Masterclass:
DISCOVERER – Why, How and What So Far?

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4th DISCOVERER General Assembly

28th November 2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 737183.

DISCOVERER Aim

"Radically Redesigning Earth Observation Satellites for Commercially Viable Sustained Operation at Significantly Lower Altitudes"

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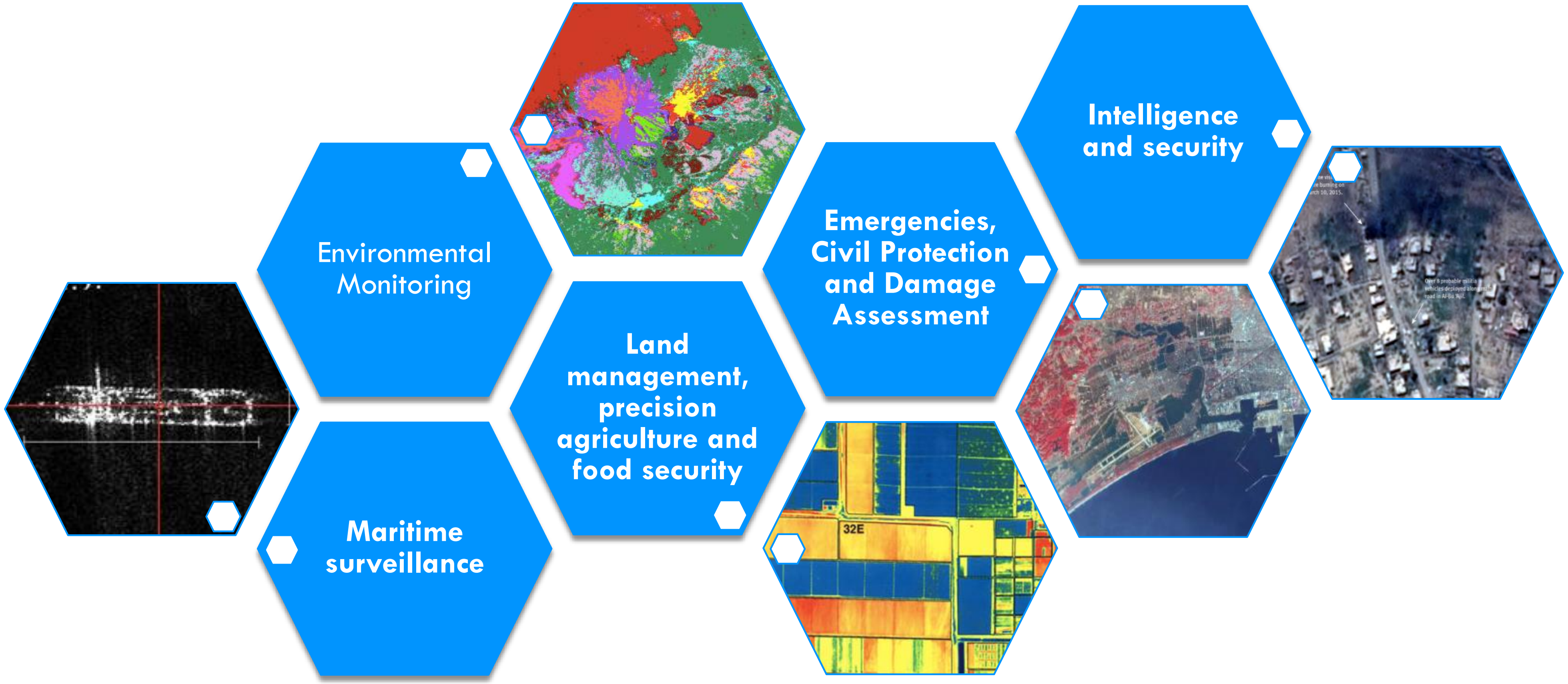
Why DISCOVERER?
Satellite Based Earth Observation



Worldwide data products market: $1.7 billion in 2015
Expected to reach $3 billion by 2025 (Euroconsult)

Image attributions: Maritime surveillance - geocento.com; Environmental monitoring – Piscini et al, Spectral analysis of Aster and Hyperion data for geological classification of volcano Teide, 2010; Precision agriculture and Civil Protection – NASA; Intelligence – Airbus DS

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Why Operate Satellites in Lower?

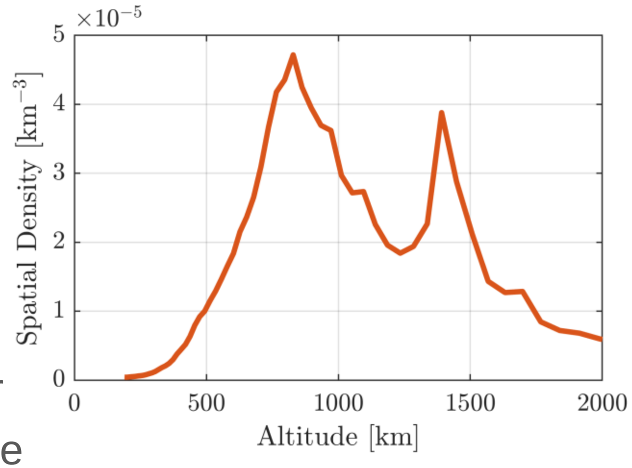
Benefits:

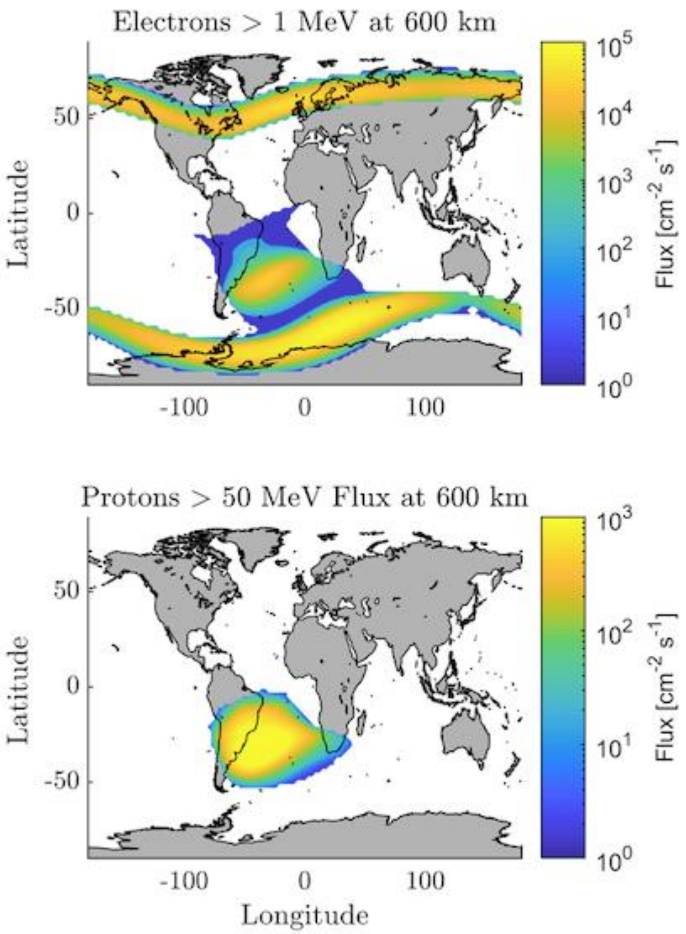
Improved payload performance

- Optical payloads have:
  - Increased resolution or reduced aperture size
  - Improved radiometric performance
- Radar and communications payloads have:
  - Significantly improved link budgets
  - Reduced antenna size and transmission power
  - Reduced latency and improved frequency reuse

Platform benefits

- More benign radiation environment
- Improved launch vehicle payload mass
- End-of-life disposal is enabled
- Reduced space debris collision risk
- Improved geospatial accuracy and reduced pointing requirements





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Very Low Earth Orbit Satellite Challenges

Residual Atmosphere:

- Increased atmospheric drag
- Increased atomic oxygen erosion
- Aerodynamic attitude and orbit perturbations
- Increased spacecraft charging

New Technologies:

- Materials and Geometries for Drag Reduction and Erosion Resistance
- Drag Compensation
  - Traditional EP
  - Atmosphere Breathing EP
- Aerodynamic Attitude and Orbit Control

Orbit geometry:

- Reduced single satellite coverage
- Increased single satellite revisit time
- Shorter single satellite communications windows with ground stations

Constellation Design

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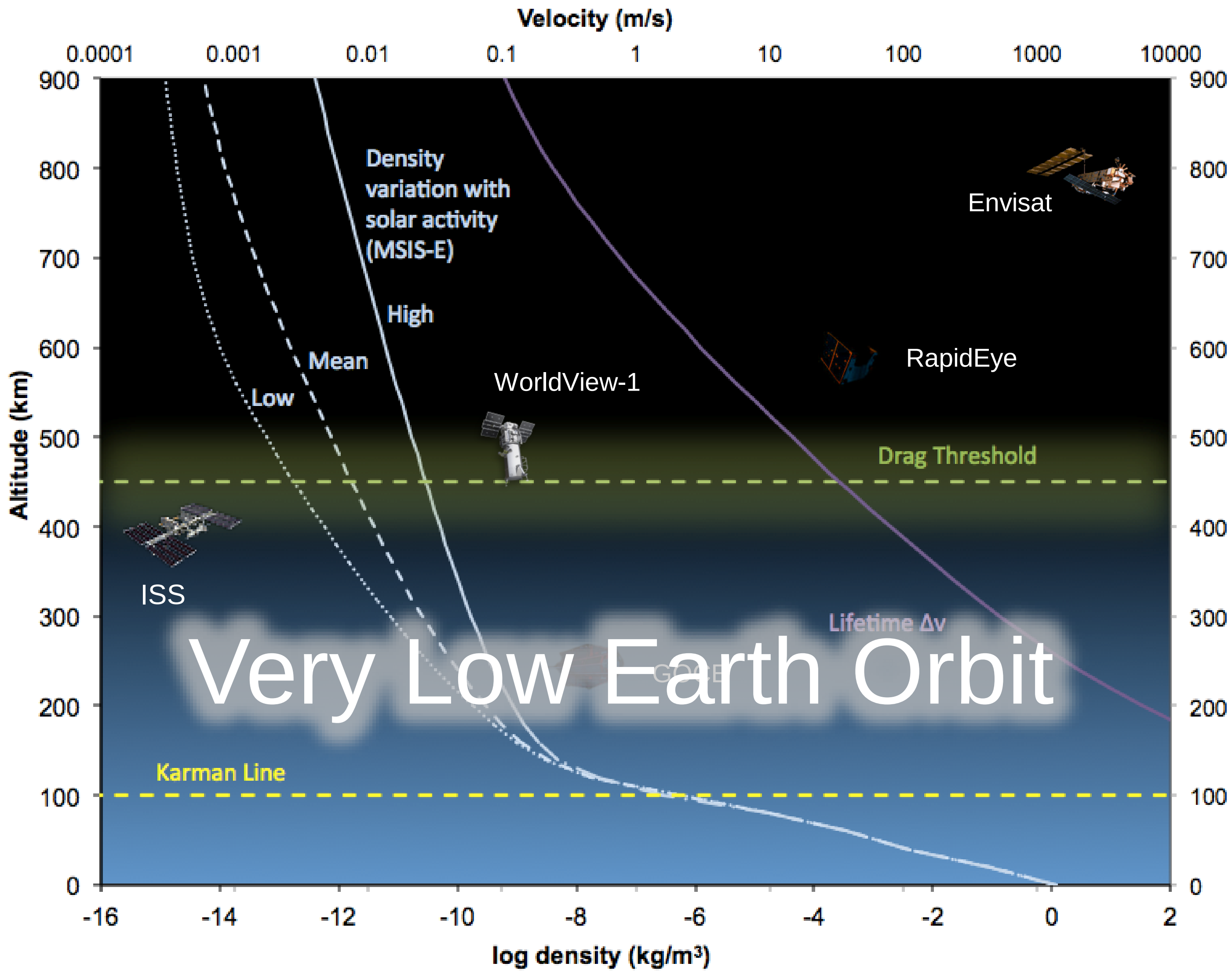
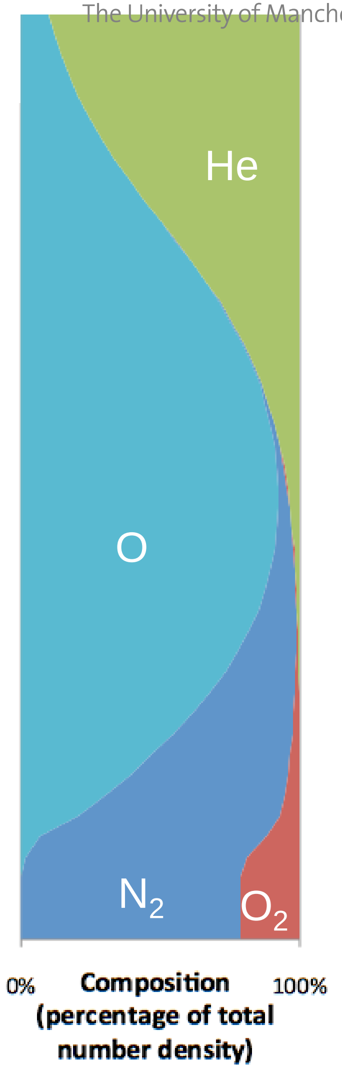
The Environment at Lower Altitudes (NRLMSIS data)





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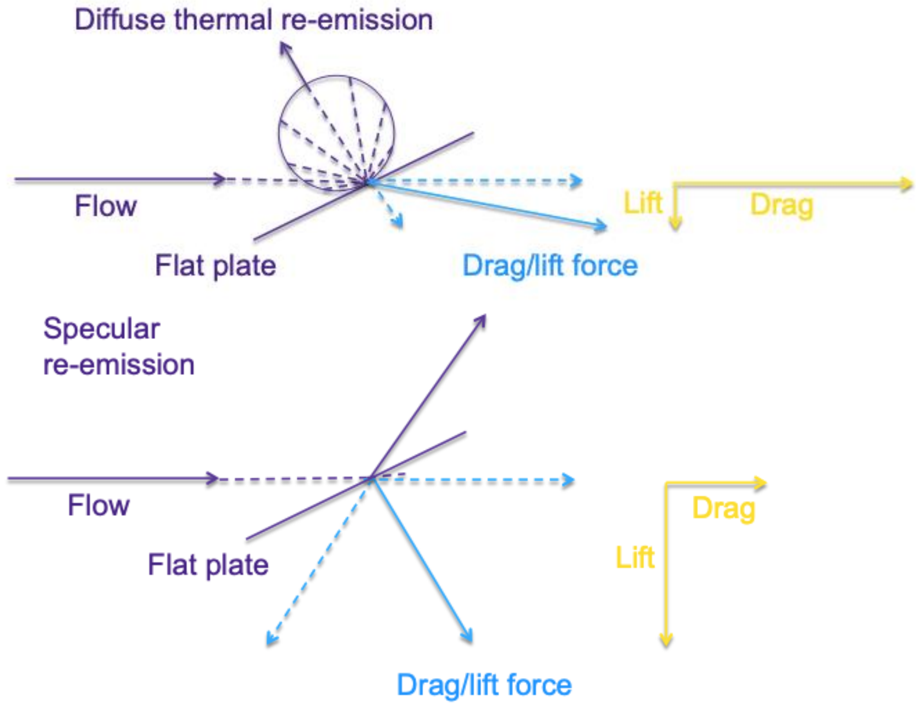
Orbital Aerodynamics 101

Mean free path >> than satellite size → Free molecular flow → Aerodynamics driven by gas interaction directly with surfaces → Most surface materials have high energy and momentum accommodation



Diffuse reemission:

- Drag is largely driven only by cross-section to the flow
- Aerodynamic control is driven by drag effects

Specular reemission:

- Angled surfaces minimise drag and can produce useable lift
- Allow concentration of gas for atmosphere breathing propulsion

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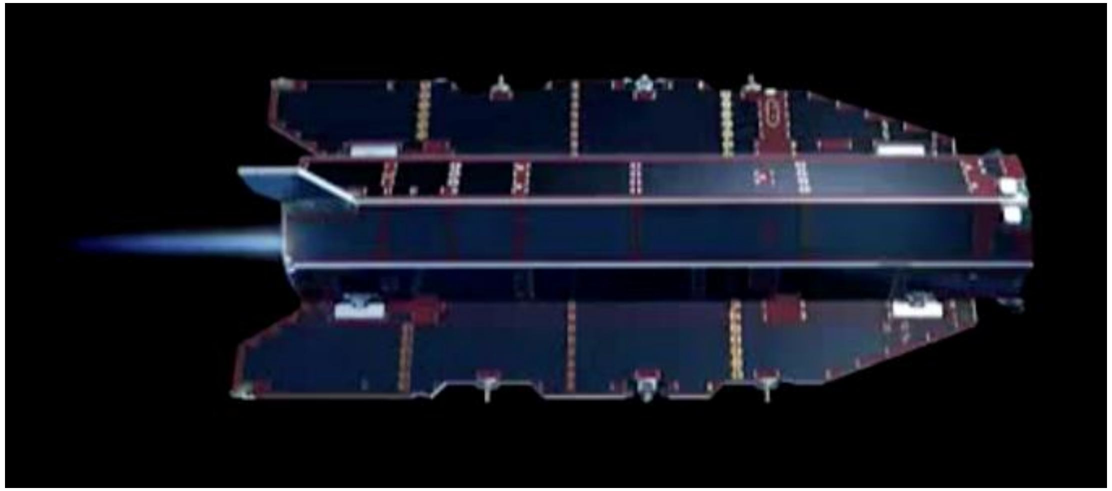
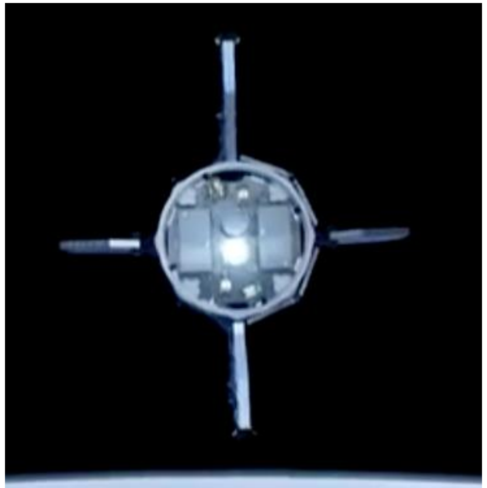
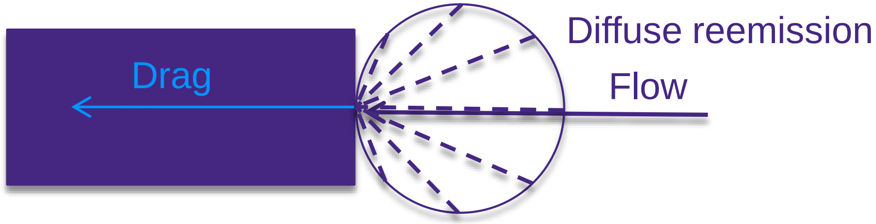
Orbital Aerodynamics 101 – GOCE Example

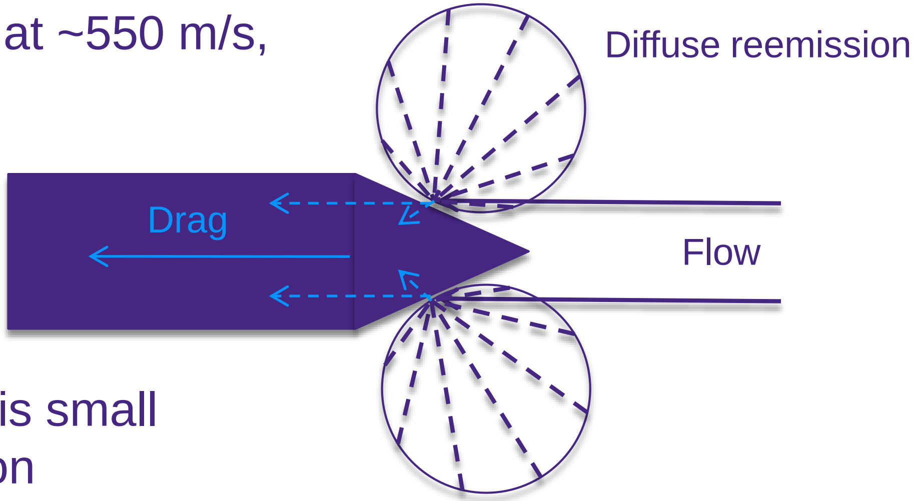




Screen captures from https://www.youtube.com/wa ?v=n3gB_ZCWkXs

At 300K, thermally accommodated reemission of O is at ~550 m/s, compared to initial orbital velocity at ~7 800 m/s





Diffuse reemission still produces drag but is small compared to the initial molecular adsorption

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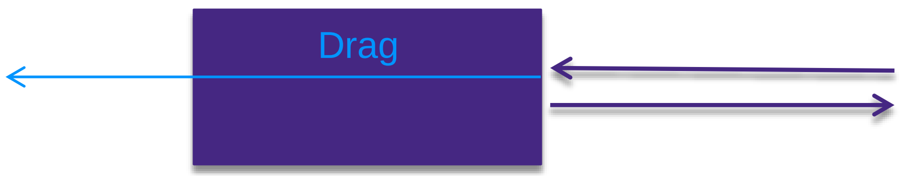
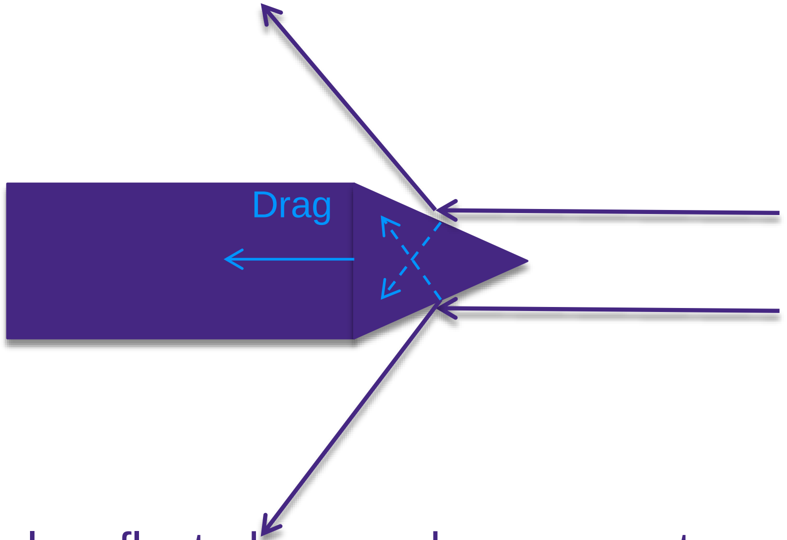
Orbital Aerodynamics 101 – Post DISCOVERER Example

Specular reflection at orbital velocity ~7.8 km/s





Drag doubled – useful for end-of-life deorbit solutions

Specularly reflected gas makes momentum exchange perpendicular to the surface, reduces drag component

Drag component of impulse $J_d = mV(1-\cos 2\alpha)$

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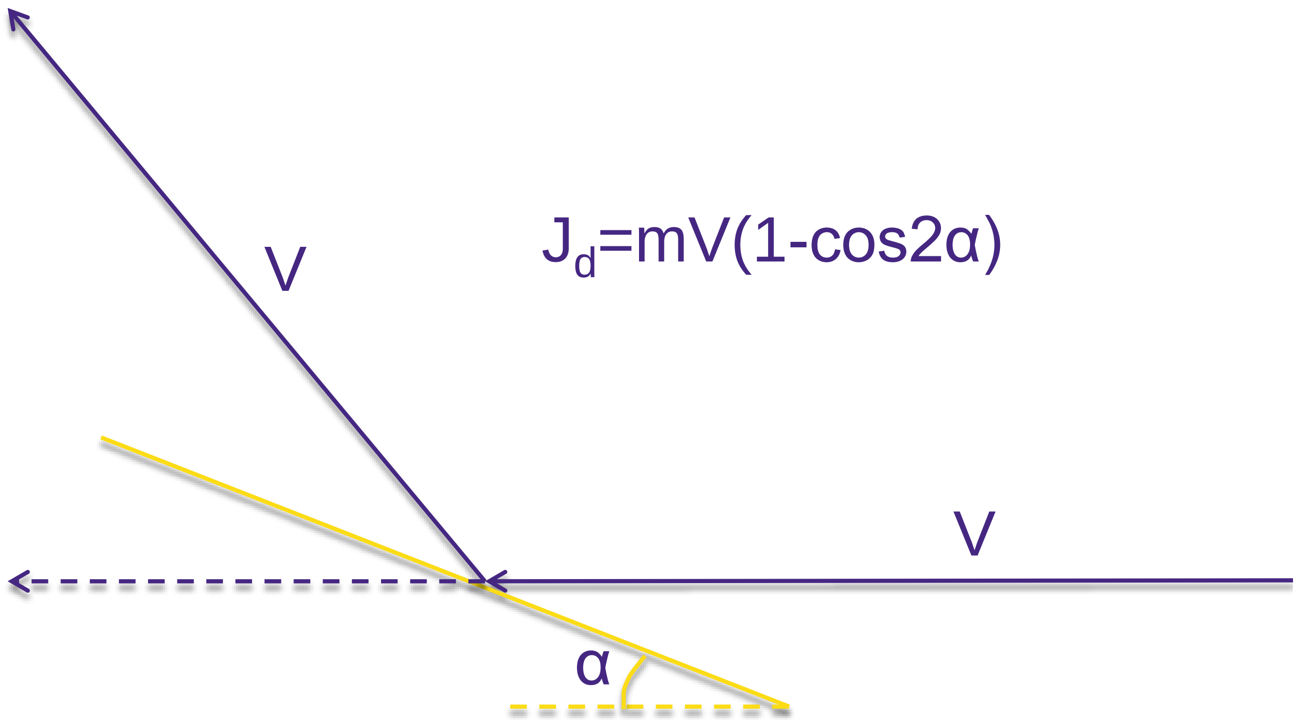
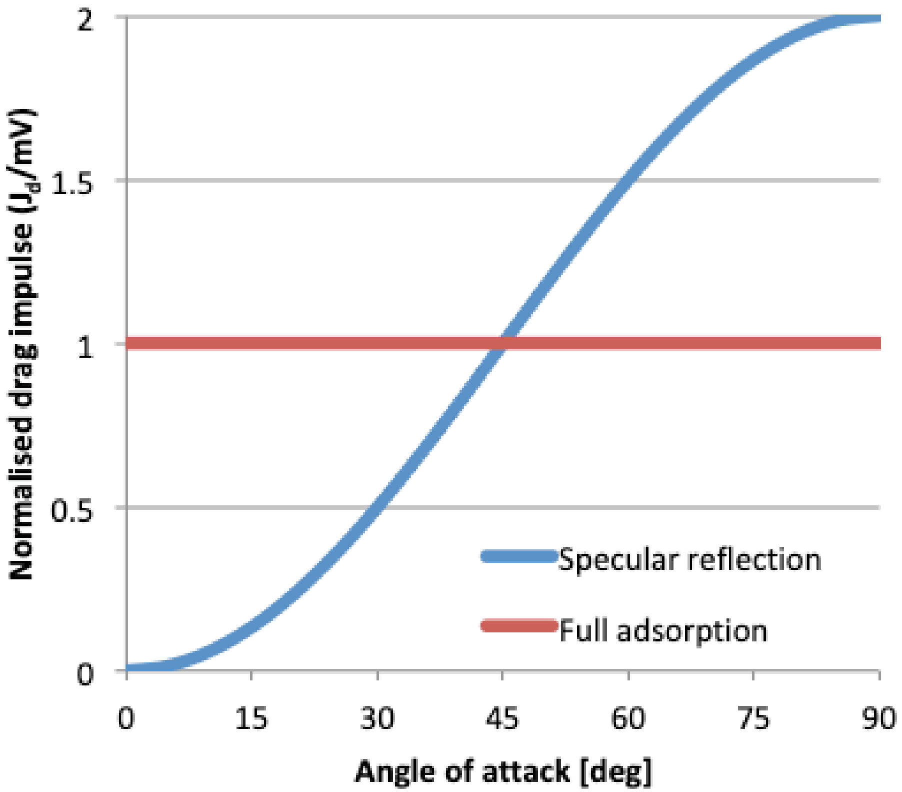
Orbital Aerodynamics 101 – Specular Momentum Exchange



$$J_d = mV(1 - \cos 2\alpha)$$



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Orbital Aerodynamics 101 – NovaSar (SSTL) as an Example

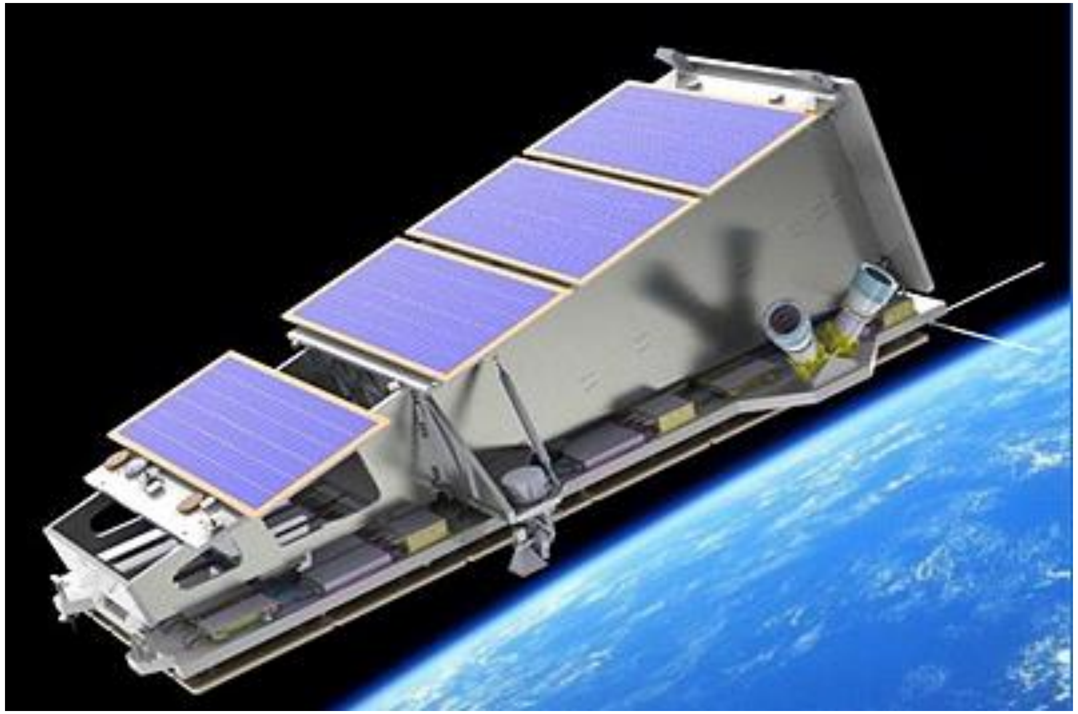
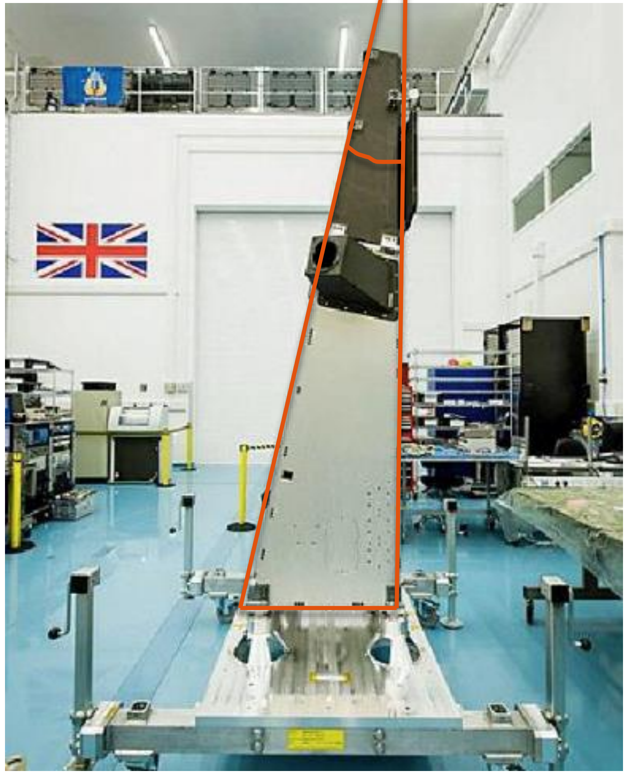


Image credits: SSTL



~13° wedge

$J_d/mV \sim 0.1$

Drag could be reduced by an order of magnitude with specularly reflecting materials

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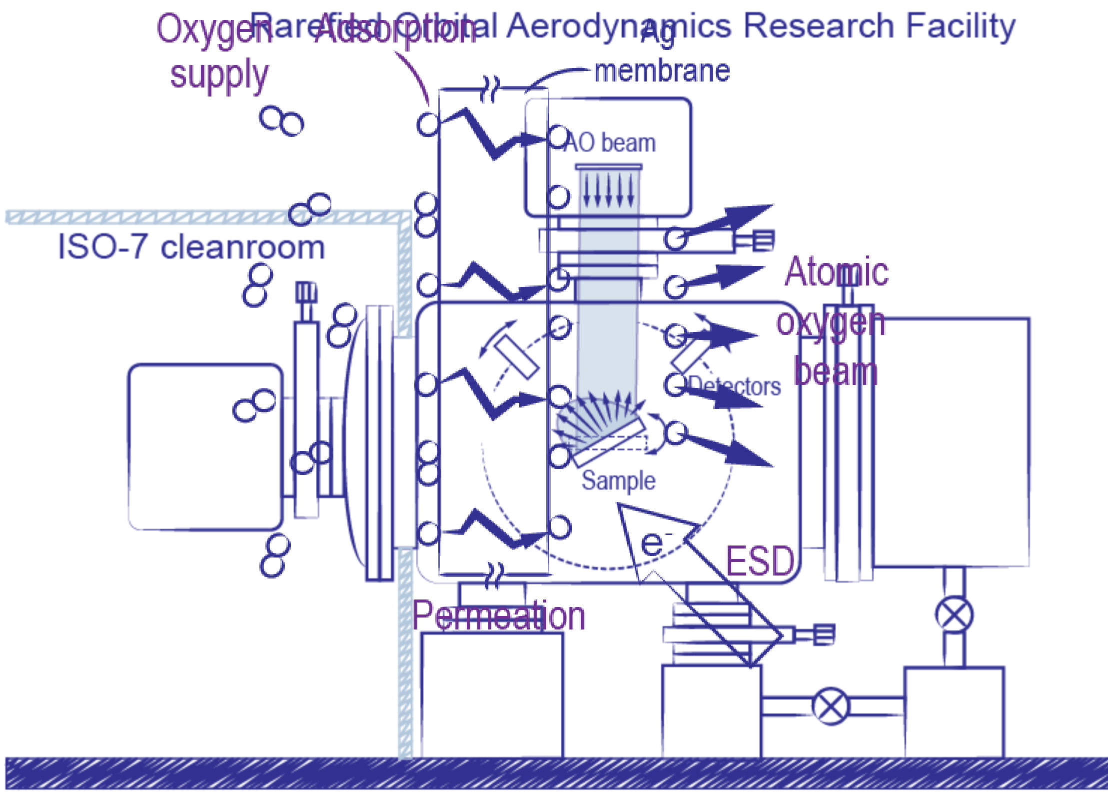
Rarefied Orbital Aerodynamics Research (ROAR) Facility

- Reproduces the most reactive component of the atmospheric flow in VLEO, atomic oxygen, at orbital velocity
- Utilises electron stimulated desorption of atomic oxygen from a thin silver membrane to produce atomic oxygen
- Free molecular flow environment – limiting impingement from residual gas in a vacuum chamber during operation implies large pumping capability



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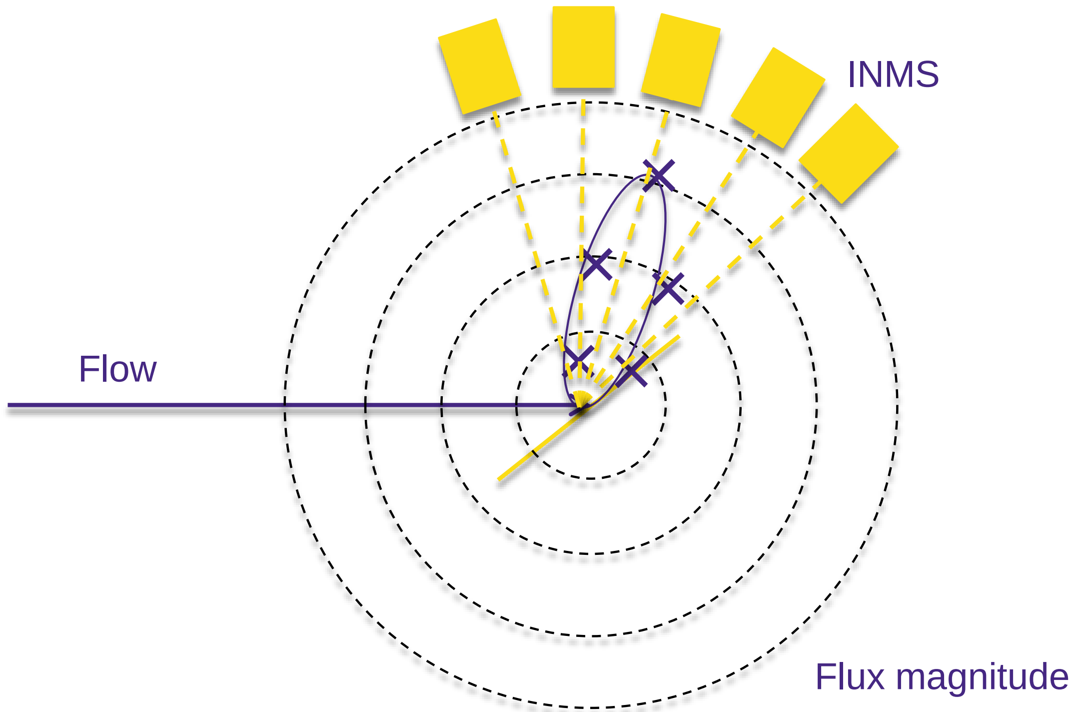
Rarefied Orbital Aerodynamics Research (ROAR) Facility

- Position controlled ion and neutral mass spectrometers for flow field characterisation
- Able to determine flux, velocity, composition and angular distribution of specularly reemitted flow
- Allow GSI to be characterised for materials
- Currently in build phase



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Rarefied Orbital Aerodynamics Research (ROAR) Facility

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Satellite for Orbital Aerodynamics Research (SOAR)

- Primary aim: To validate aerodynamic materials performance in the real VLEO environment
- Secondary aim: To validate aerodynamic manoeuvres
- Payloads:
  - Ion and neutral mass spectrometer – flow velocity, density, temperature and composition
  - Steerable fins – materials exposure and aerodynamic control
- Due for launch in August 2020

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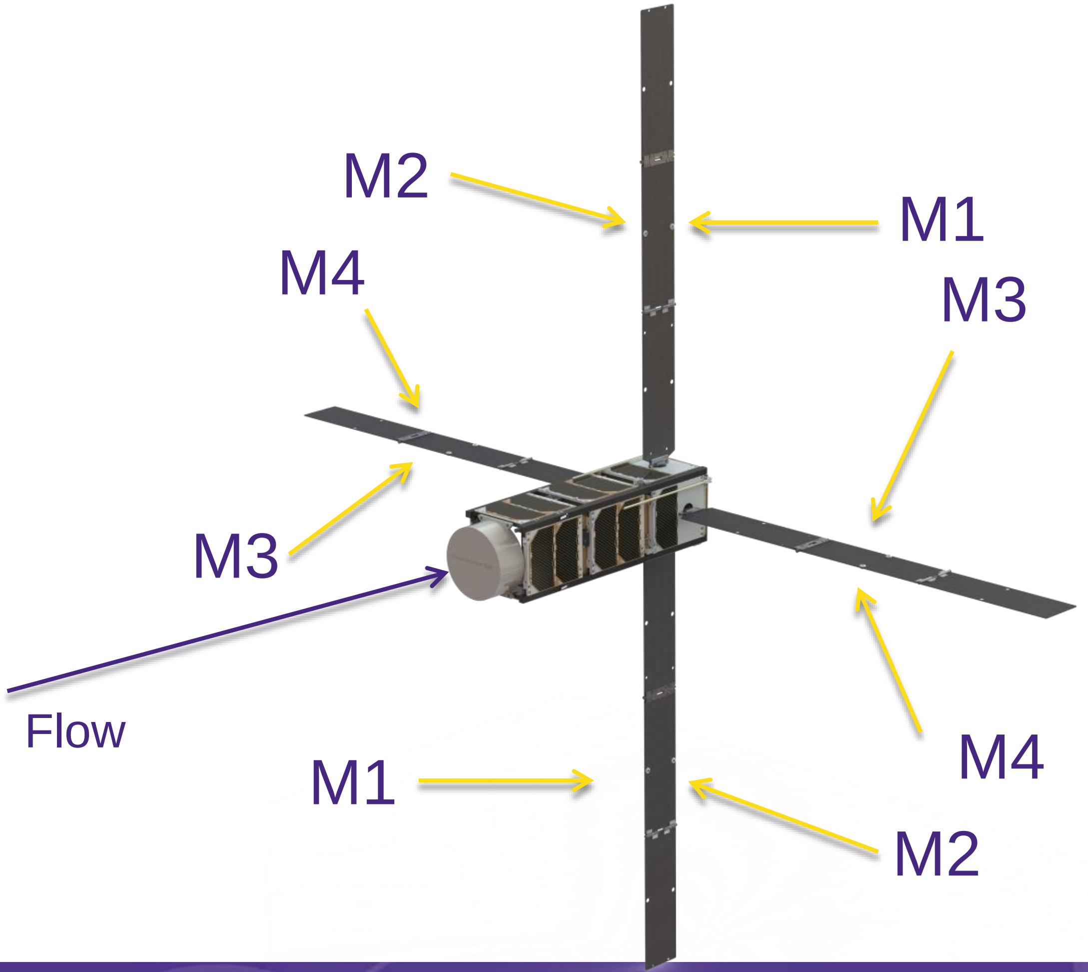
SOAR Experimental Method

Simplified Experimental Method:

- Sides of fins coated with different candidate materials
- Turning opposing fins at the same incidence angle to the flow induces:
  - Additional drag – changes orbital parameters as measured by the GPS
  - Attitude changes – measured by ADCS
    - Counter rotated produces roll torque
    - Co rotated produce pitch or yaw
- Combined data gives lift to drag of materials at different angles of incidence
- Validation against ROAR data/measured GSIs



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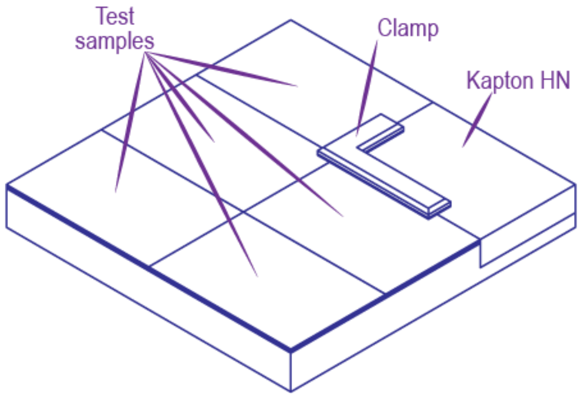
Materials International Space Station Experiment

- Exposing candidate materials to the full space environment
- Launched and returned for full post flight analysis allowing comparison with samples exposed in ROAR.
- Launched 2 November 2019 on NG-12 (Antares/Cygnus to the International Space Station)
- Deployed on MISSE Flight Facility awaiting exposure



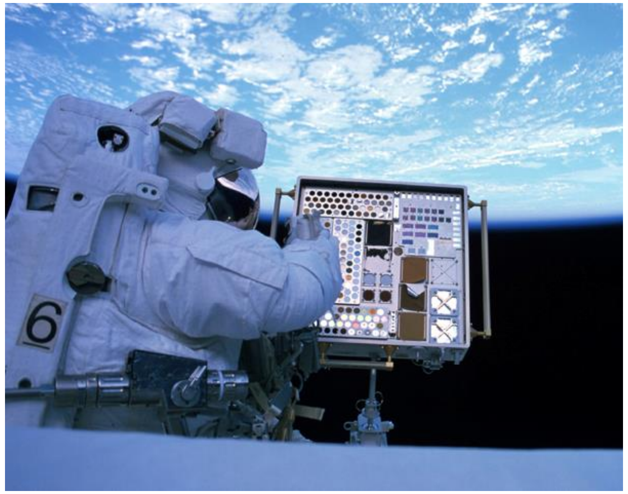


Image credit: NASA

Alpha Space owns and operates the MISSE facility under agreements with NASA and the Center for the Advancement of Science in Space (CASIS)

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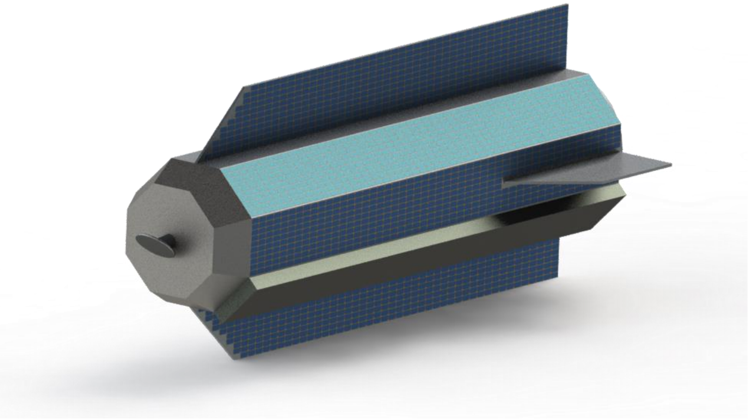
Aerodynamic Attitude and Orbit Control

- Minimising drag typically achieved by minimising the cross-section to the flow
- Leads to aerostable designs

- What does aerostable mean?
  - Atmospheric co-rotation
  - Thermospheric winds up to ~500 m/s
  - Density variations
  - Insignificant aerodynamic damping
  - .. all lead to disturbed pointing

- Requirements for Earth observation
  - Stable pointing during imaging operations
  - Accurate slewing to point to targets of opportunity
    - Body fixed payloads need turn away from the flow
    - .. leads to momentum build up in wheels



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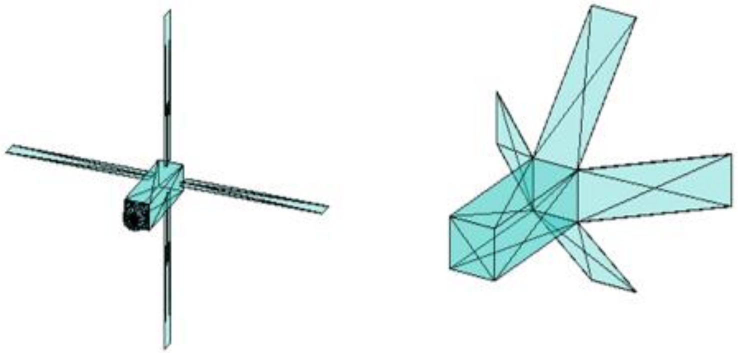
Aerodynamic Attitude Control Concepts

Attitude concept	Application
Fixed aerostable	Optical coverage, simple SAR, communications
Aerostable with control (active aerodynamics)	High resolution optical, SAR
Neutrally stable (with or without aerodynamic surfaces)	High agility platforms

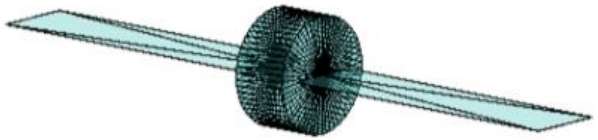
Aerostable



Neutrally Stable

Sphere?

Cylinder?



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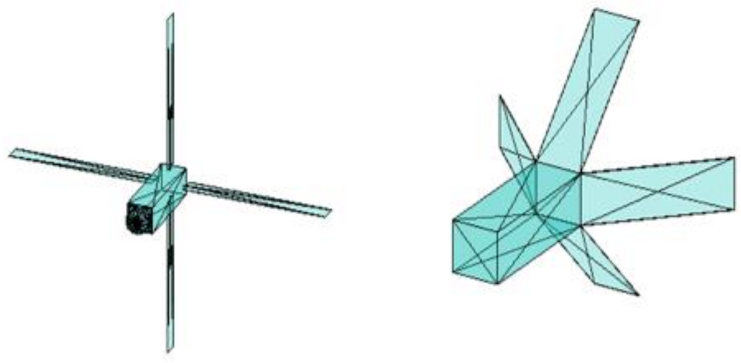
Aerodynamic Attitude Control Approaches

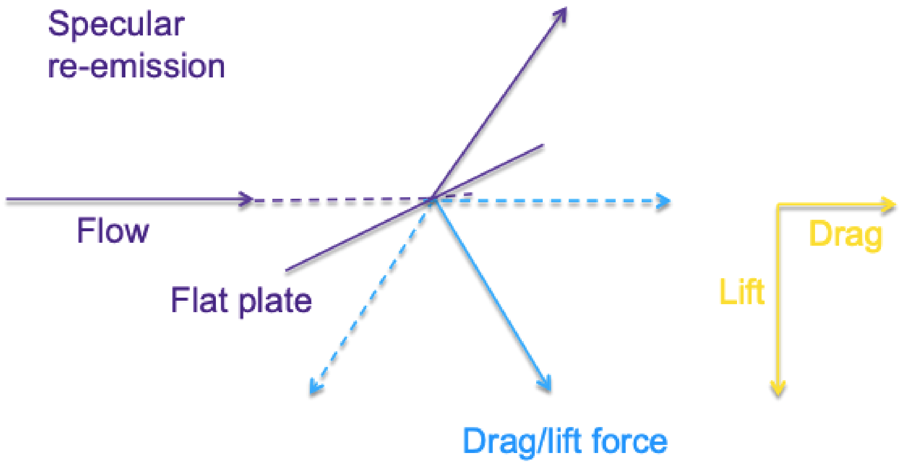


Reaction wheels still the best for fine pointing

- Aerodynamic surfaces for coarse pointing control
  - Aerodynamic trim in non-flow aligned orientations
    - Maintaining inertial pointing, pointing to targets of opportunity
  - Momentum management

Reflecting materials benefits:

- Reduced drag penalties associated with aerodynamic control
- Drag based ➔ Lift based
- Roll control becomes possible



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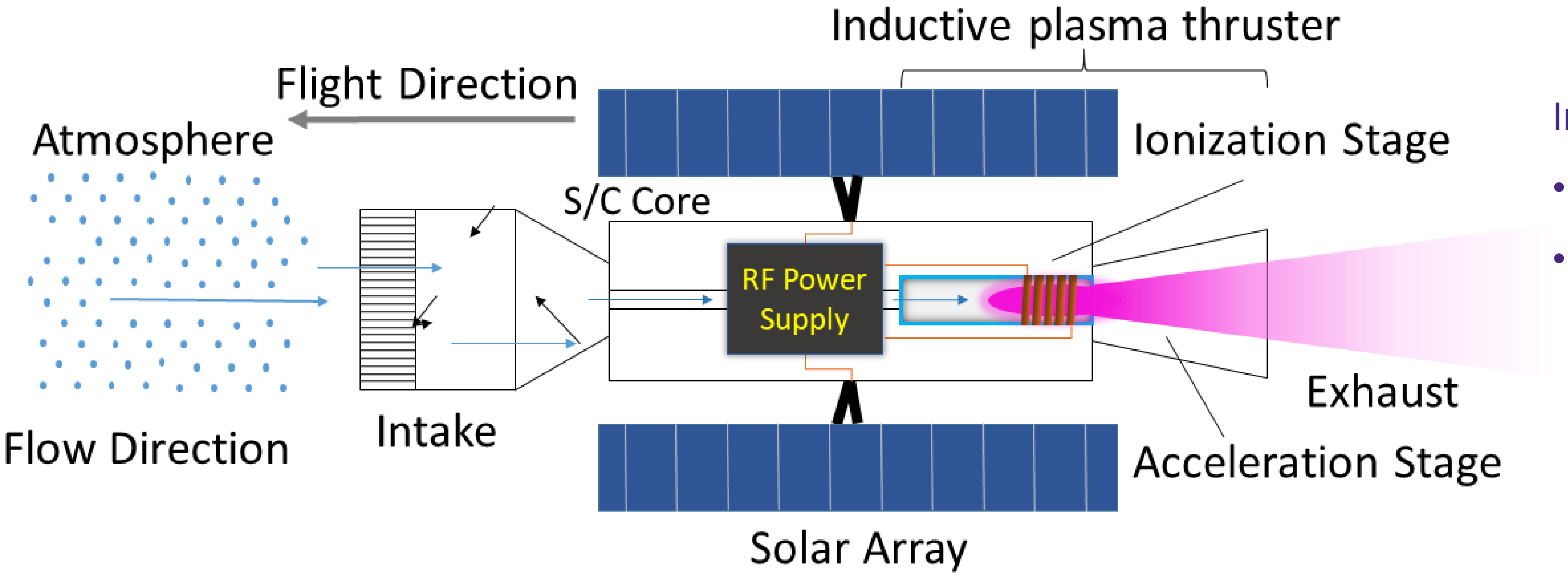
Atmosphere-Breathing Electric Propulsion (ABEP)

- Use of residual atmosphere as propellant for an electric thruster;
- **Intake** collects the atmosphere molecules and feeds the thruster;
- **Thruster** process and accelerate them for thrust generation: compensate the drag!



Inductive Plasma Thruster, IPT

- Electrode-less;
- Neutralizer free.

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Atmosphere-Breathing Electric Propulsion (ABEP)

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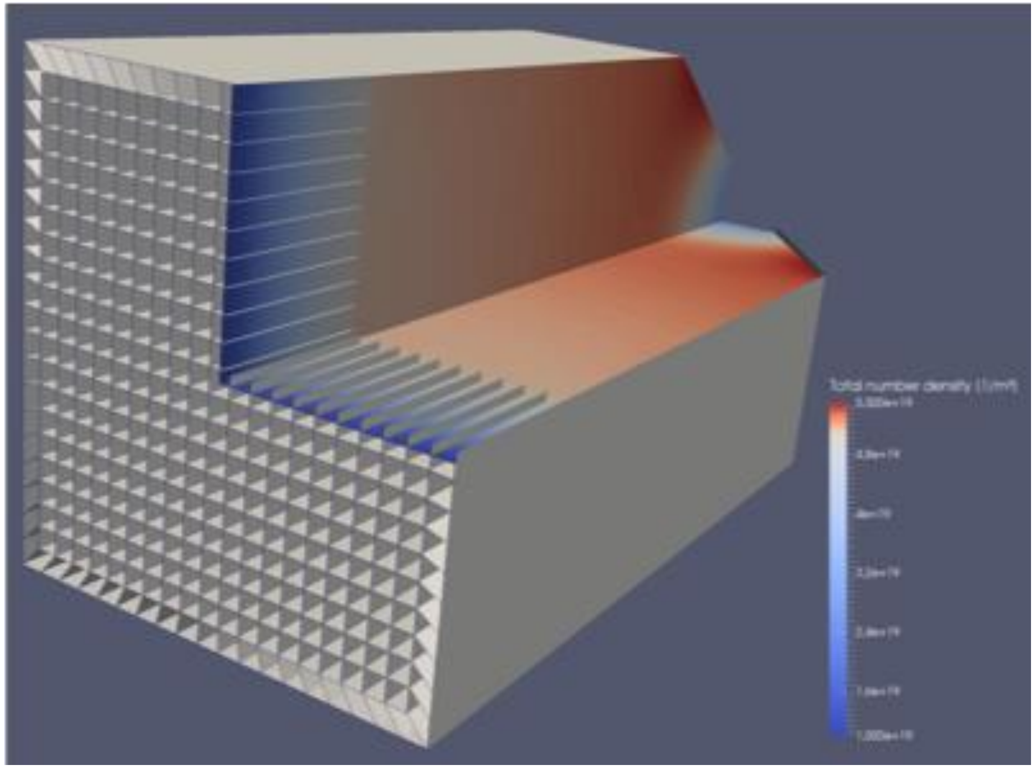
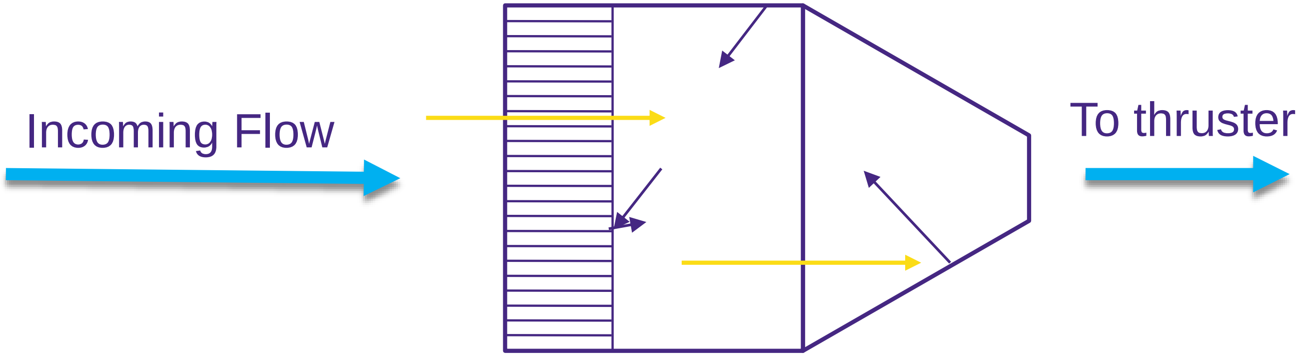
How do we collect the atmospheric particles?

EFD: Intake Advanced design, collection efficiency up to 45%, improvable.



- Let atmospheric particles into the intake;
- Trap them inside by a honey-comb structure of ducts in the front;
- Feed the thruster.



Trapping Principle

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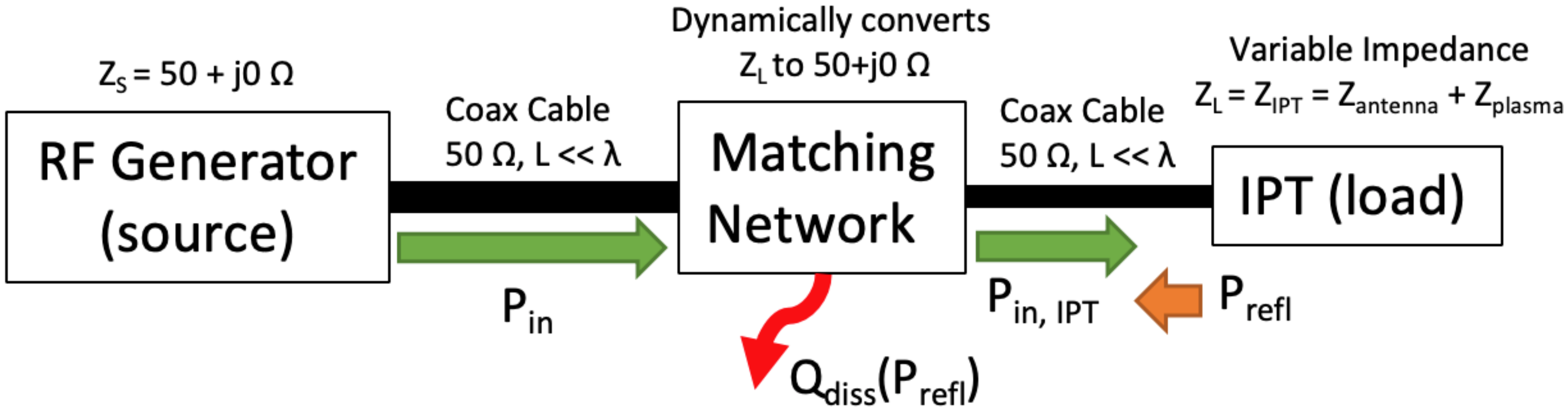
- P_{in} < 5 kW, ABEP variable mass flow, RF and contact-less → eliminate erosion issues;
- High exhaust velocity → EM acceleration → high ionization degree → helicon wave-based plasma;
- Our results → $f > 27.12\ MHz$ better for ignition at low pressure and high $n > 1 \times 10^{17} m^{-3}$;
- Started with a coil antenna → at high frequency high reactance X → high reflected power;
- Seek for antenna and whole RF circuit **optimization**.



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Atmosphere-Breathing Electric Propulsion (ABEP)

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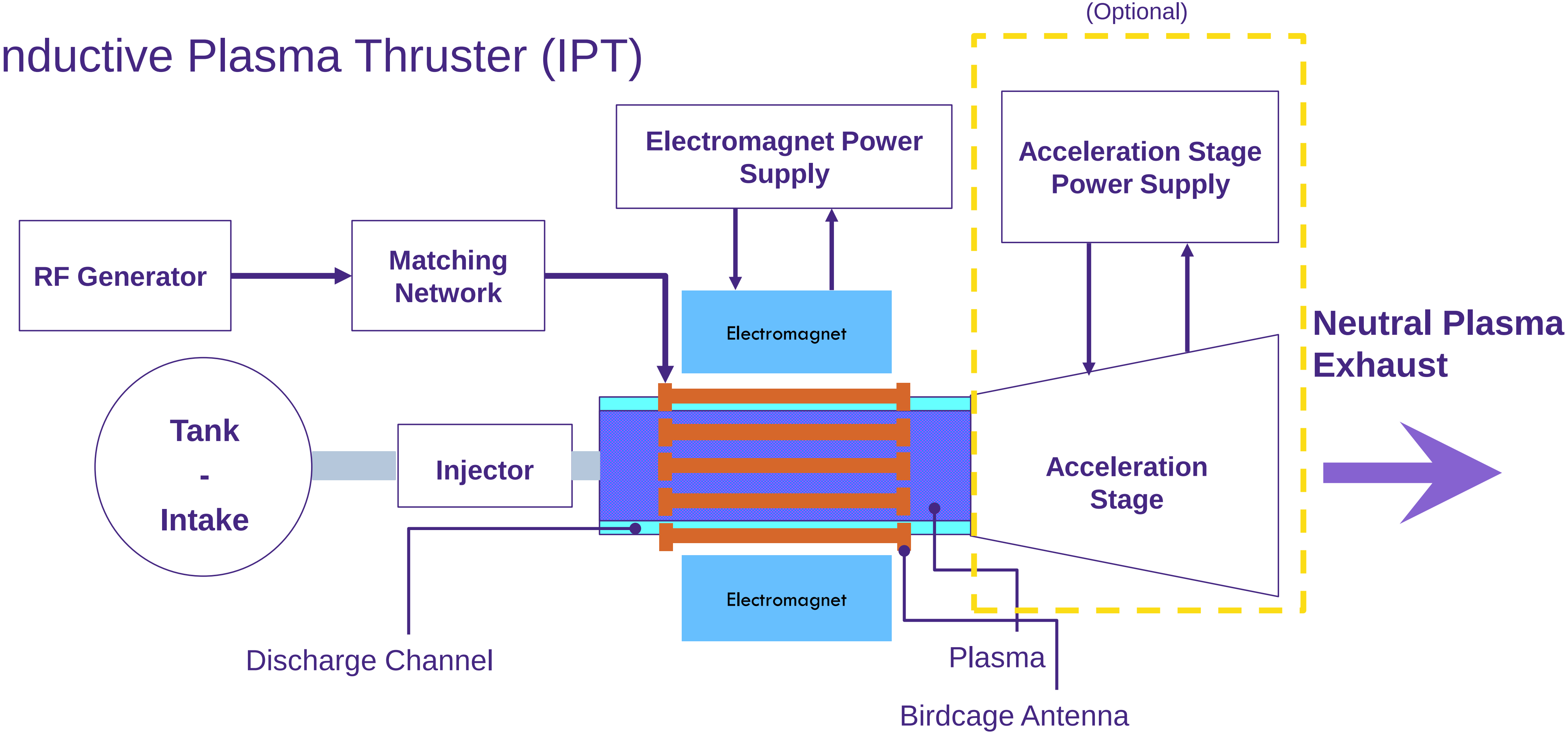
Inductive Plasma Thruster (IPT)



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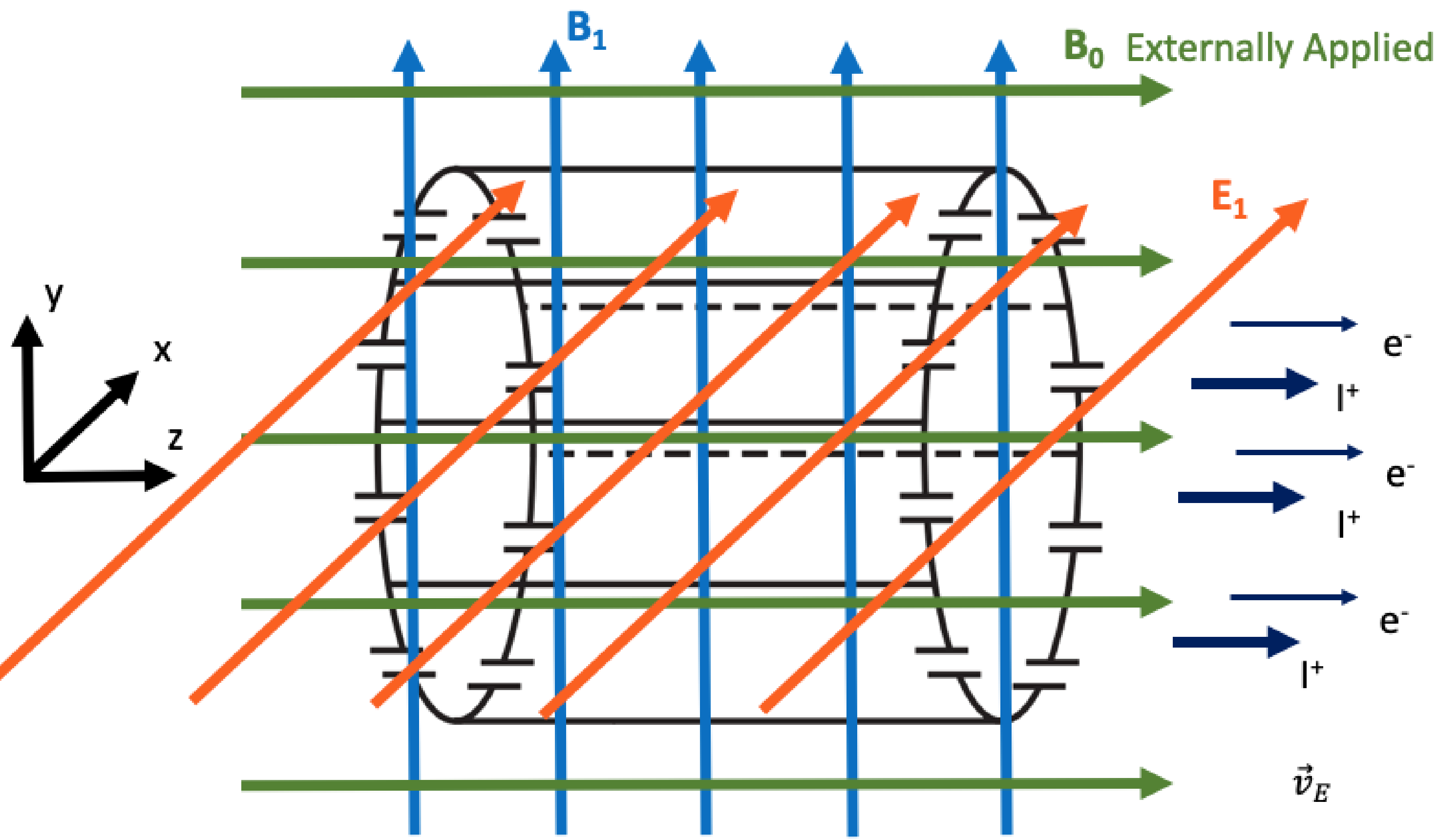
Atmosphere-Breathing Electric Propulsion (ABEP)

Birdcage antenna



- Heritage from MRI machines, operates at resonance frequency, X=0;
- Legs connected at bottom and top by end-rings, capacitors in between to match resonance condition;
- At the correct resonance mode, **E**x**B** field configuration: drift velocity for ions and electrons along same direction.

$$\vec{v}_E = \frac{1}{\vec{B}^2}\left\|\begin{matrix}\hat{x} & \hat{y} & \hat{z}\\ E_1 & 0 & 0\\ 0 & B_1 & B_0\end{matrix}\right\| = \frac{1}{{B_0}^2 + {B_1}^2}\begin{Bmatrix}0\\ -E_1 B_0\\ E_1 B_1\end{Bmatrix}$$

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Atmosphere-Breathing Electric Propulsion (ABEP)

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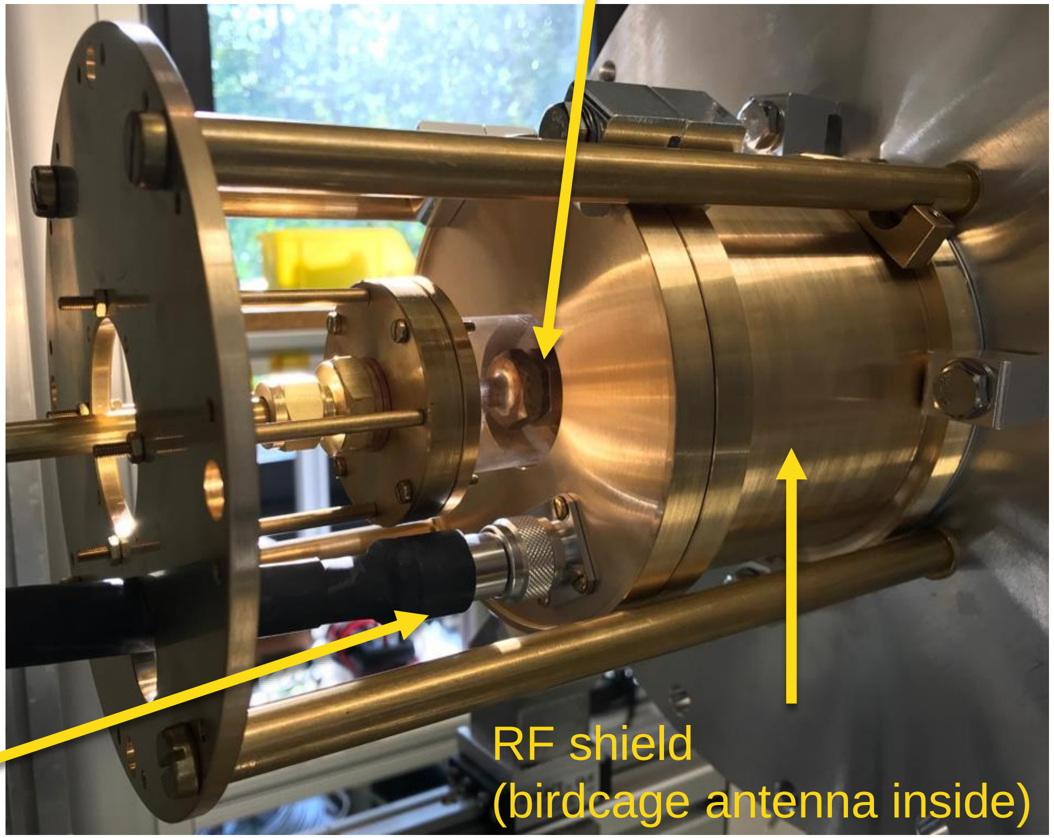
Inductive Plasma Thruster (IPT):

- Based on birdcage antenna and applied external magnetic field;
- Laboratory model P<1.5 kW, f=40.68 MHz;
- No neutralizer required;
- First ignition of prototype expected 2019.



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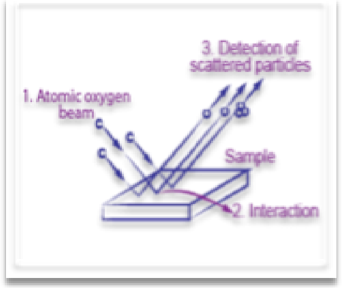
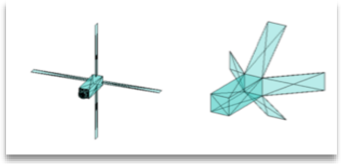
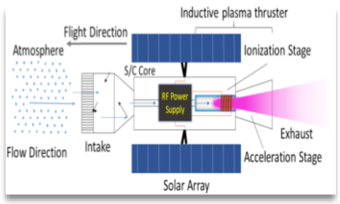
DISCOVERER Activities

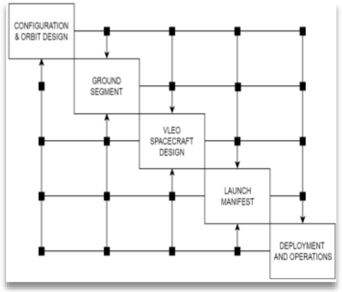


Materials


Aerodynamic Control

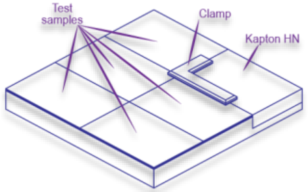


Atmosphere Breathing Electric Propulsion



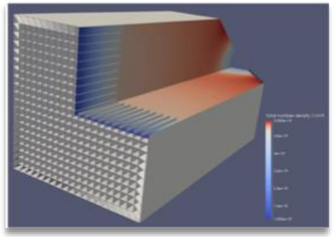
System and Business Modelling

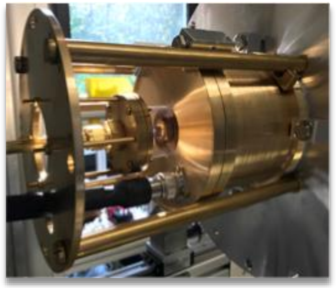

Rarefied Orbital Aerodynamics Research Facility (ROAR)



Materials on the International Space Station Experiment (MISSE)


Satellite for Orbital Aerodynamics Research (SOAR)


Atmospheric Intakes


RF based Inductive Plasma Thruster

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5.7 M€
Horizon 2020 project

8
partners

4¼
years duration

5
countries

For more information and news:

Web: DISCOVERER.space **Twitter: @DISCOVERER_EU**

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