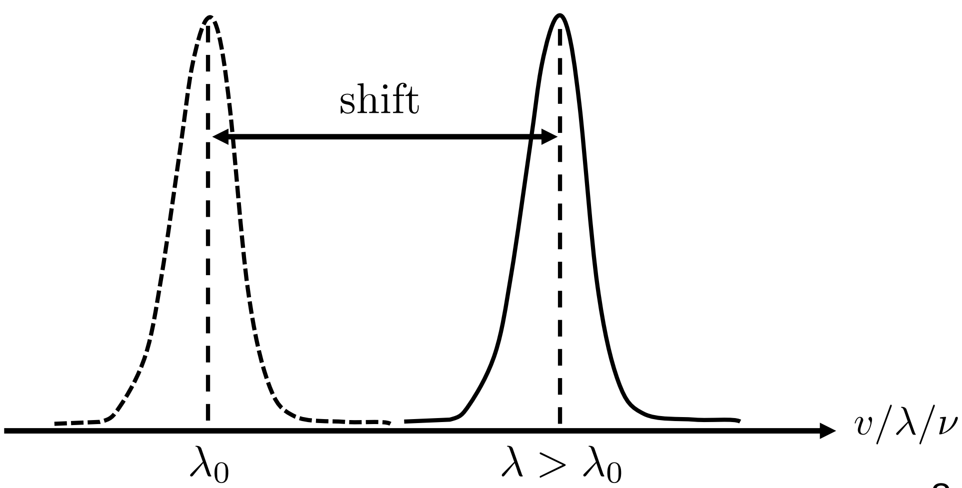
3. LIF QCT Ion Velocimetry





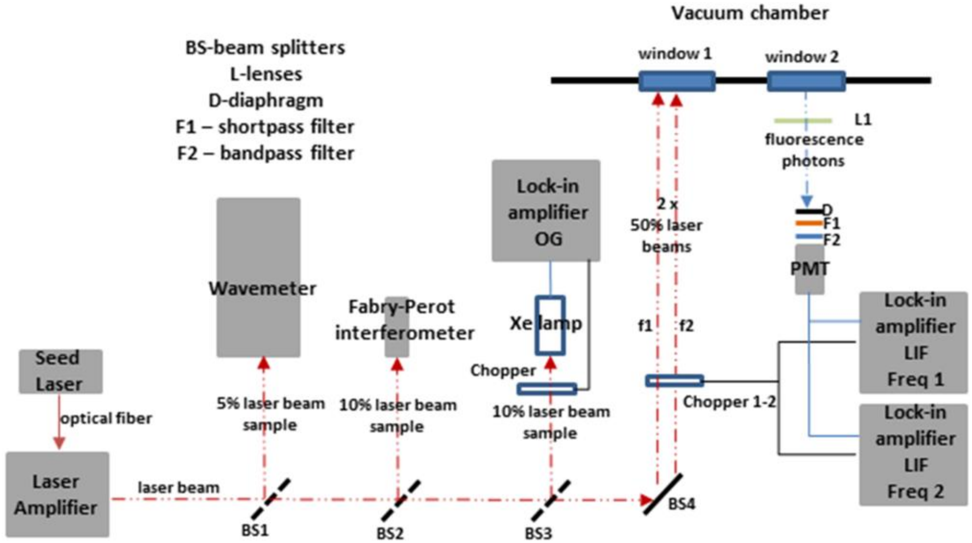
Moving ions see a Doppler shift in the incoming light



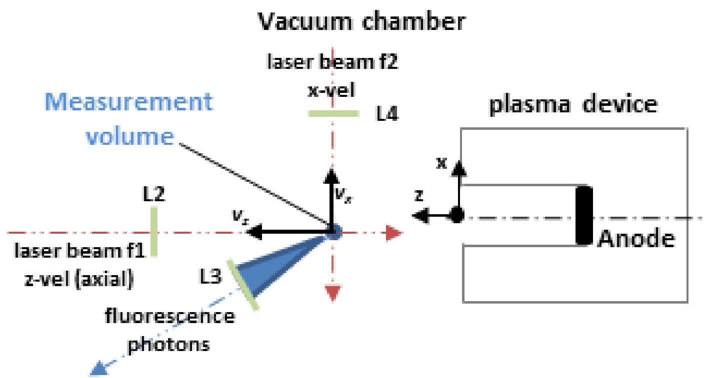


3. LIF QCT Ion Velocimetry

Laser source and optical diagnostics aligned outside the vacuum chamber



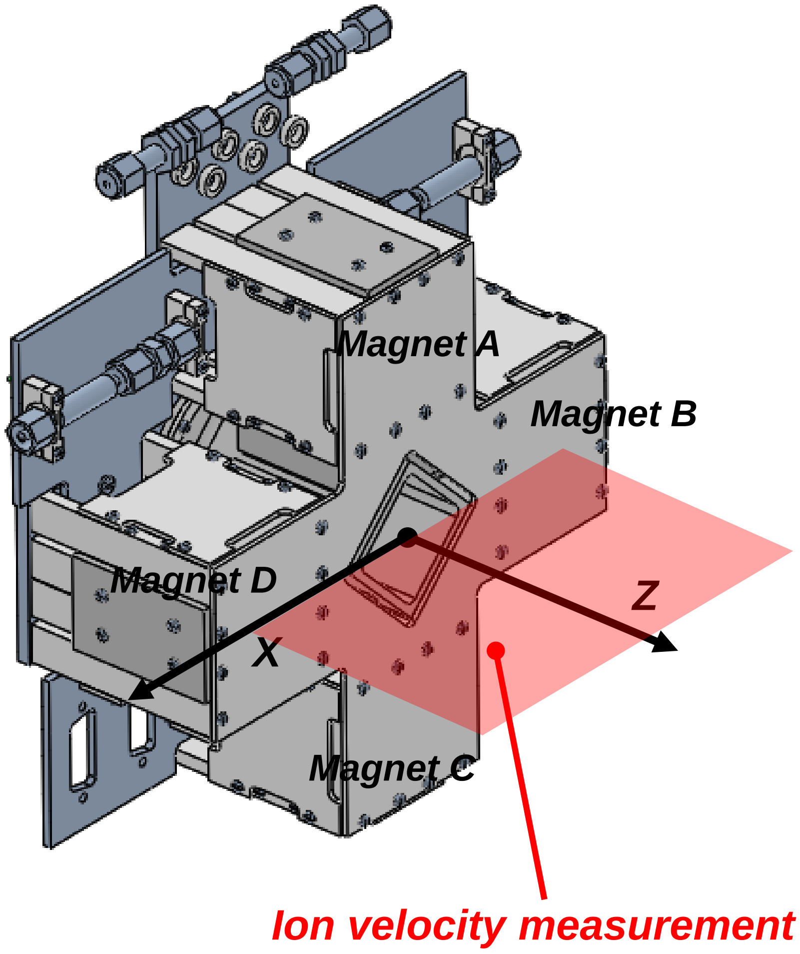
Laser beams and collection optics aligned and focused in the thruster plume

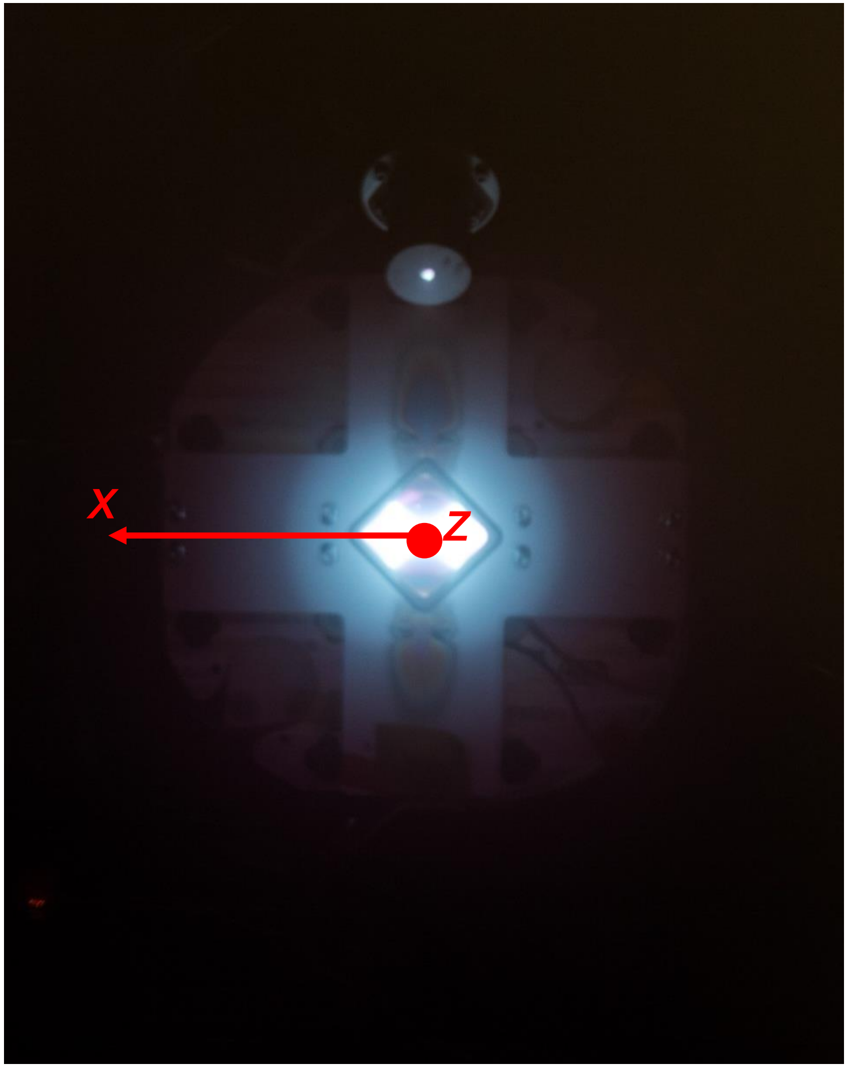


- **Xe II Doppler Shift:** moving ions in plume absorb laser radiation at a different wavelength compared with a stationary reference
- **Xe I Optogalvanic Reference:** neutrals in hollow cathode lamp excited by laser ionize and produce temporary spike in discharge current
- **Laser Scan:** precise wavelength in time reconstructed using known reference peak and Fabry-Perot interferometer (1.5 GHz FSR, 200 Finesse)
- **Homodyne Detection / Optical Bandpass Filtering:** used to reject plasma background light noise and scattered laser photons

3. LIF QCT Ion Velocimetry

Typical testing parameters
Anode power: 200 W (130 V/1.6A)
Anode mass flow: 8 sccm (Xe)
Cathode mass flow: 4 sccm (Ar)
Vacuum chamber pressure: 2.5e-5 Torr





3. LIF QCT Ion Velocimetry

Ion velocity maps with uniform B-field

For information:
a.luccafabris@surrey.ac.uk

3. LIF QCT Ion Velocimetry

Ion velocity maps with uniform B-field

For information:
a.luccafabris@surrey.ac.uk

3. LIF QCT Ion Velocimetry

Ion velocity maps with uniform B-field

For information:
a.luccafabris@surrey.ac.uk

3. LIF QCT Ion Velocimetry

Ion velocity maps with non-uniform B-field

For information: a.luccafabris@surrey.ac.uk

4. Conclusions

- The measurements have shown evidence of ion acceleration in a 200 W QCT discharge
- A free space ion acceleration layer is observed 8 cm downstream of the discharge channel exit plane
- The strong divergence of the ion trajectories suggests a correlation with the semi-spherical plume structure
- In the standard magnetic configuration ions accelerate from 3 km/s to 10 km/s within a 1 cm region
- The magnetic field distortion (Magnets C and D only) generates changes in both ion velocity and metastable (probed) ion density
- **<u>Open discussion</u>: physics of the ion acceleration layer**

Thank you for your attention