Introduction to the PTetra workshop

Sigvald Marholm

University of Oslo
Department of Physics

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Outline

Orbital motion-limited (OML) theory

Case study

From beginning to end

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Orbital motion-limited (OML) theory

Energy and momentum conserving orbits.

Current due to attracted species s:

$$I_s = \underbrace{C \overbrace{A}^{\text{area}} q_s n_s \sqrt{\frac{kT_s}{2\pi m_s}}}_{I_{\mathrm{th,s}}} \Bigg(1 - \underbrace{\frac{q_s V}{kT_s}}_{\eta_s}\Bigg)^{\beta}$$

Current due to repelled species s:

$$I_s = I_{\mathrm{th},s} \exp\left(\frac{q_s V}{kT_s}\right)$$

Mott-smith and Langmuir, DOI: 10.1103/PhysRev.28.727

	Plane	Cylinder	Sphere
C	1	$2/\sqrt{\pi}$	1
β	0	0.5	1

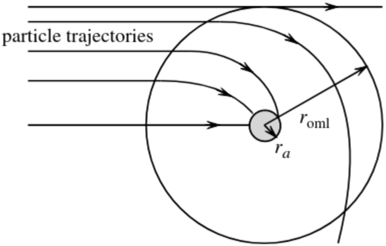

Figure: Orbital motions (From Bilén, PhD thesis, 1998)

Orbital motion-limited (OML) theory

Energy and momentum conserving orbits.

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Assumptions to OML theory:

- Radius $r \ll \lambda_{De}$
- Length $l \gg \lambda_{De}$ (for cylinders)
- $\eta_s > 2$ (for cylinders)
- No drift velocity
- No magnetic field

Mott-smith and Langmuir, DOI: 10.1103/PhysRev.28.727

Orbital motion-limited (OML) theory

Langmuir probes:

Vary V, measure I, infer e.g. n_e.

E.g. Jacobsen *et al.*, DOI: 10.1088/0957-0233/21/8/085902

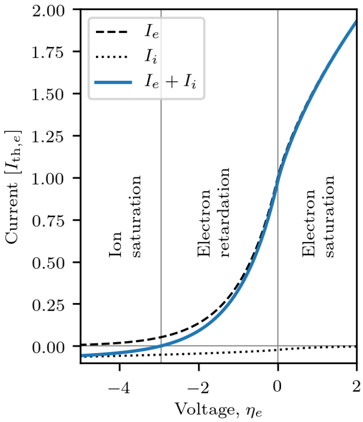

Figure: OML IV-charactersitic for cylinder. (From Marholm, PhD thesis)

Orbital motion-limited (OML) theory

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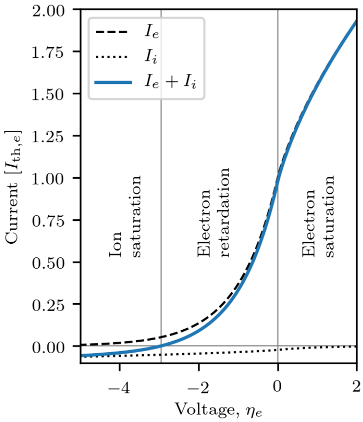
Unconnected objects (spacecraft, dust, etc.) in plasma settle at the *floating potential*:

$$V = \text{const} \Rightarrow I_e + I_i = C\frac{\mathrm{d}V}{\mathrm{d}t} = 0$$



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Spaceborn probes are biased wrt. the spacecraft, and the probe current also charge the spacecraft!

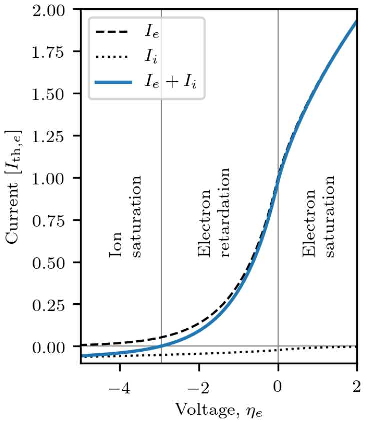

Figure: OML IV-charactersitic for cylinder. (From Marholm, PhD thesis)

Outline

Case study

- Each team given an object
- Simulate the object
  - at 1V
  - at 2V
  - at 3V
  - split at 1V and 3V
  - at the floating potential

at *ionospheric conditions*

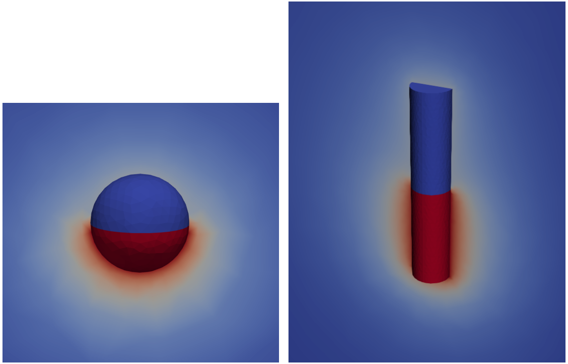

Figure: A spherical and cylindrical object where the two halves are biased at different voltages, along with the surrounding electric potential.

Ionospheric conditions

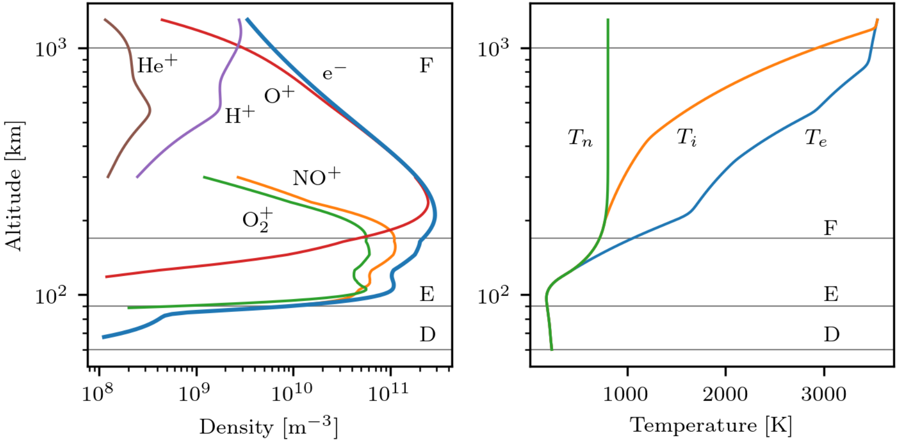

Figure: IRI-2016 model of the ionosphere, $45^\circ N$ local noon. (From Marholm, PhD thesis)

Ionospheric conditions

Parameters for low Earth orbit simulations:

- $n_e = n_i = 10^{11}\,\mathrm{m}^{-3}$
- $T_e = T_i = 1000\,\mathrm{K} = 0.0862\,\mathrm{eV}$
- $m_i = 16\,\mathrm{amu} \quad (O^+)$
- $u = 7000\,\mathrm{m/s}$ (drift speed)

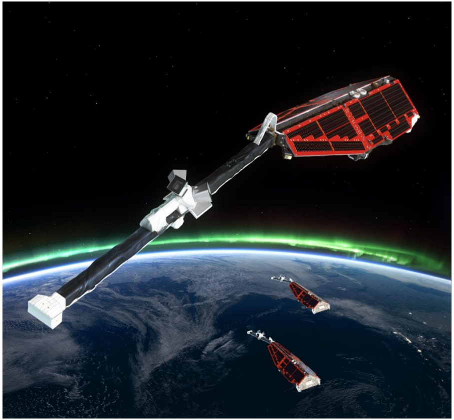

Figure: The Swarm satellites ESA/AOES Medialab

Ionospheric conditions

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- $n_e = n_i = 10^{11}\,\mathrm{m}^{-3}$
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- $m_i = \cancel{16\,\mathrm{amu}} \to 1/16\,\mathrm{amu} \gg m_e$ (speed up sim.)
- $u = 7000\,\mathrm{m/s}$ (drift speed)

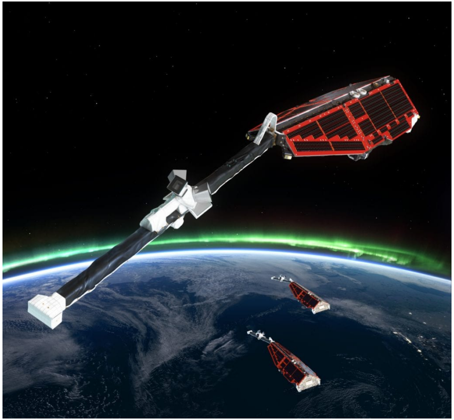

Figure: The Swarm satellites ESA/AOES Medialab

Reduced mass ratio

Reduced m_i/m_e...

- Speeds up simulations ($\tau \propto \sqrt{m_i}$)
- Changes the physics, e.g.:
  - increases ion current (see OML)
  - the mach cone half-angle

$$\theta = \arcsin\left(\frac{1}{M}\right), \quad M = \frac{u}{c_s},$$

where c_s is sound speed

$$c_s = \sqrt{\frac{kT_e + 3kT_i}{m_i}}.$$

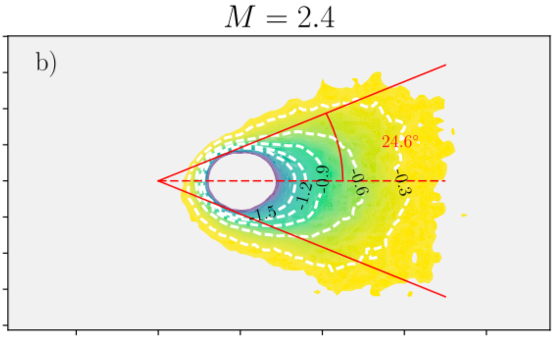

Figure: Mach cone superimposed on numerical simulation of rocket wake. (From Darian *et al.*, DOI: 10.1002/2017JA024284)

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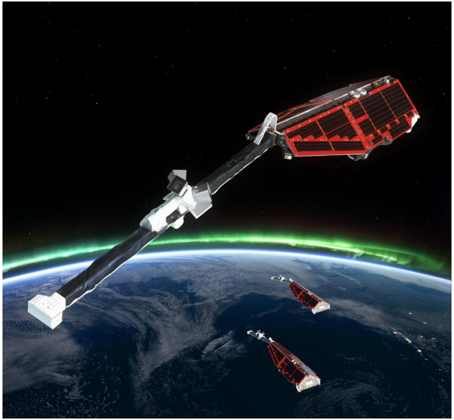

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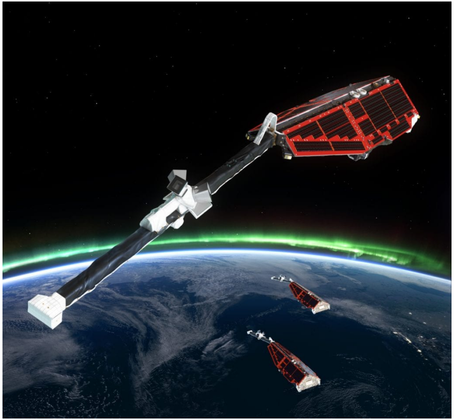
Parameters for low Earth orbit simulations:

- $n_e = n_i = 10^{11}\,\mathrm{m}^{-3}$
- $T_e = T_i = 1000\,\mathrm{K} = 0.0862\,\mathrm{eV}$
- $m_i = \cancel{16\,\mathrm{amu}} \rightarrow 1/16\,\mathrm{amu} \gg m_e$ (speed up sim.)
- $u = \cancel{7000\,\mathrm{m/s}} \rightarrow 112000\,\mathrm{m/s}$
  (maintain correct wake dynamics)



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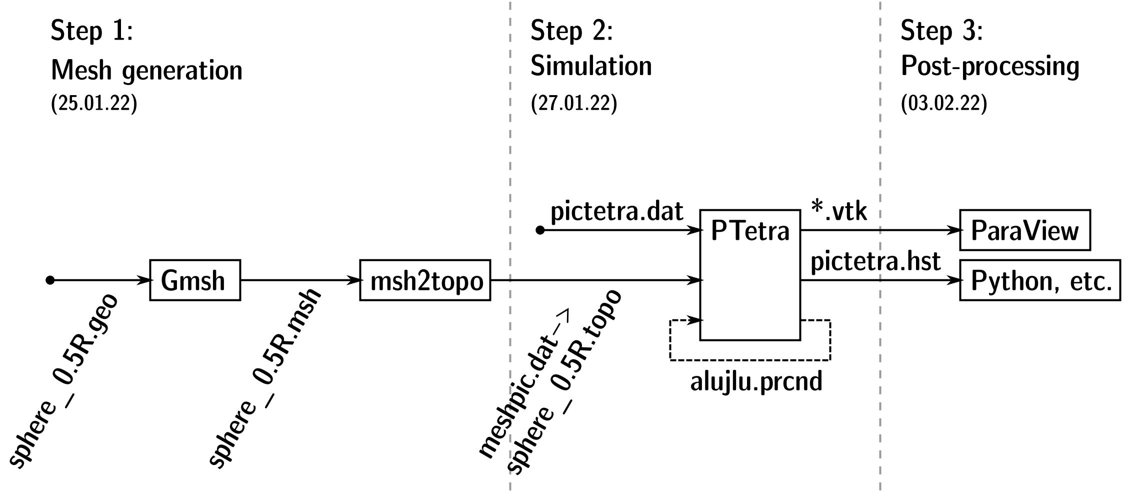

Naming conventions

```
PTetraWorkshop
├── Geometry
│   ├── sphere_0.5R.geo
│   ├── sphere_0.5R.msh
│   ├── sphere_0.5R.topo
│   ├── sphere_0.5R.alujlu.prcnd
│   ├── msh2topo → ../msh2topo/msh2topo
│   └── msh2topo.dat
└── Sphere_0.5R_3V_3V
    ├── alujlu.prcnd → ../Geometry/sphere_0.5R.alujlu.prcnd
    ├── mptetra → ../MPI_V50i/mptetra
    ├── meshpic.dat → ../Geometry/sphere_0.5R.topo
    ├── pictetra.dat
    ├── pictetra.hst
    └── *.vtk
```

Geometry names:

sphere_0.5R.geo
- sphere: shape
- 0.5R: radius in Debye lengths

cylinder_0.2R_10L.geo
- 10L: length in Debye lengths

Simulation folder names:

Sphere_0.5R_1V_3V_112kms/
- Sphere_0.5R: same as geometry
- 1V_3V: voltages of the two halves
- 112kms: drift speed

Sphere_0.5R_FV_112kms/
- FV: floating voltage