Plasma for the space exploration

On the Hall effect thruster performances

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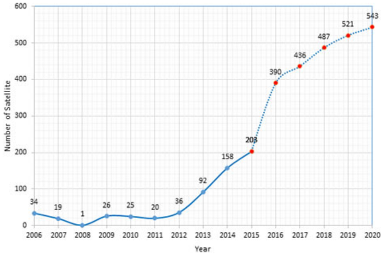
Propulsion for satellites

Introduction

- Increasing use/need satellite
- Propulsion is key : life time, capability, etc.



The Hall effect Thrusters

Introduction

- The efficiency of a thruster is linked to the echaust velocity :

Exhaust velocity	Dry mass	mass at launch to G
$1km/s$	2.10^3	5.10^3
$10km/s$	2.10^3	3.10^3

- Hall Effect Thrusters (HET) is a very promissing technology :
  - High exhaust velocity ($\sim 12km/s$)
  - Succesfully used since 1970s
  - *Smart1* spacecraft used it to the moon (ESA, 2009)

However: **the HET is still poorly understood**

What don't we know ?

Introduction

Better inderstanding of HET is more and more important. Indeed :

- Performance (thrust, efficentcy, etc.) isn't predictable:
  - the wall effect is poorly understood
  - the electron mobility is anormaliously high ($\sim 10\times$)
- The life time isn't predictable
  - Walls are eroded by ion impact sputtering
  - Walls resistes from 1000 h to 7000h
  - Anormalous wall erosion are also observed

Why ?

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Why ? Because plasma physics are **difficult**

plasma physics are difficult

- Measurments and diagnotics are difficults
  - low densities and high magnetic field: standard diagnotics are not precise enought
  - high temperature : probs can melt !
  - probs will modify the plasma propertis
- The therory is complexe:
  - Plasma : fluid equation mixed with Maxwell equations $\rightarrow$ Non-linear
  - Many degres of freedom

$\rightarrow$ Simulation is a big help, specialy Particlar simulations.

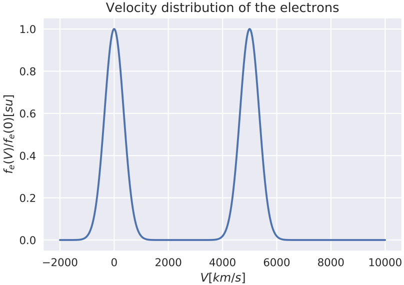
Plasma Beam Instability

Some Plasma Physics

An exemple of "simple" plasma behavious : the plasma-beam instability.

The system is simple:

- a static plasma background
- an electron beam with high velocity
  $v_b >> v_{th}$
- Collision are neglected (low pressure)
- uniform spatial density



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Hall Effect Thruster : presentation

More details

Figure: Hall Effect Thruster (PPS-1350, Safran)

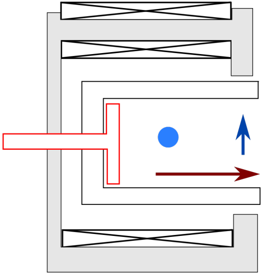
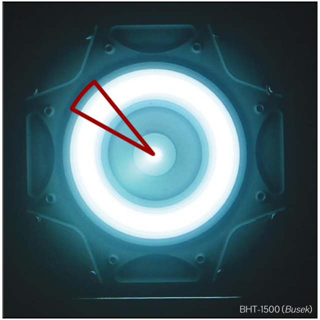


Figure: Shematic cut of an HET

Simulation presentation

Investigating the ECDI

Investigating the Electron Cyclotron Drift Instability (ECDI)



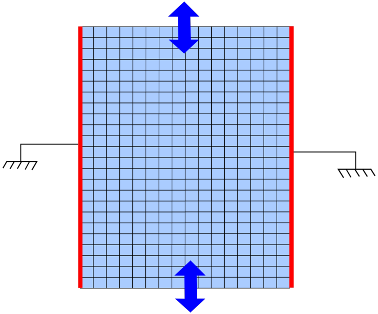


Figure: Shematic cut of the simulation

Simulation results

Investigating the ECDI

The plasma potential evolution in function of time.

The instability observed is certainly the Electron cyclotron drift instability !

Simulation results

Investigating the ECDI

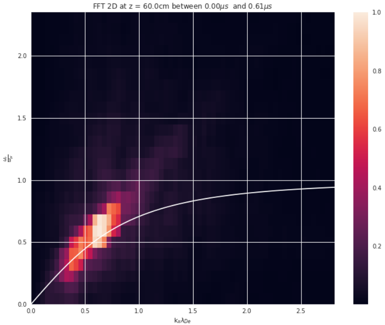


Figure: Bi-dimentional Fourier Transform of E_θ and the theoritical dispertion relation $\omega(k_\theta)$ of the ECDI.

$\mu(t)$ plot form Vivien's thesis

Improving Thuster simulation

How to improve the simulation of the HET ?

Improving Thuster simulation

How to improve the simulation of the HET ?

- Plasma - wall interaction
  - Electron induced secondery electron emition (SEE) [Vivien Croes]
  - Dielectric layer : modify electrostatique bondary condition
- Simulating the third direction O_z
  - 2D simulation of the (O_z, O_θ) plan [with Thomas Charoy]
  - Adding third "fake" direction in the 2D simulation

Improving Thuster simulation

Wall effects

Model of Secondary electron emission:

Emission probability :

$$\sigma = \sigma_0 + (1 - \sigma_0)\frac{\epsilon}{\epsilon^*}$$

with $\epsilon = \frac{1}{2} m_e v^2$, and σ_0 and ϵ^* fonctions of the ceramic

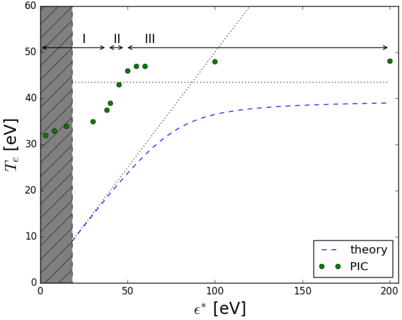


Figure: Electron temperature T_e function of ϵ^*, $\sigma_0 = 0.5$, compared to the actual theory

Improving Thuster simulation

Wall effects

Dielectric effect on potential

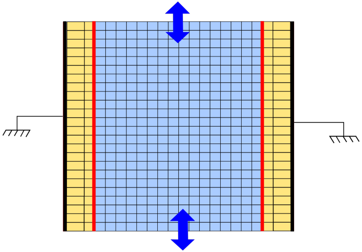
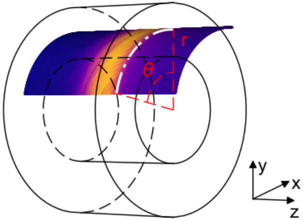


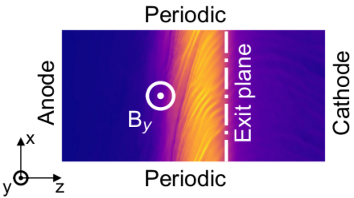
Figure: Added ceramic layers

→ No significant effect without SEE

O_z direction:

- Propagation direction
- self-consistent ionization, density and electric field
- of the the wall effect





Improving Thuster simulation

Wall effects

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There Is No Largest Prime Number

The proof uses *reductio ad absurdum*.

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1. Suppose p were the largest prime number.

4. But $q + 1$ is greater than 1, thus divisible by some prime number not in the first p numbers.

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A longer title

- one
- two