# Measuring the efficacy of a satellite VLF transmitter with magnetic loop/solenoid antenna in a plasma chamber (proof of concept)

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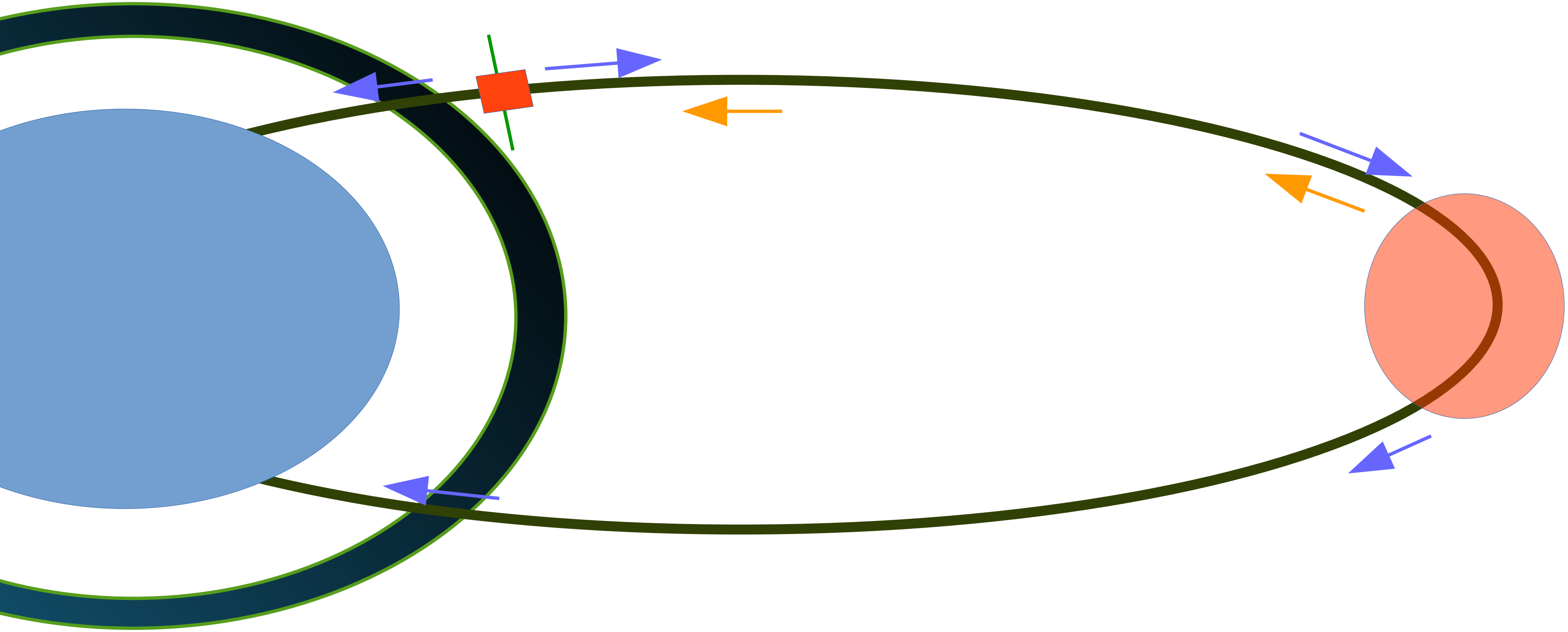
# Scientific concept: POPRAD VLF *transmitter*

## Probing the Plasmasphere and the Radiation Belts (POPRAD)

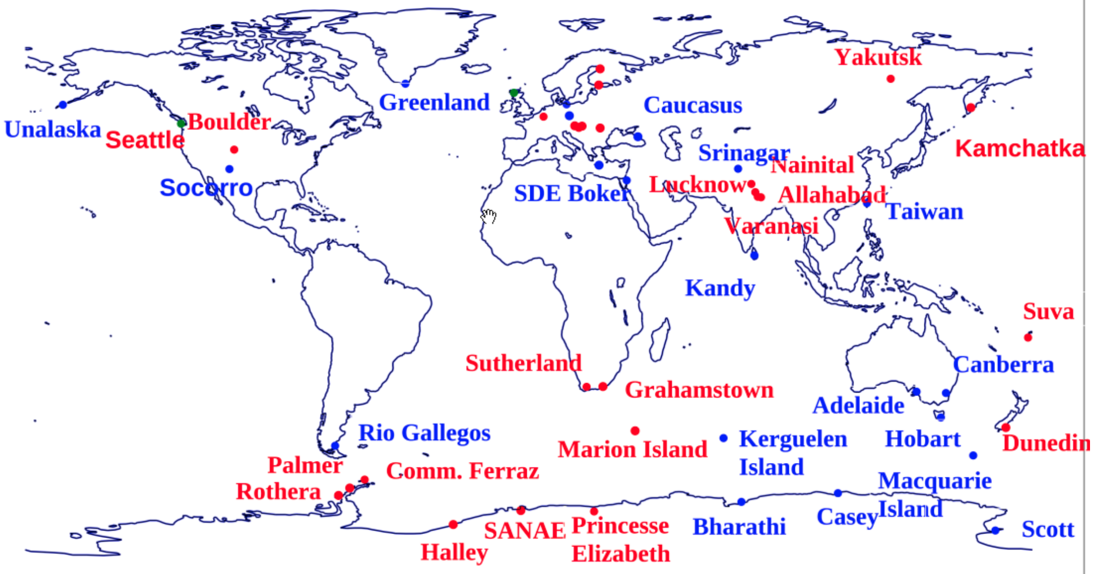


# Scientific concept: POPRAD VLF *transmitter*

## Scientific Objectives:

1. Systematic probing of the ***plasmasphere*** by coded VLF pulses - “artificial whistlers”:
    - the code contains the time of transmission, thus the time of the excitation (the most uncertain parameter for whistler inversion)
    - the field line of the propagation is known from satellite position – it has to be estimated during the whistler inversion process
    - existing ground based VLF receiver network (AWDANet) can be used to detect the signals
    - polar orbit allows to monitor the plasmasphere at all magnetic latitude within 20 minutes

# Automatic Whistler Detector and Analyzer Network (AWDANet)
# a worldwide network of automated whistler receivers

# Scientific concept: POPRAD VLF *transmitter*

## Scientific Objectives:

2. Systematic probing of the ***energetic electron*** population - “artificial chorus/hiss”:
   - a transmitted frequency ramp between 1-10kHz can interact with the counter-streaming electrons and precipitates them by pitch angle scattering into the atmosphere
   - an energetic electron detector – on the same or on different spacecraft – can systematically survey the presence and energy of the population
   - operating this mode continuously along the orbit maps the energetic electron population in the inner and outer radiation belts as well as in the slot region

# Scientific concept: POPRAD VLF *transmitter*

## Scientific Objectives:

3. Systematic probing of the ***ionosphere*** by VLF pulses - “inverse fractional hop whistler or VLF TEC ”:
   - the pulses can propagate not only upward, but downward as well – fractional hop
   - the code contains the time of transmission, thus the time of the excitation (the most uncertain parameter for whistler inversion)
   - the field line of the propagation is known from satellite position – it has to be estimated during the whistler inversion process
   - existing ground based VLF receiver network (AWDANet) can be used to detect the signals
   - the whistler-mode propagation in VLF range is more strongly affected by the magneto -ionic medium than at higher frequencies (e.g GPS signal), thus the state of the ionosphere can be estimated more precisely.

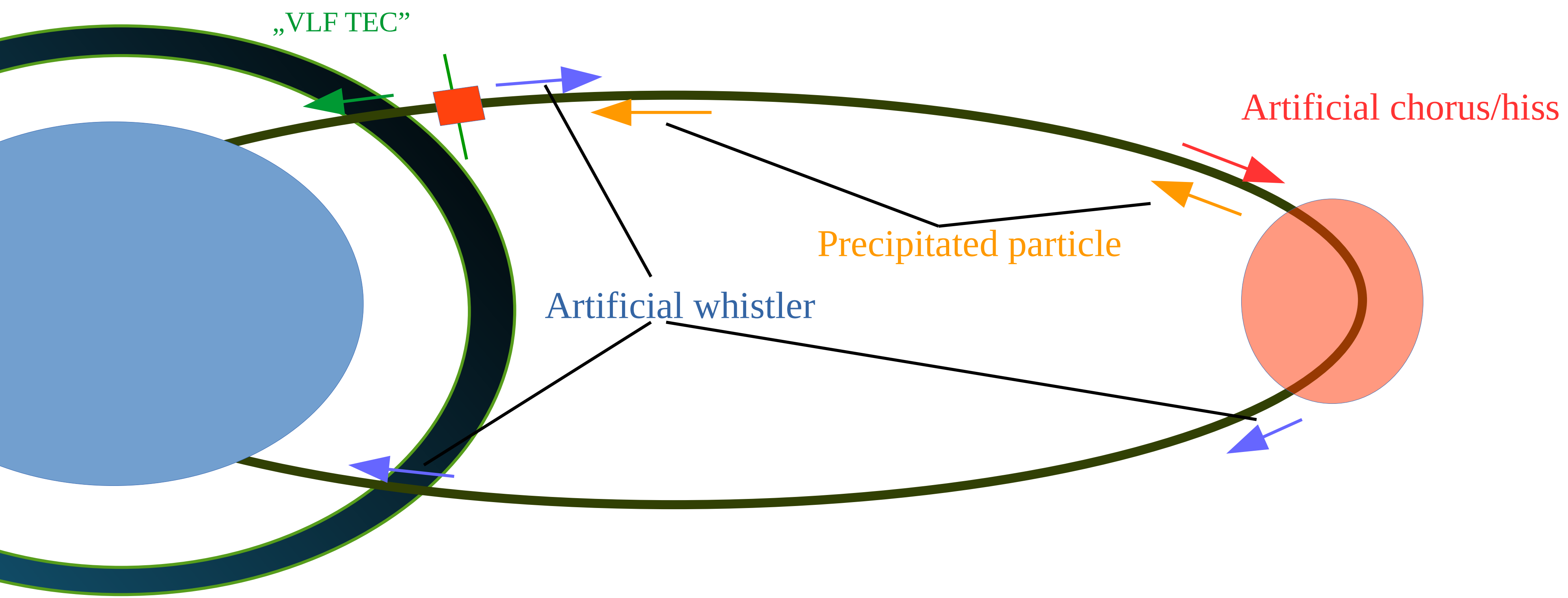
# Scientific concept: POPRAD VLF *transmitter*

## Scientific Objectives:

4. Monitoring the **termosphere** neutral density variation by VLF amplitude attenuation:
   - the VLF signal propagating through the ionosphere is attenuated by neutral-electron collision → the variation of neutral density can be deduced form the attenuation

→ ***„atmospheric drag"***

# **POPRAD VLF *transmitter:*** Polar LEO satellite and transmitted VLF waves



# PRODEX Project

**Results of recent experiments (*DSX*) concluded, that VLF transmitters using large electric dipole antenna may not be suitable to transmit wave energy comparable to natural signals generated in or propagating through the inner magnetosphere.**

**The critical point, the efficacy of the transmitter will be tested in a plasma chamber at ESTEC *(in a new plasma facility to be build, ~4mx0.5m plasma)* using the Similarity Principle (Alfven & Falthammer, 1963) → ESA PRODEX project, *started on 1 July 2023***

***Magnetic field strength of natural waves is ~0.01-1nT***

# PPODEX *Project*

## The total radiated power is the same at the top of the ionosphere and in a plasma chamber!

| $\gamma$=2236 | Ionosphere (600km) | Plasma chamber |
|---|---|---|
| Frequency | 10kHz | 22MHz |
| Electron density | $2*10^5$ /cm$^3$ | $1*10^{12}$ /cm$^3$ |
| Magnetic field | 30000 nT | 670G |
| Refractive index | 44.1 | 44.1 |
| Wavelength | **680m** | **0.43m** |

Hypothesis #1: particle velocities **v** and energies *E* in space and laboratory are equal

Hypothesis #2: scaling parameter $\gamma$ is a ratio of a characteristic scale-size of space plasma process and its laboratory "model"

**From Maxwell's equations and equations of motion:**

| Characteristic parameters | Laboratory value vs. space value |
|---|---|
| Electron and ion directional velocities, temperatures, phase and group velocities of the waves, plasma $\beta$, total radiated power, … | 1 |
| Frequencies, wavelengths$^{-1}$, Debye length$^{-1}$, gyroradii$^{-1}$, electric and magnetic fields, antenna length$^{-1}$, … | $\gamma$ |
| Plasma and space charge density, current density, electromagnetic energy density, … | $\gamma^2$ |

# Facility Requirements

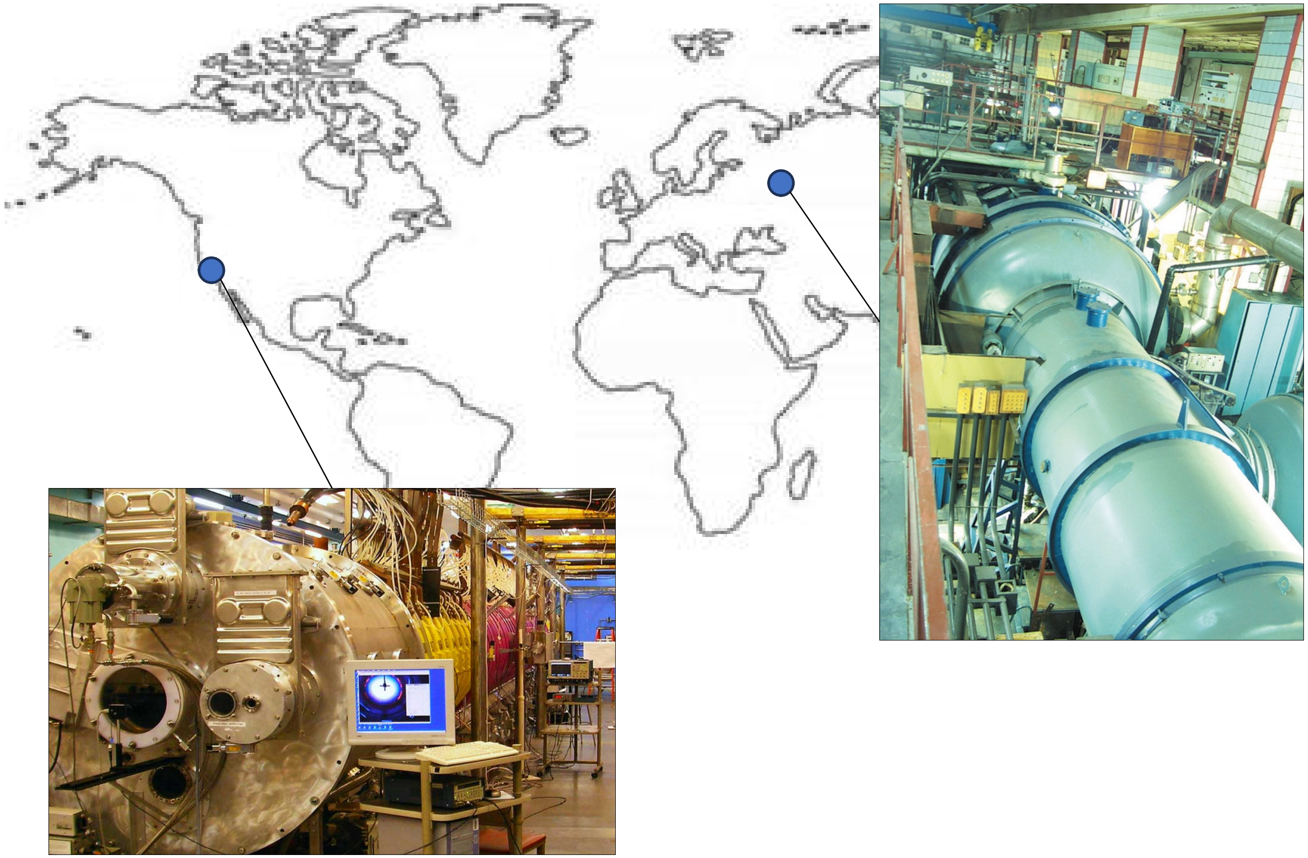
| Electron density log(Ne [cm$^{-3}$]) | | Electron temperature [eV] | | Ion temperature [eV] | | Magnetic field (static) [kG] | | Geometry | Plasma dimension |
|---|---|---|---|---|---|---|---|---|---|
| **Min** | Max | Min | Max | Min | Max | Min | Max | | |
| **8** | **12 (13)** | **0.2** | **10** | **0.2** | **5** | **0.2** | **3** | **Straight cylinder** | **∅ 0.3-0.5m x 3-4m** |

**Stepped approach in implementation**

# Similar facilities

1. Large Plasma Device (LAPD)
   - UCLA
   - California, USA
   - Built 1991; upgraded 2000

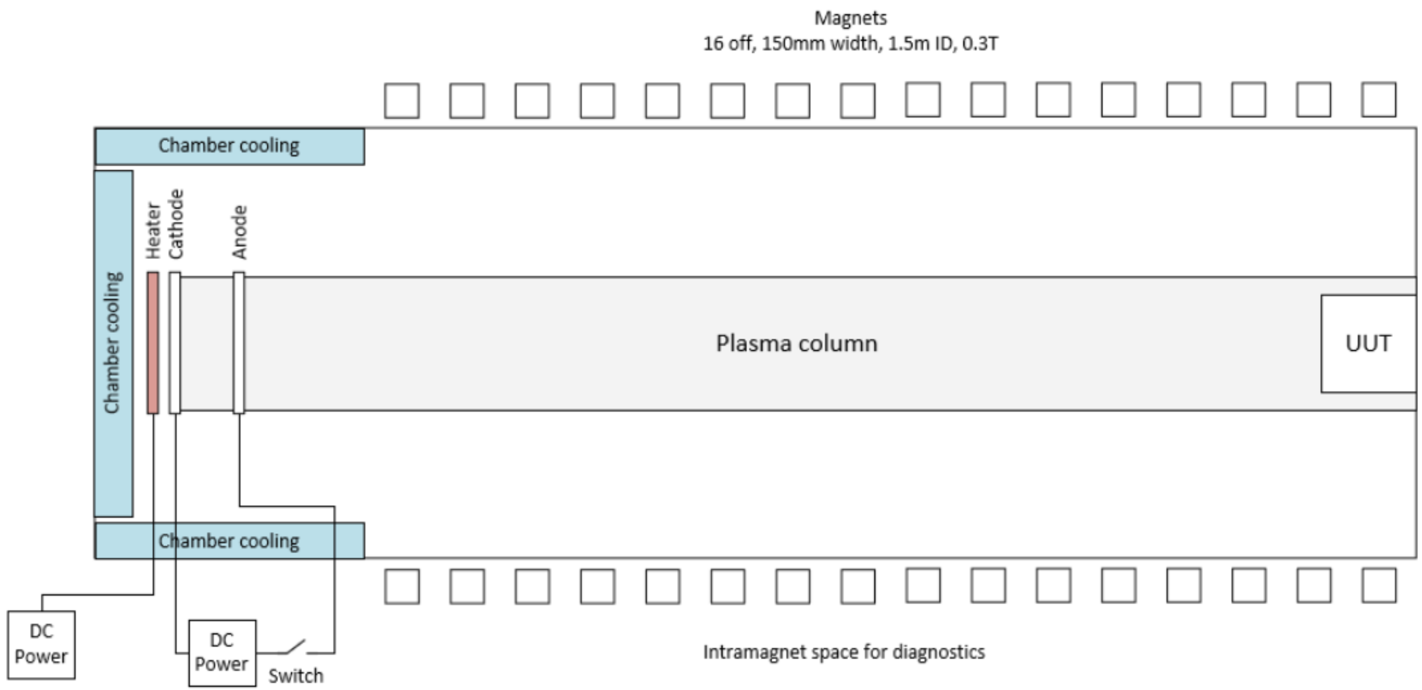
2. KROT facility
   - IAP RAS
   - Nizhniy Novgorod, Russia
   - Built 1980s



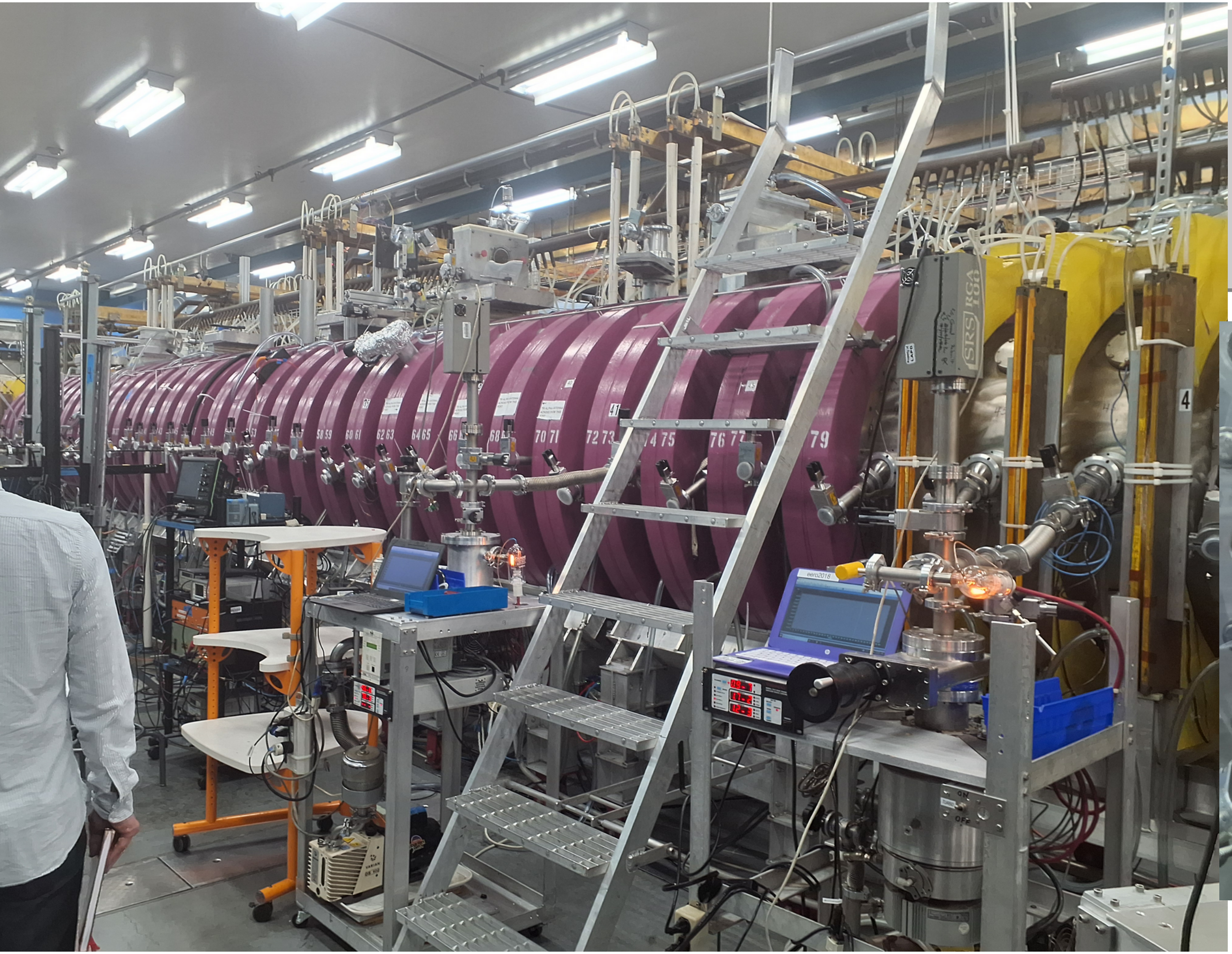
# ESTEC plasma device: modeled after LAPD – basic version :

- Smaller length → 3.5-4m
- Smaller magnetic field → 300-600G
- Same diameter of plasma column → 0.5-0.6m
- Same density → $10^8 - 10^{12}$ /cm$^3$

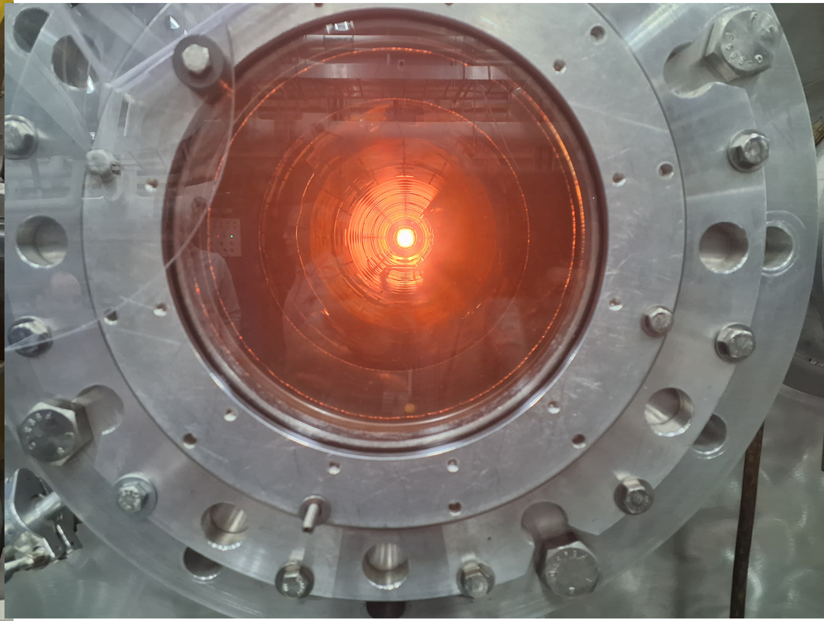
Plasma source / Vacuum Chamber



# ESTEC plasma device: modelled after LAPD:



$LaB_6$ cathode, 24kA, 1700 degree



# ESTEC plasma device: what it can be used for other than this PRODEX project?

The plasma column is in ~steady state, allowing long tests (days/weeks)

1. Testing sensors in cold plasma environment
2. Testing materials in cold plasma environment
3. Testing electronic parts/ platform elements/ small satellites in cold plasma environment
4. Same tests, but with trapped energetic particle in magnetic mirror

# Conclusions

**- A feasibility study is about to start on building a new plasma chamber at ESTEC**

**- It will be first used to test the VLF transmitter**

**- but it can be used to many other instrument and environmental tests**

***- a poll will be initiated to gather ideas for usage from scientific community at the end of the summer/ early autumn***