



Micro**A**RES

Plasma simulations with SPIS

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On Earth



Pan

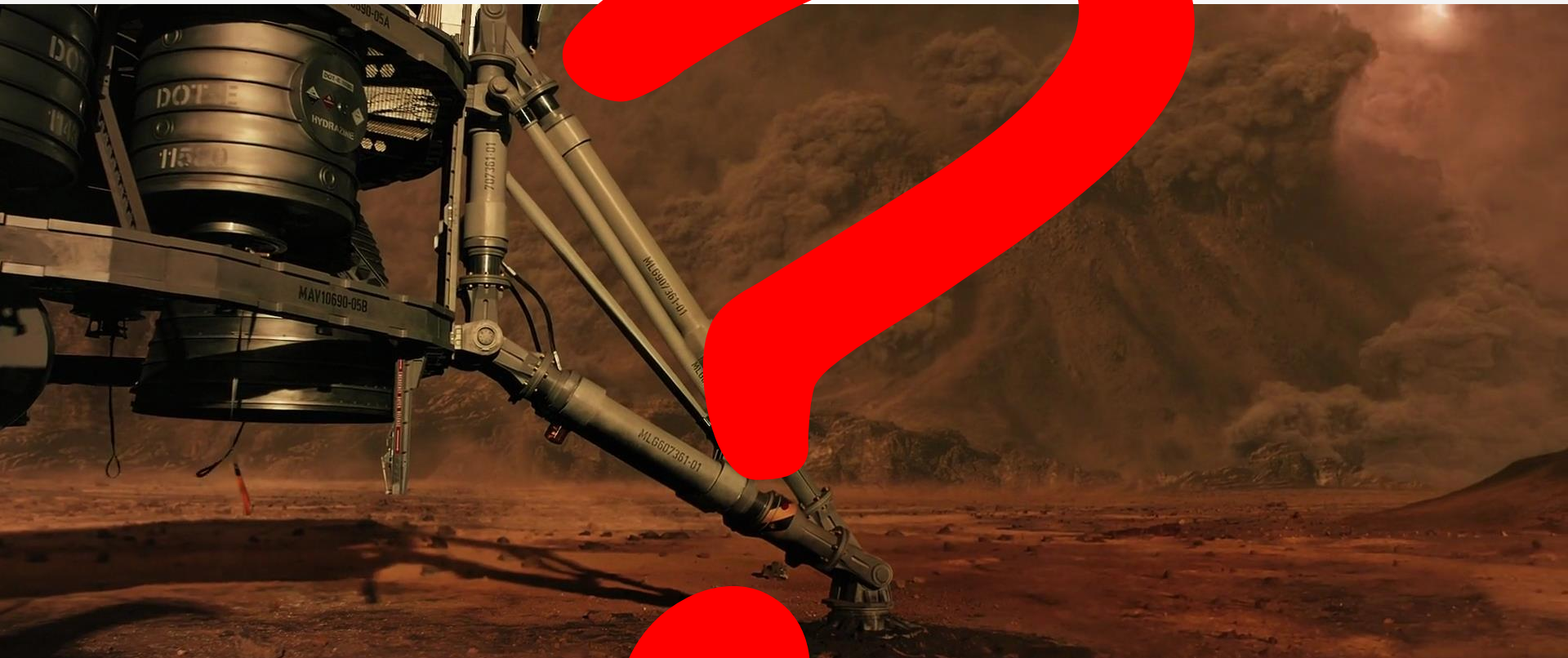


Stefnison



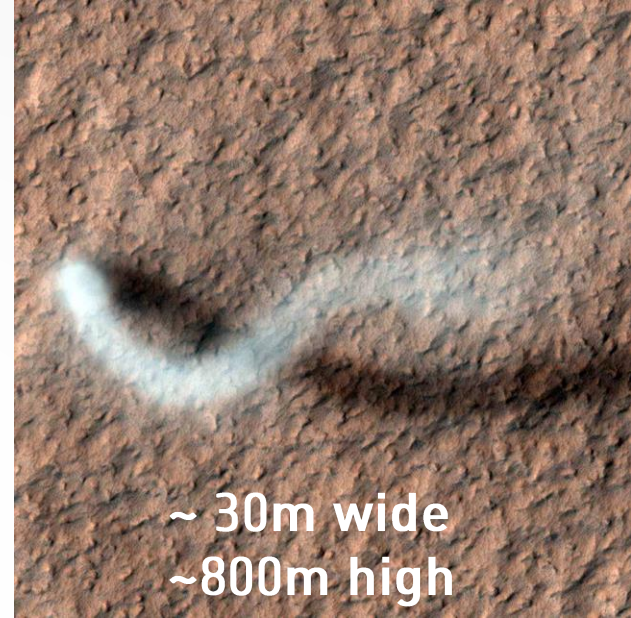
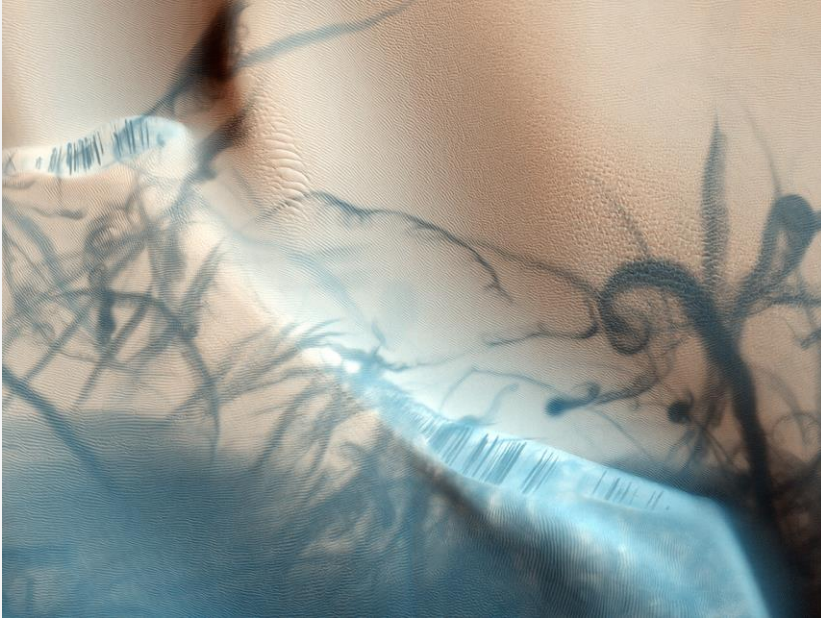
Delory 2006

On Mars ?



Martian dust events

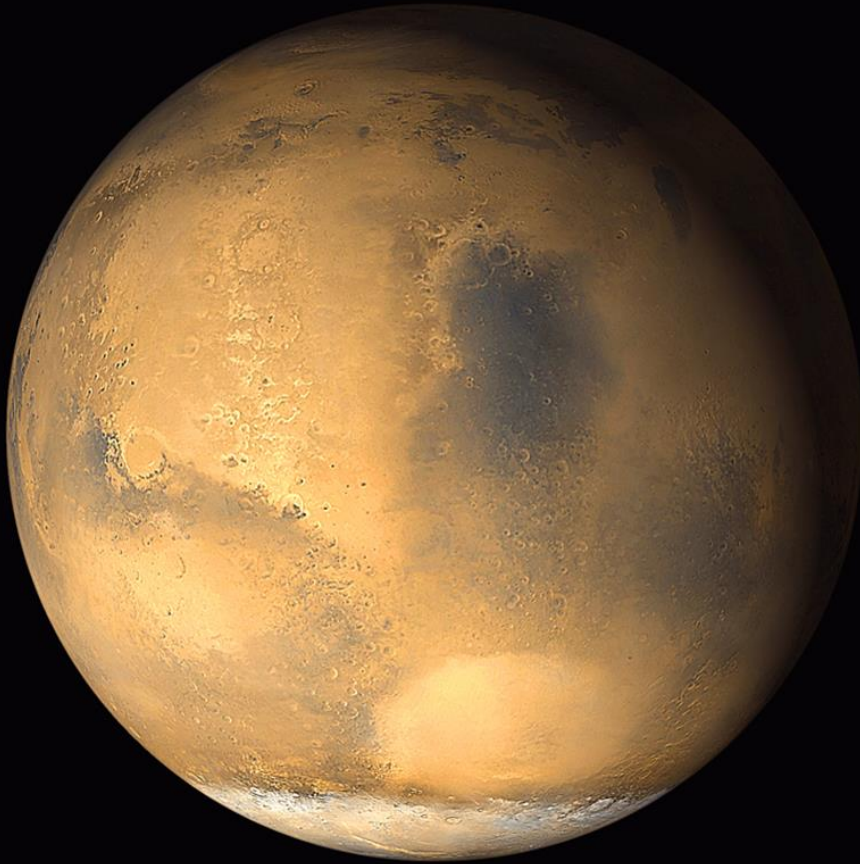
4



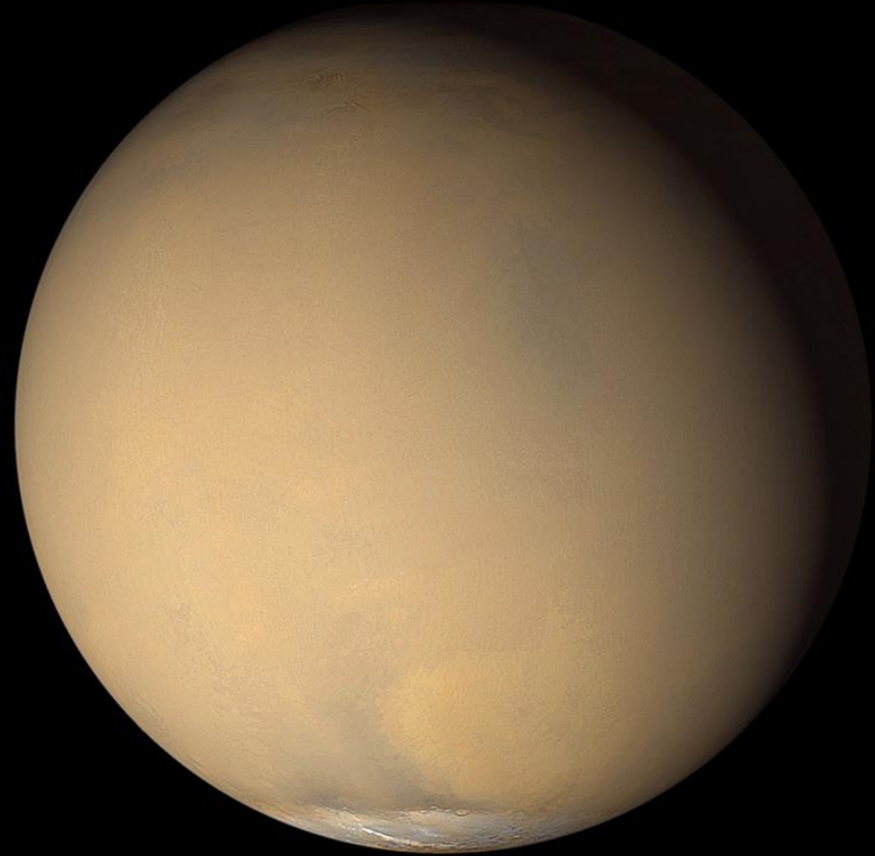
Martian dust events

5

June 2001



July 2001

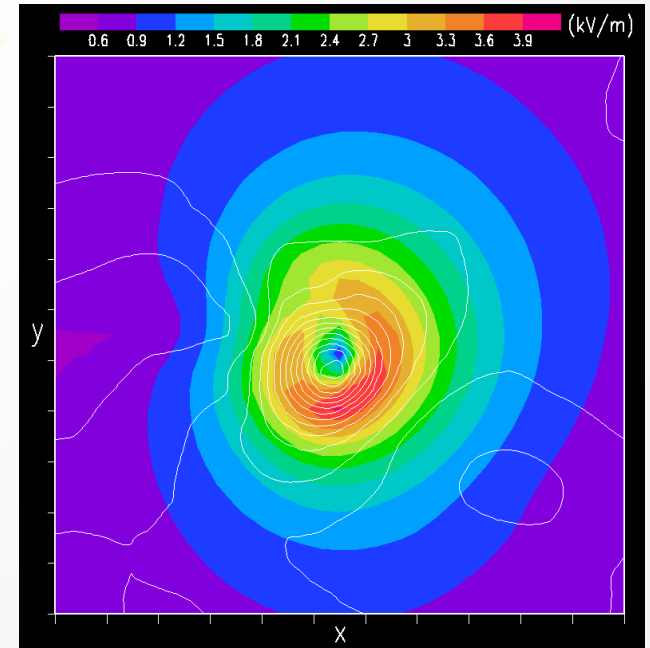
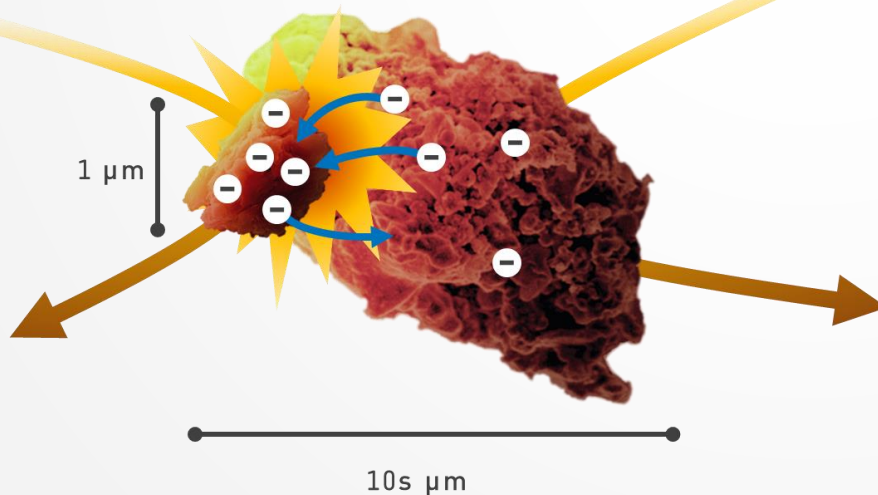
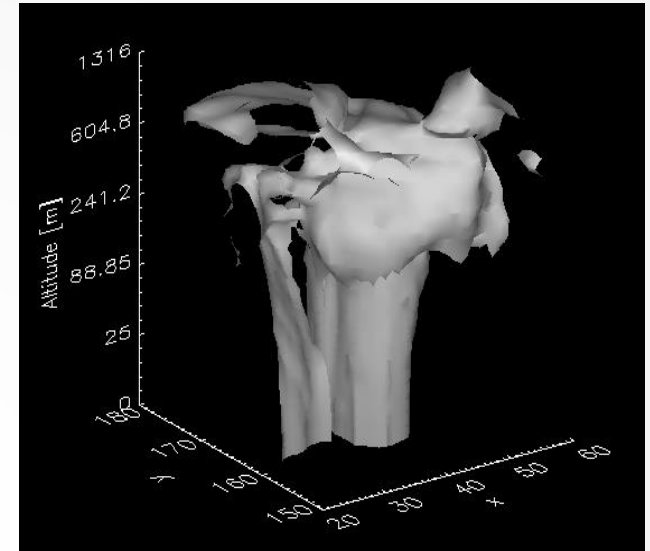


NASA / JPL-Caltech

The generator: triboelectricity

6

- ▶ **Charging** depending on
 - ▶ Grain **size**
 - ▶ Grain **composition**
- ▶ **Photo-detachment**
- ▶ **Attachement with ions and electrons**

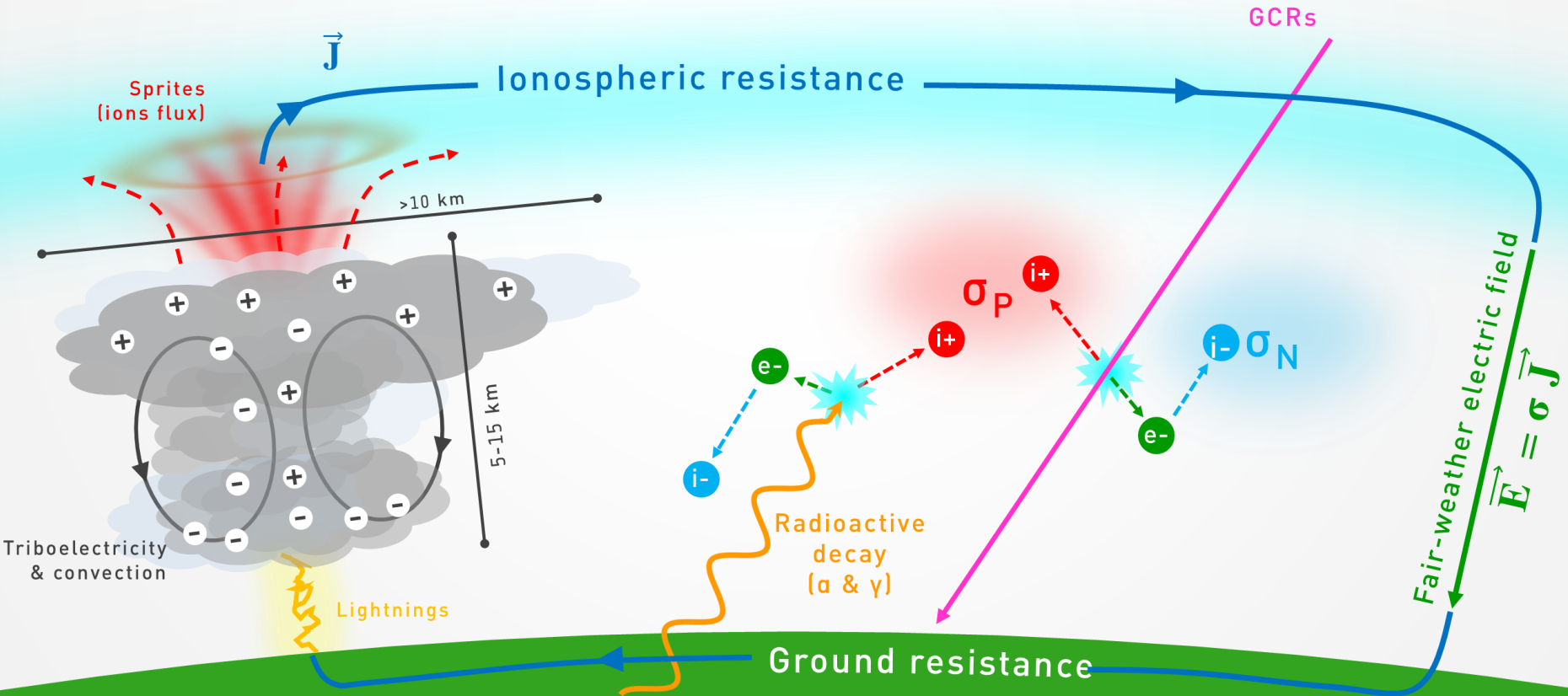


Barth & Rafkin

The global circuit on Earth

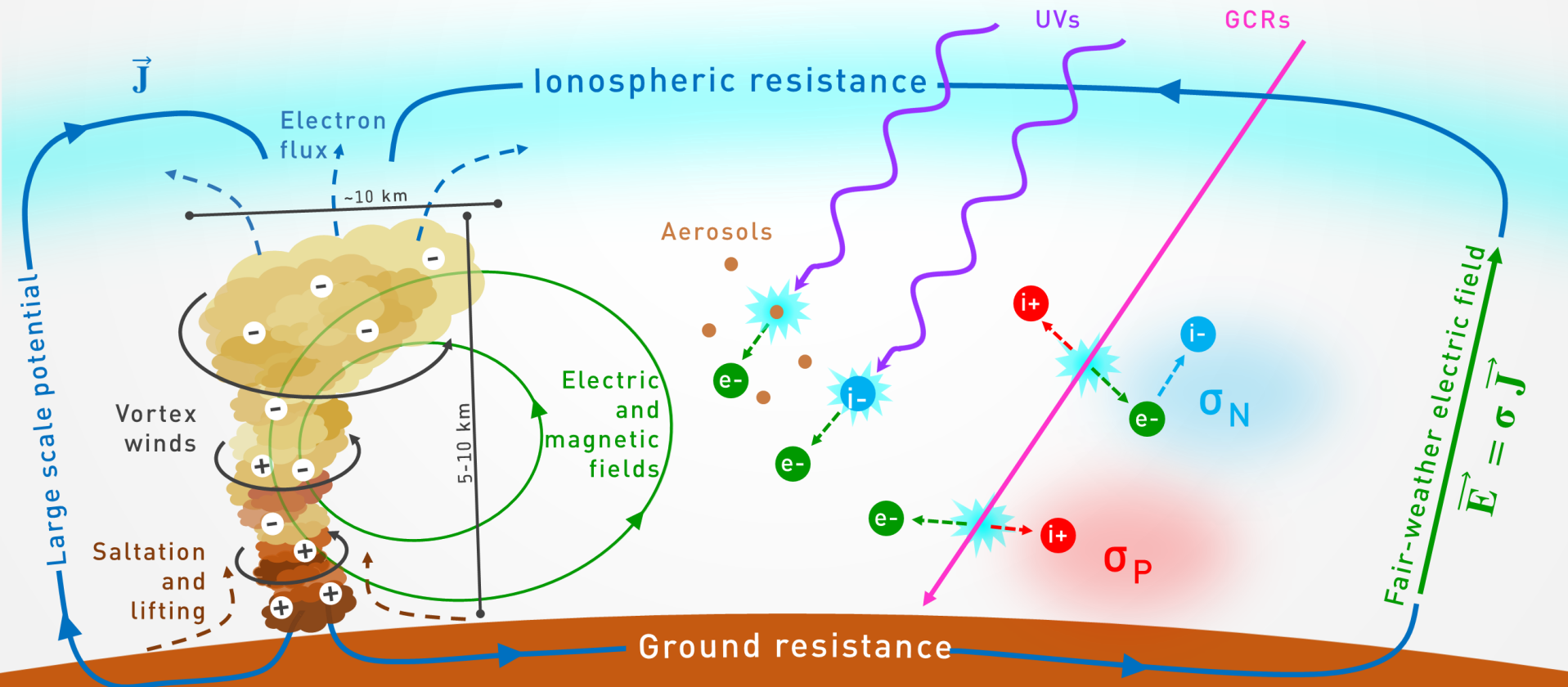
► Constant thunderstorm **current**

► **Fair weather** electric field $\sim -150\text{V/m}$
► Fair weather **current** $\sim 2\text{pA/m}^2$ } **Conductivity**



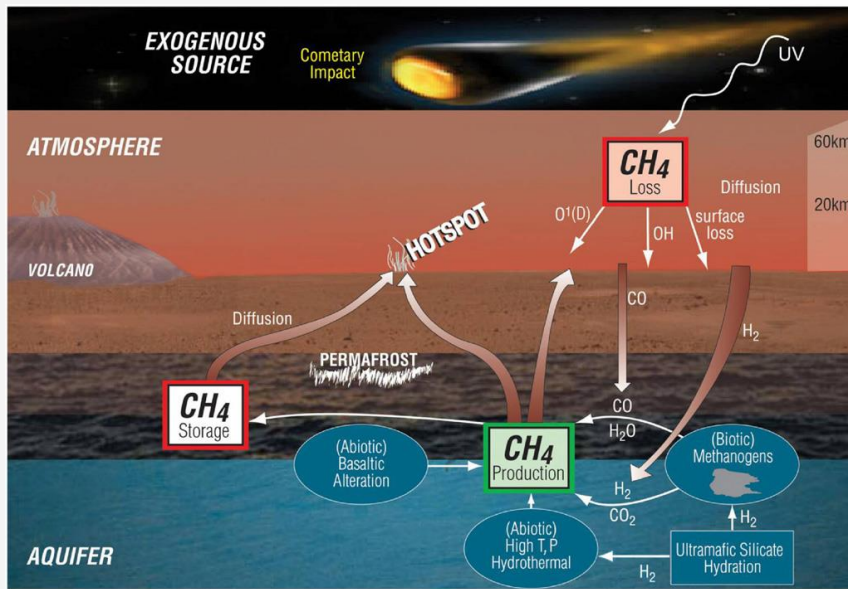
A Martian global circuit ???

- ▶ More **variability**
 - ▶ 500 V/m with a **regional/global dust storm**
 - ▶ 0,1 V/m with only **dust devils** (Aplin 2006)
- ▶ **Global** measurement for a **local** value

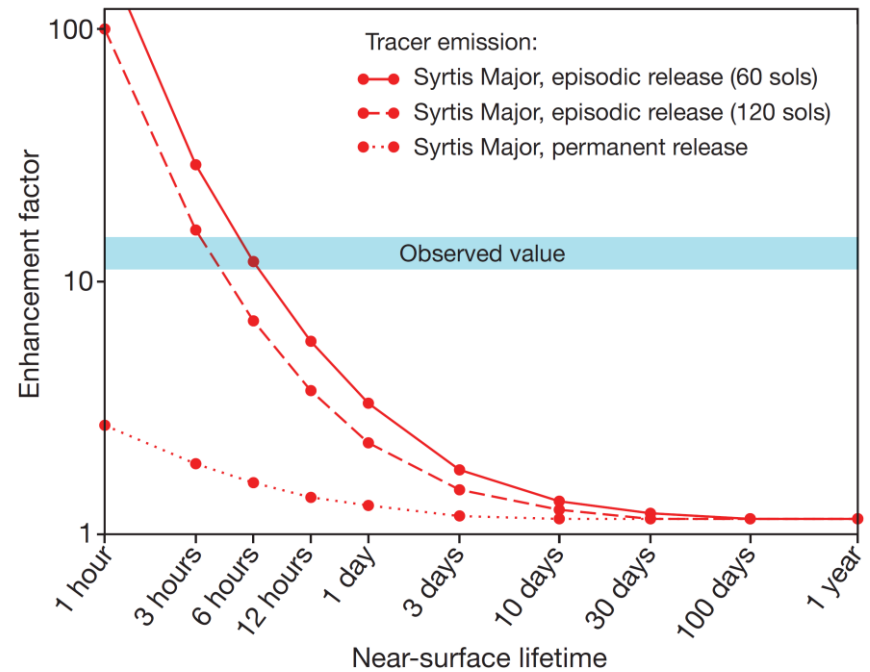


Life on Mars?

► UV dissociation > short **methane** lifetime



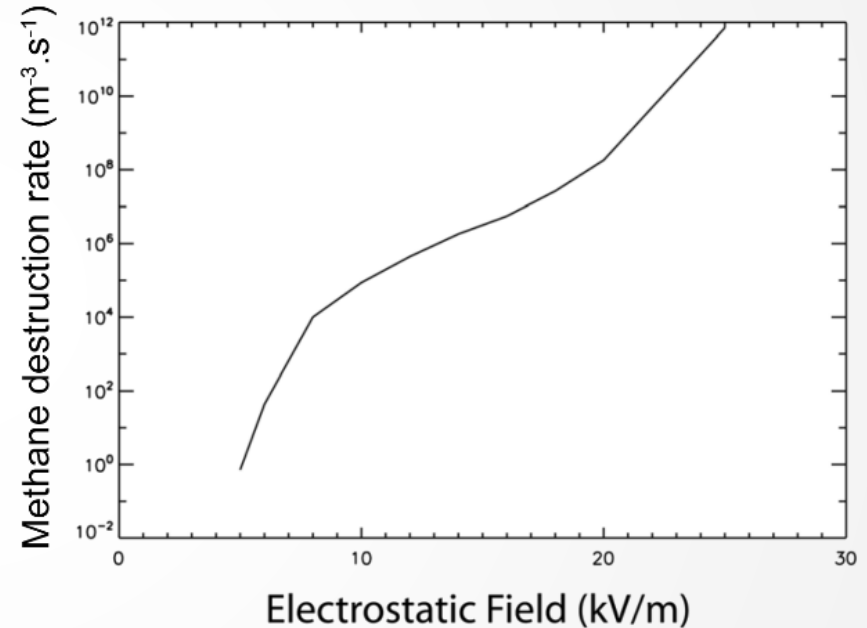
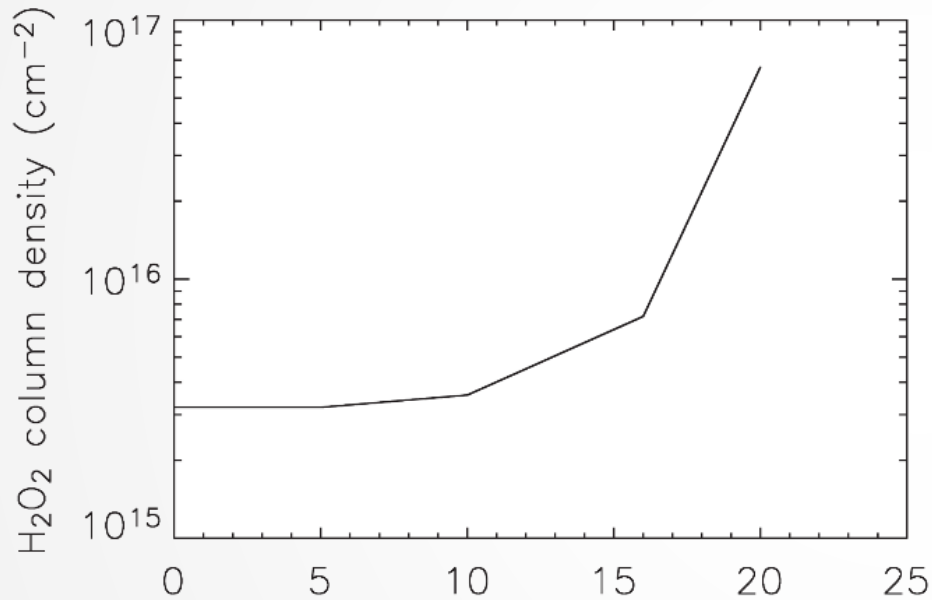
Atreya 2007



Lefèvre & Forget 2009

Electric fields and oxidants species

- ▶ Large **e-fields** > energized **electrons** > **oxidants** species > **organics** removal



Atreya & Delory 2006

Generator :
thunderstorms

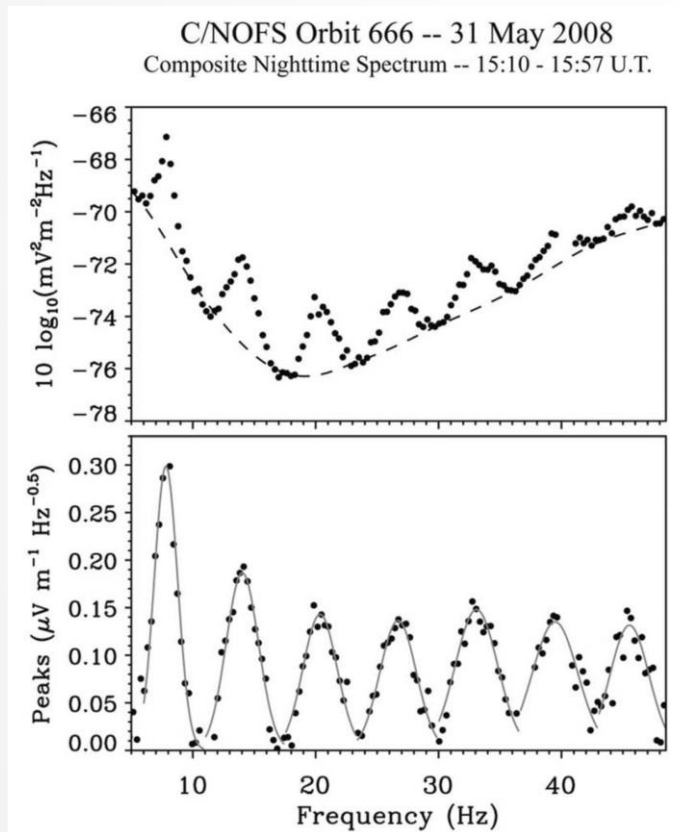
Low σ_{atm} &
~symmetric
ionosphere :
resonance
maintained



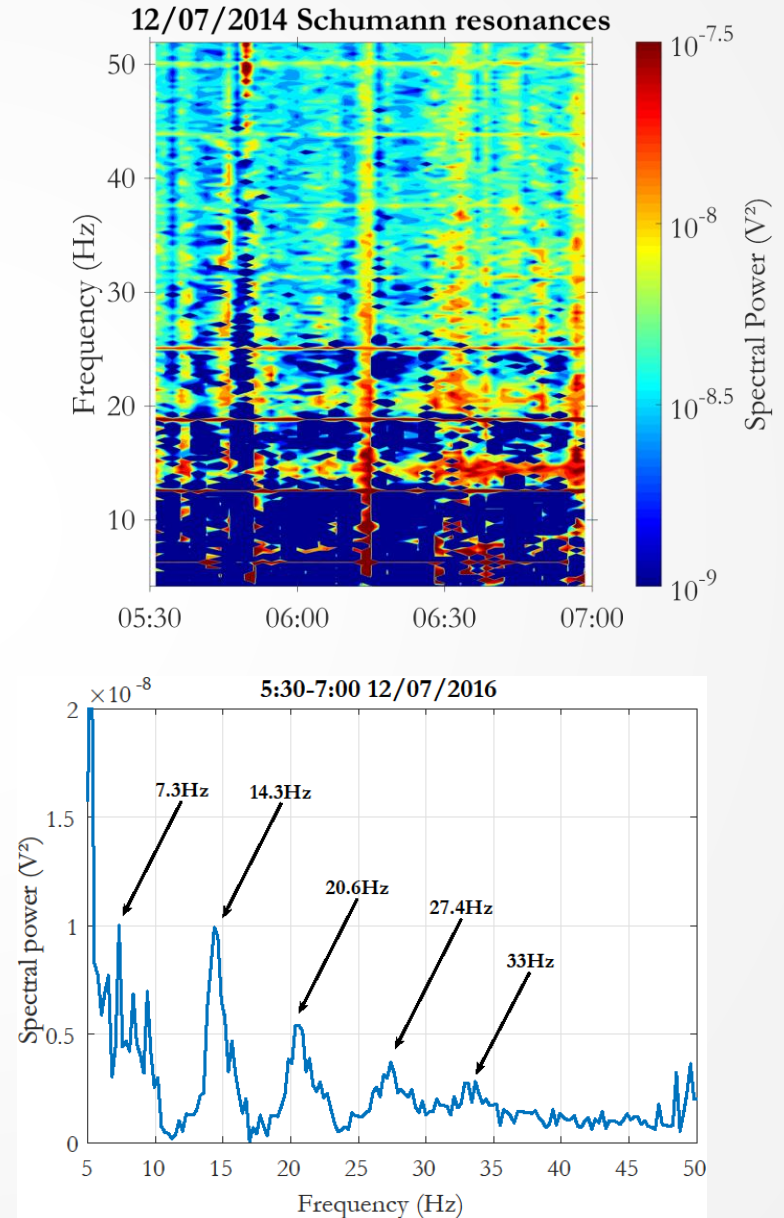
$$f_n = \frac{V_{ph}^{(n)}}{2\pi R_{planet}} \sqrt{n(n+1)}$$

Schumann resonances: on Earth

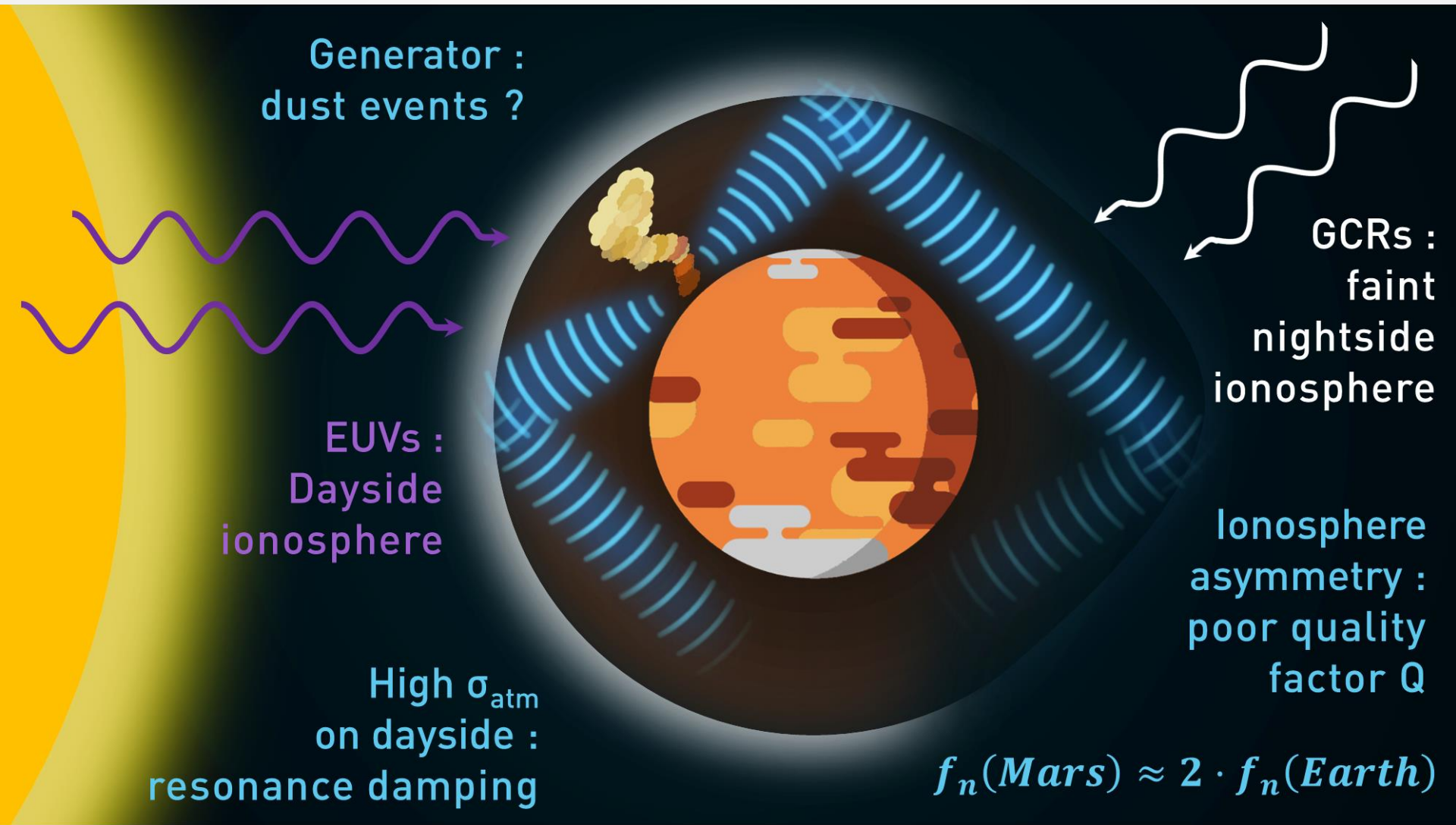
- ▶ Predicted in 1952 by *Schumann*
- ▶ Observed in 1960 by *Balser & Wagner*



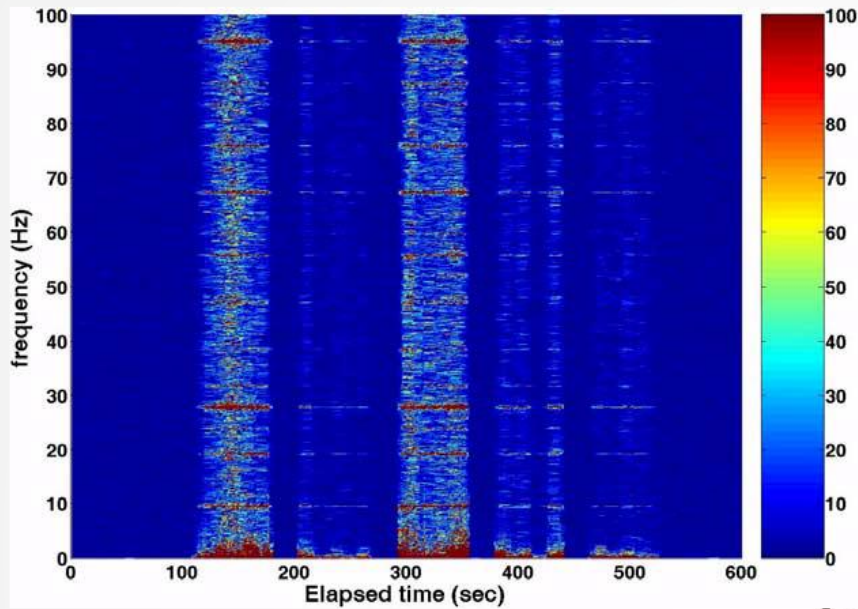
Simões 2011



Schumann resonances: on Mars ???



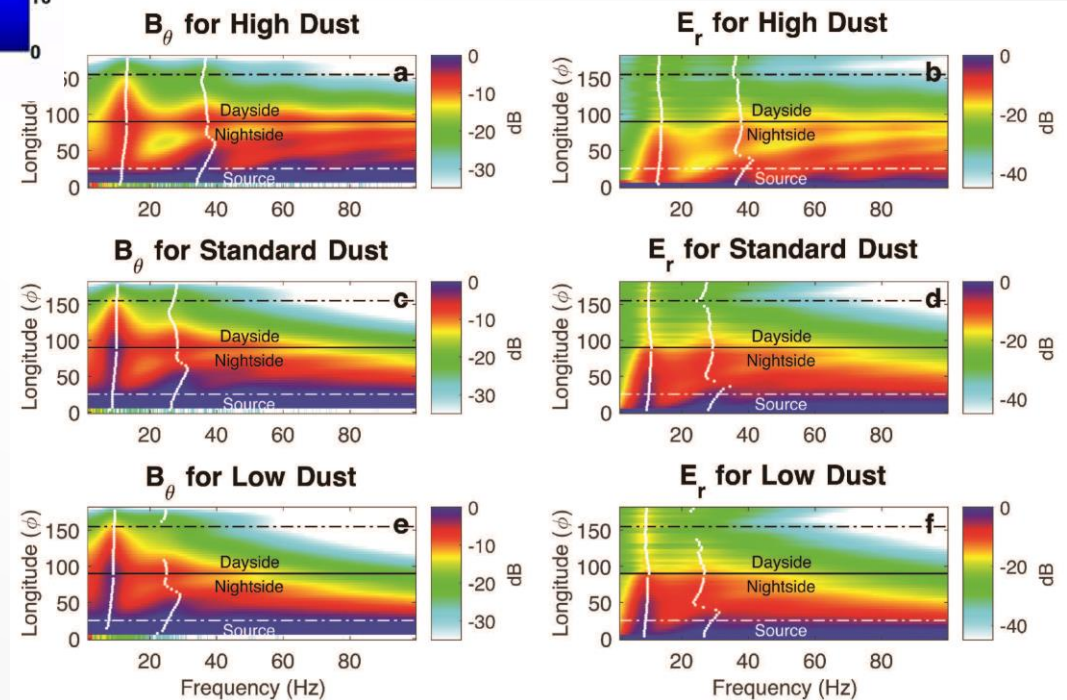
Schumann resonances: on Mars ???



Ruf 2009

► Observed ?

► Simulations



Toledo-Redondo 2017

Martian electricity implications

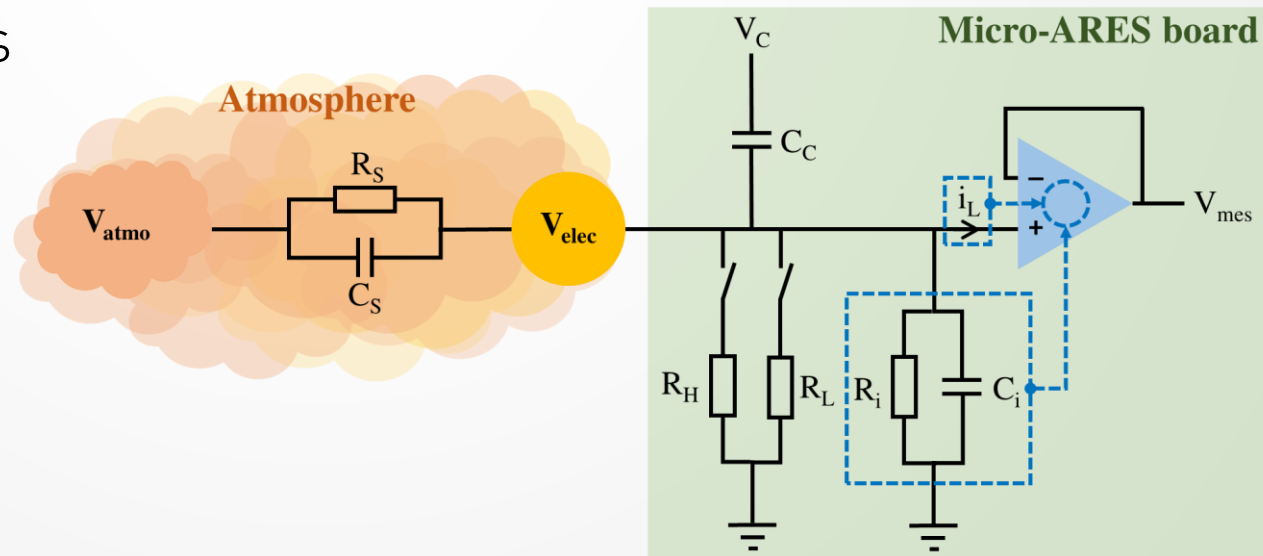
15

- ▶ Search for **life**
- ▶ Better knowledge of the **Martian dust** cycle
 - ▶ Implications on the planetary **climate** and its **modelling**
- ▶ Improve knowledge on the **ionosphere**
- ▶ Implications on **habitability**
 - ▶ Habitats **hazards**
 - ▶ Large solar panels installations damages (no grounding possible)

Micro-ARES: potential and relaxation

16

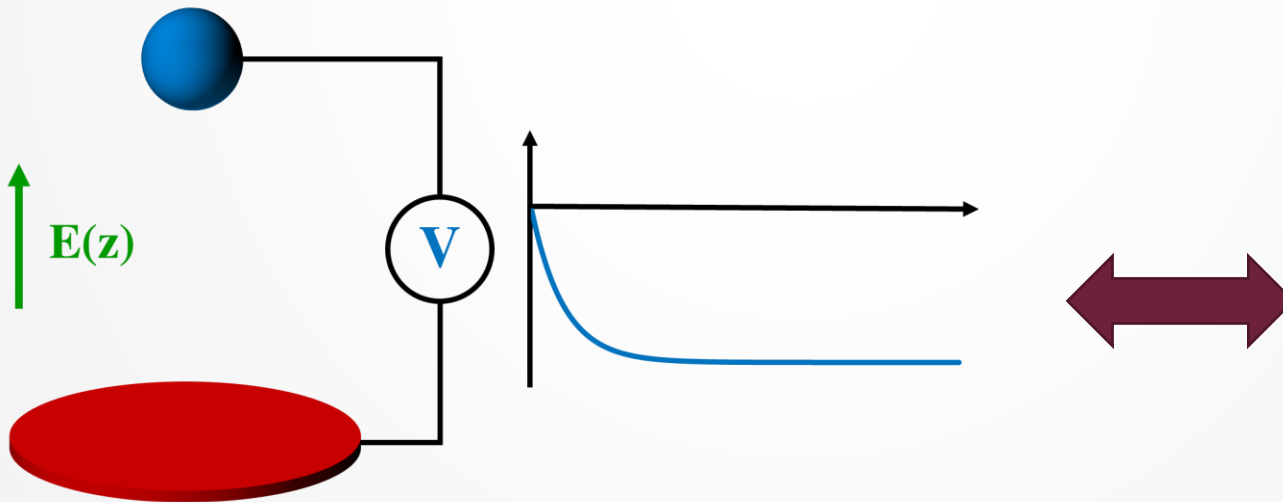
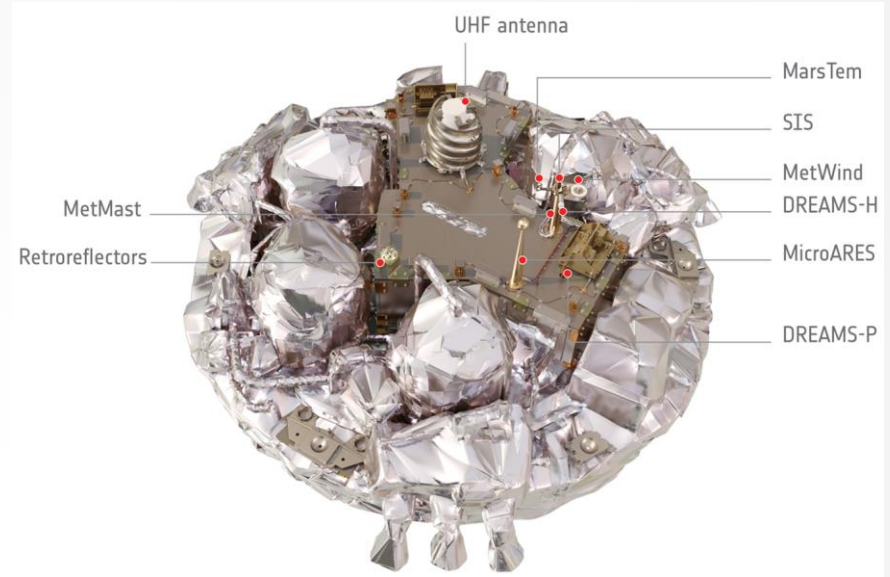
- ▶ Atmospheric **R**elaxation and **E**lectric-field **S**ensor
 - ▶ Measures the electrode potential > **electric field**
 - ▶ And relaxation time > **conductivity**
- ▶ Between +/- 100V/m
- ▶ Up to kV/m with input resistances
- ▶ Electric field and conductivity interleaved
- ▶ Trickier to process



On ExoMars 2016

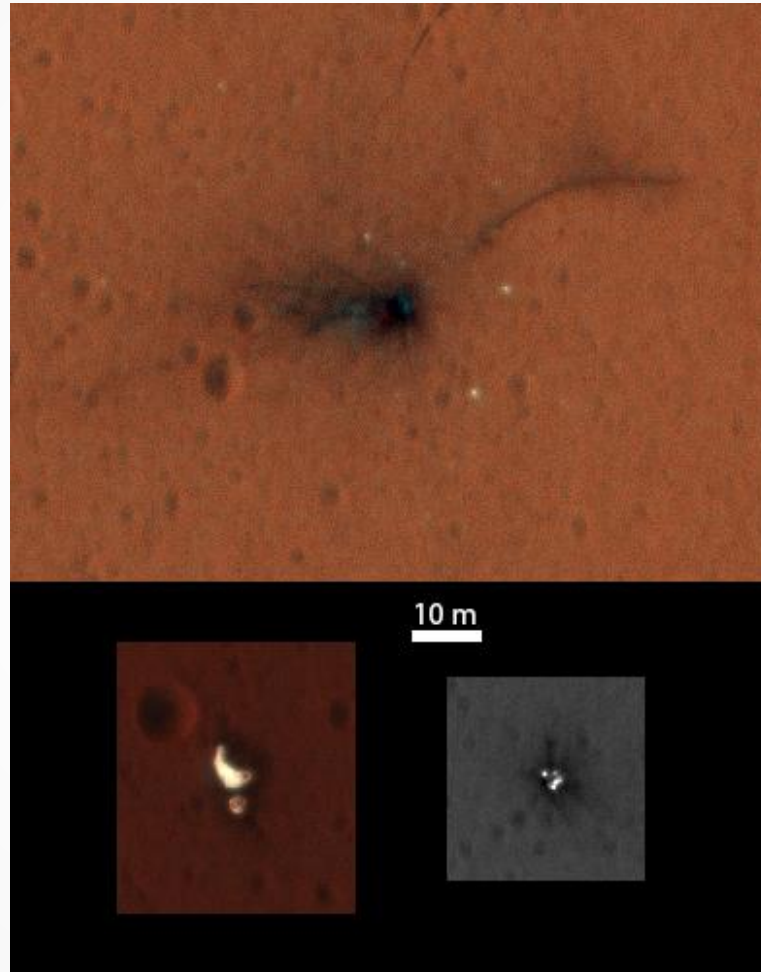
- ▶ Very limited **power**
- ▶ Strict **mass** budget
- ▶ 300g and 300mW

- ▶ On Schiaparelli > perturbations
- ▶ **Modelling work**



No electric-fields measurements yet ...

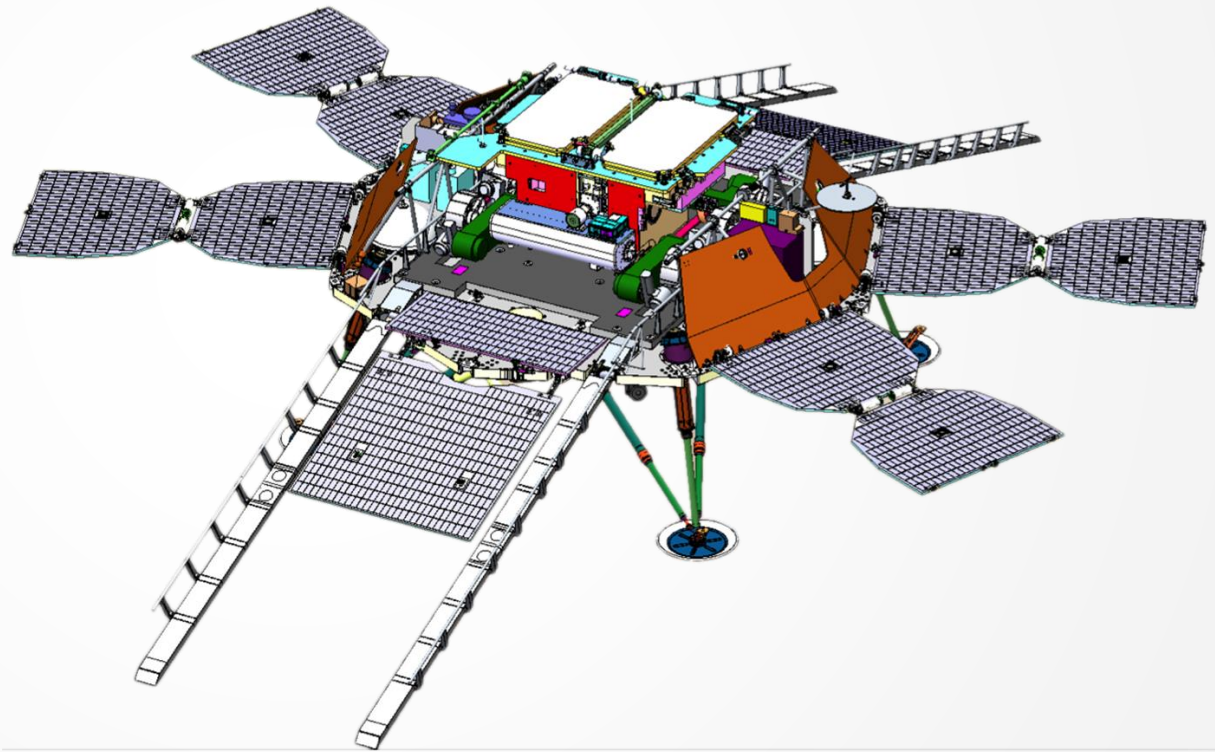
18



In 2020 and later ...

- ▶ Instrument is developed and high **TRL**
- ▶ Dust package and Electric-field sensor on the **ExoMars 2020 lander**

- ▶ **Less constraints**
- ▶ **Long survey**

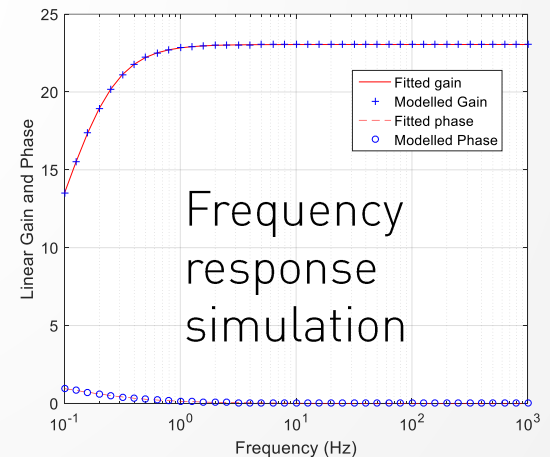
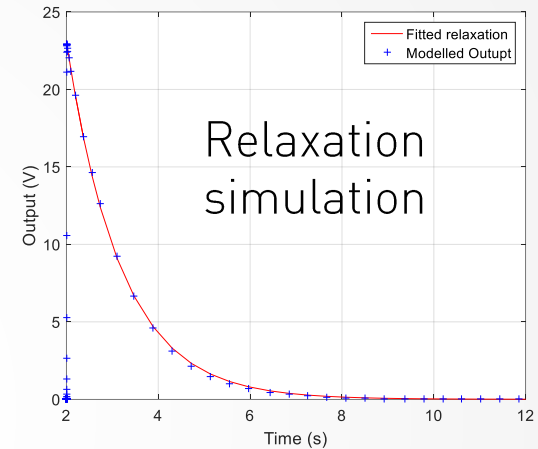


- ▶ **Electric fields will be unveiled**

Model #1: The electrostatic model

20

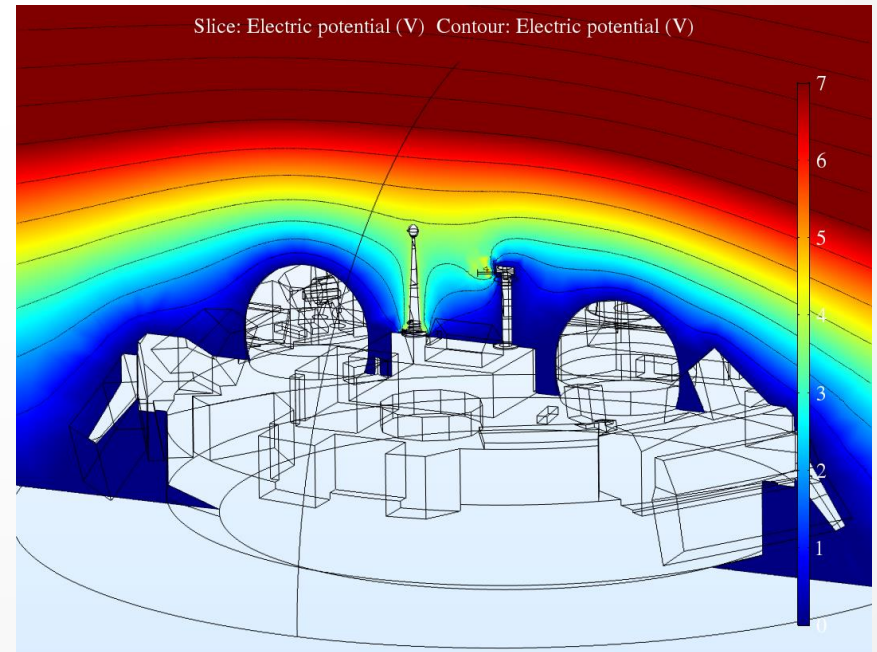
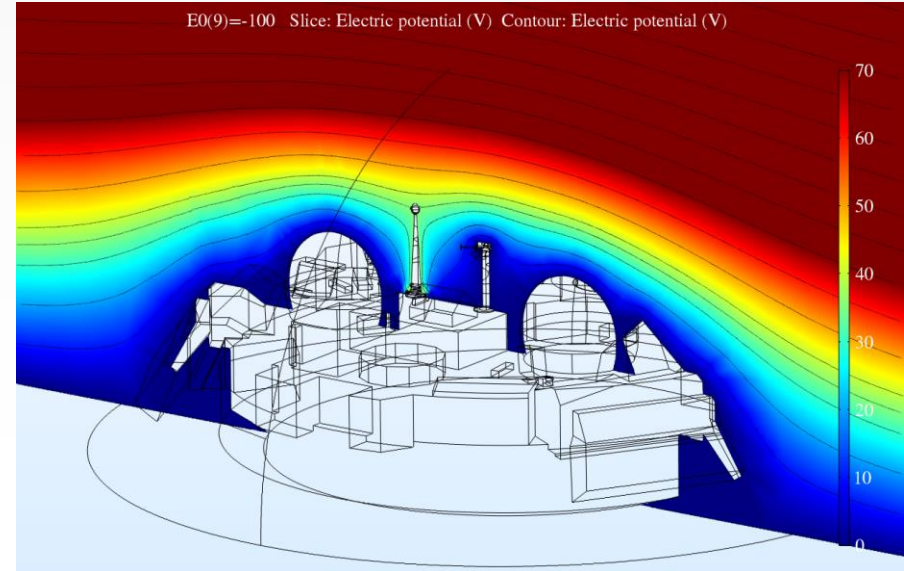
- ▶ **Current conservation** and generalized **Ohm law** : $\nabla J = Q$ $J = \sigma E$ $E = -\nabla V$
- ▶ Solved in **finite elements**
- ▶ Slightly different from the **analytical** solutions
- ▶ $C_e = 1,2 \text{ pF} \neq 4\pi\epsilon_0 r_e = 1,7 \text{ pF}$
- ▶ $R_e = 7.10^{11} \Omega \neq \frac{1}{4\pi\sigma r_e} = 5.10^{11} \Omega$
- ▶ Perturbations from **geometry** taken into account
- ▶ **Equipotential** deformations from geometry



An incomplete model ...

21

- ▶ But the medium **charge carriers** are left **unperturbed**
- ▶ The surrounding plasma still **unperturbed**
- ▶ **One** conductivity describes the atmosphere
- ▶ Any local potential is “seen” from far away
- ▶ No **screening effects** beyond the Debye length



Model #2: The plasma model

- ▶ Fluid approach: **Collisional** plasma

$$\frac{dN_+}{dt} + \vec{\nabla} \cdot (-D_+ \vec{\nabla} N_+ - \mu_+ N_+ \vec{E}) = \mathbf{q}_{GCR} - \alpha N_+ N_- - \alpha_e N_+ N_e - \beta_+ N_+ N_a$$

$$\frac{dN_-}{dt} + \vec{\nabla} \cdot (-D_- \vec{\nabla} N_- - \mu_- N_- \vec{E}) = K N_e - \alpha N_+ N_- - \Gamma N_- - \beta_- N_- N_a$$

$$\frac{dN_e}{dt} + \vec{\nabla} \cdot (-D_e \vec{\nabla} N_e - \mu_e N_e \vec{E}) = \mathbf{q}_{GCR} + \Gamma_a N_a + \Gamma N_- - \alpha_e N_+ N_e - K N_e - \beta_e N_e N_a$$

$$\vec{\nabla} \cdot \vec{E} = e_0 \frac{N_+ - N_- - N_e + q_a N_a}{\epsilon_0}$$

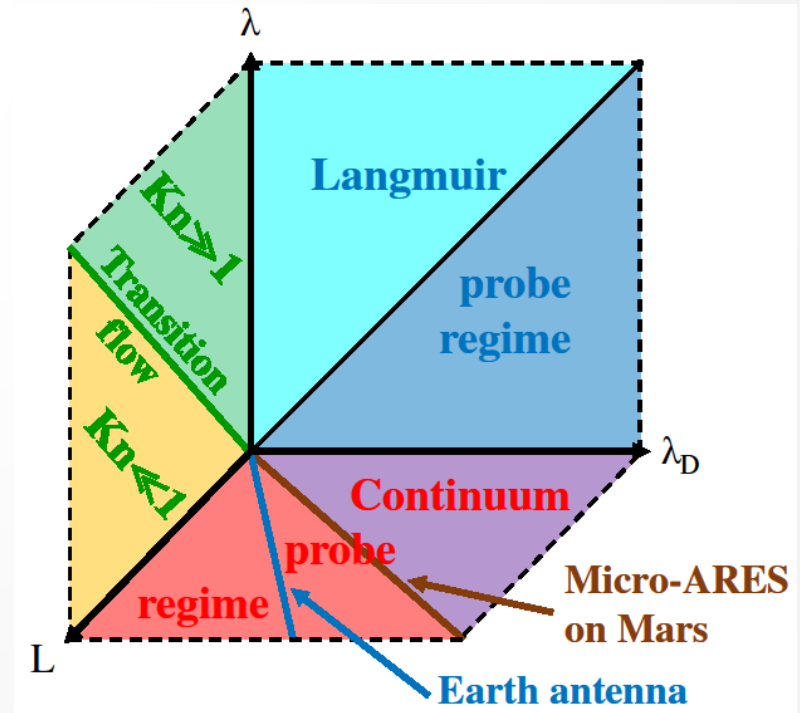
$$K = k_{O \cdot} N_O + k_{O_2 \cdot} N_{O_2} \cdot M + k_{O_3 \cdot} N_{O_3}$$

- ▶ The considered ions are: $\text{CO}_3^- (\text{H}_2\text{O})_2$ and $\text{H}_3\text{O}^+ (\text{H}_2\text{O})_4$ (Cardnell 2016)

- ▶ @5mbars and 150K: $\lambda \simeq \lambda_D \simeq 10^{-5} \text{ m}$
thus $\mathbf{Kn} = \lambda/L = 10^{-4} \ll 1$

- ▶ Discussed boundary condition at absorbing walls: $N=0$

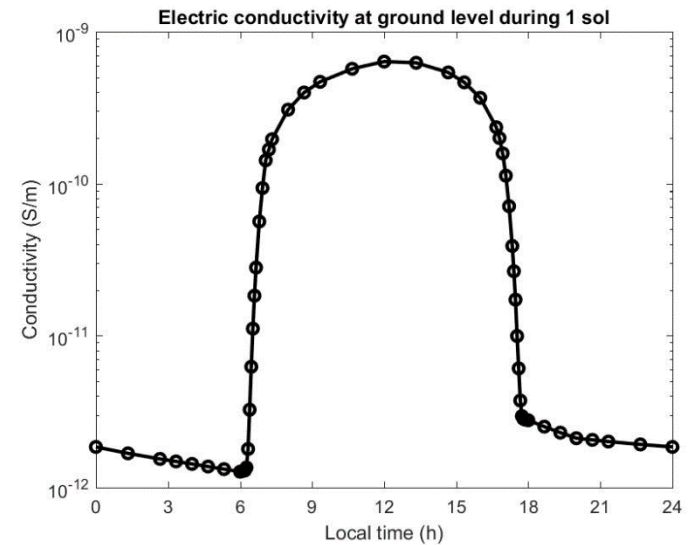
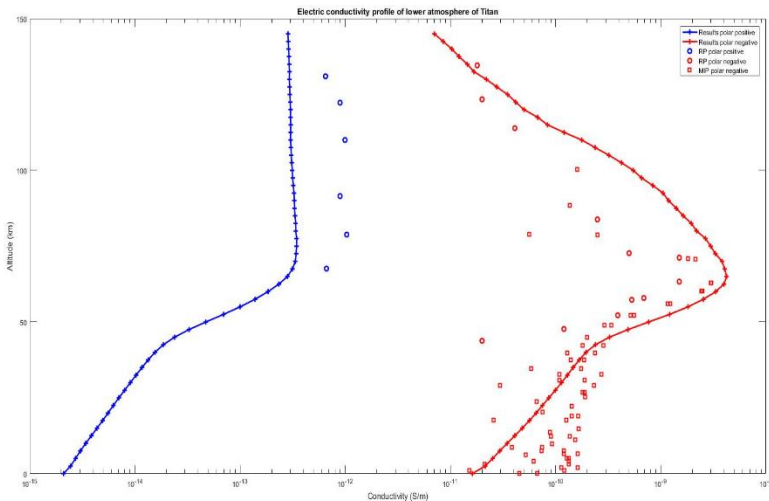
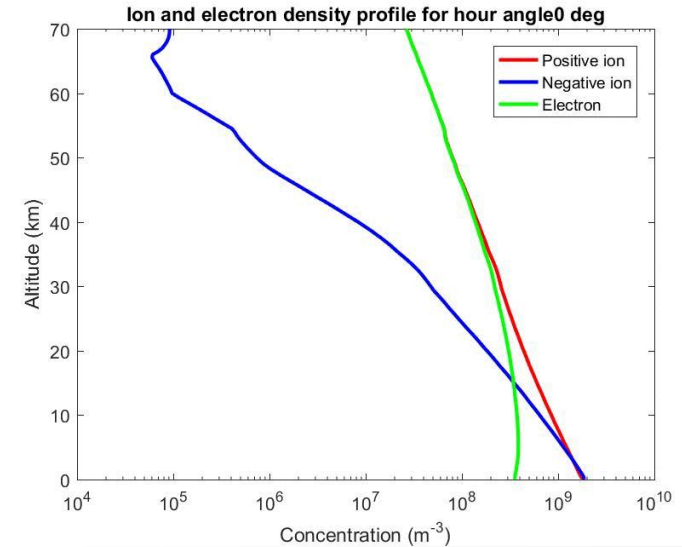
GCR ionization
 $\text{O}, \text{O}_2, \text{O}_3$ reactions
 Aerosols interaction
 Photoemission



Atmospheric conductivity simulations

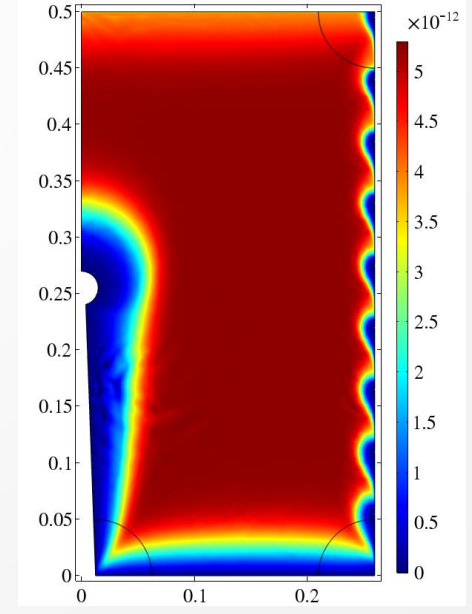
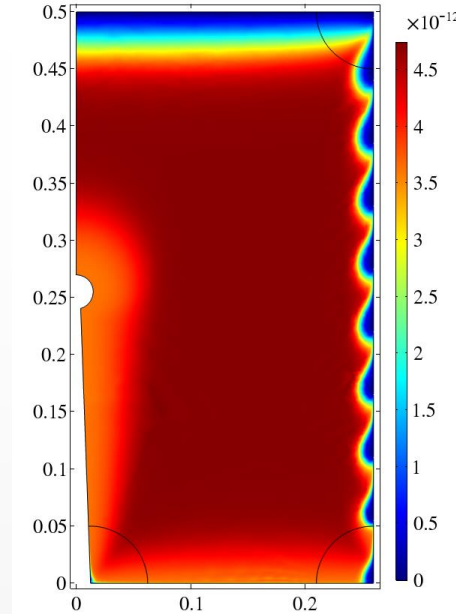
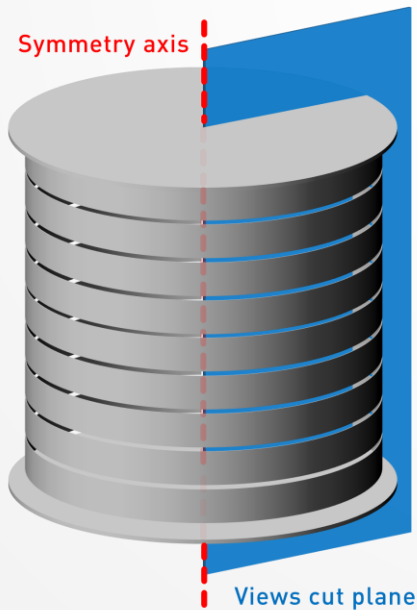
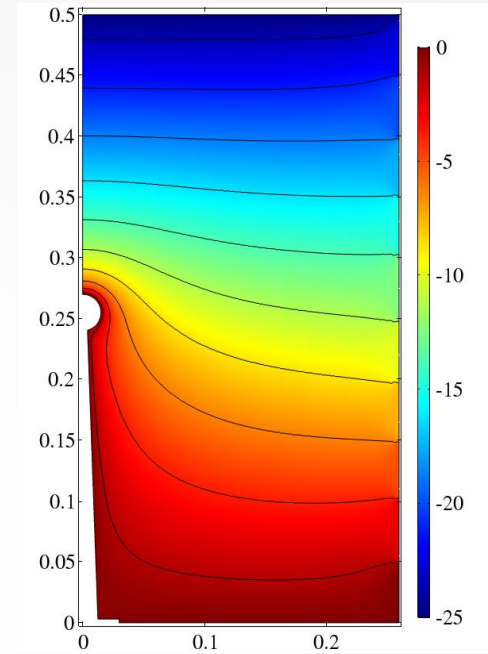
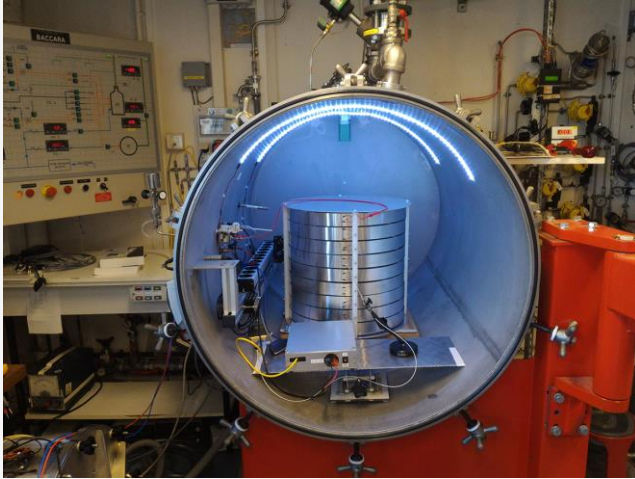
23

- ▶ Cardnell et al. (2016)
- ▶ The previous **source** terms
- ▶ Method of **Moments** on aerosols charge
- ▶ N_+ , N_- , N_e and N_a/q_a between 0 and 70km
- ▶ Model tested on **Titan** vs. Huygens **RP**



Plasma model tests

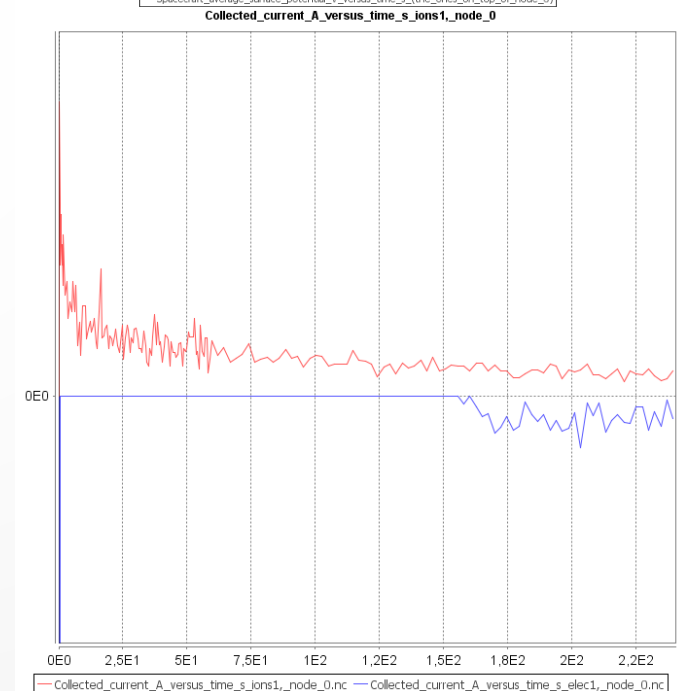
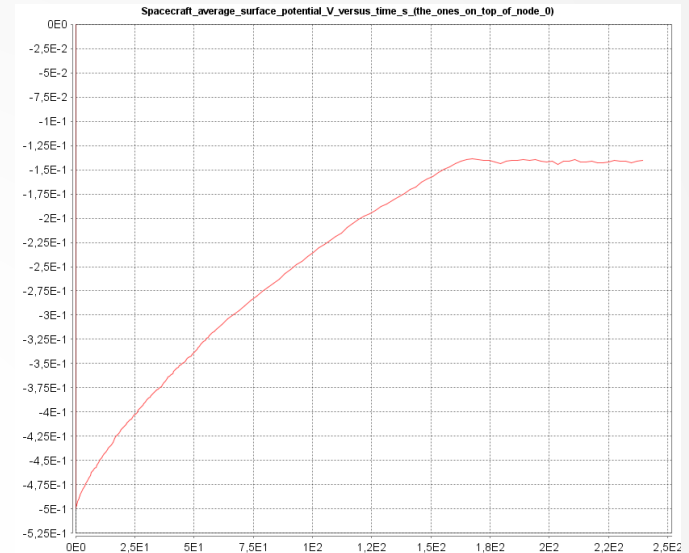
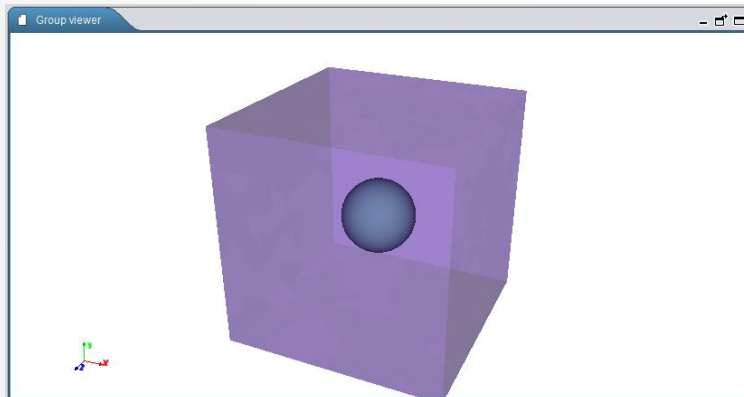
- ▶ Model and experiment in Radon chamber



Model #3: PIC approach with SPIS

25

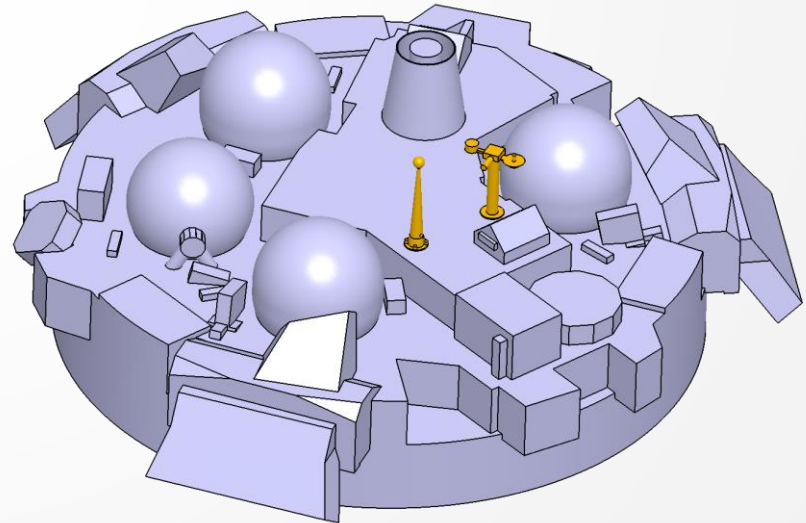
- ▶ Reliable physical model, easily understood
- ▶ Simplified case (1m box, 10cm electrode)
- ▶ Version: **SPIS-Dust 5.2.0**
- ▶ Heavy ions (Ar^+) + electrons
- ▶ Collisions only for **positive ions**
- ▶ **Collisions ONLY with the background**

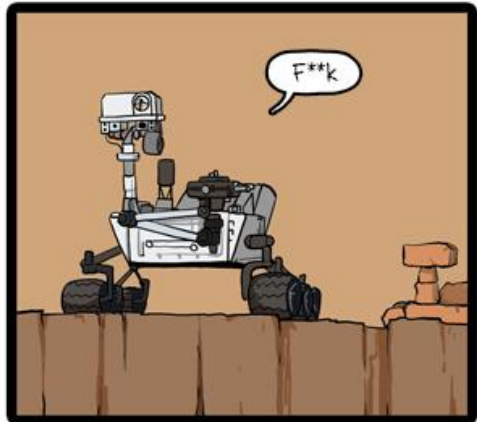
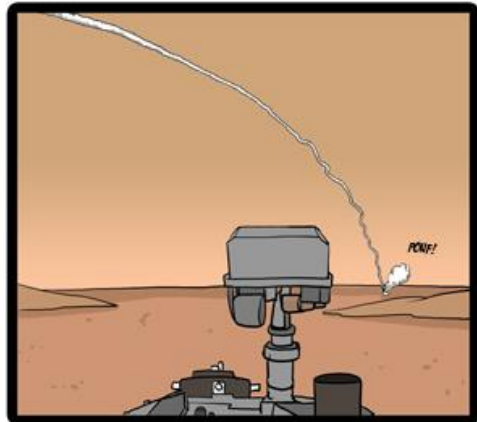
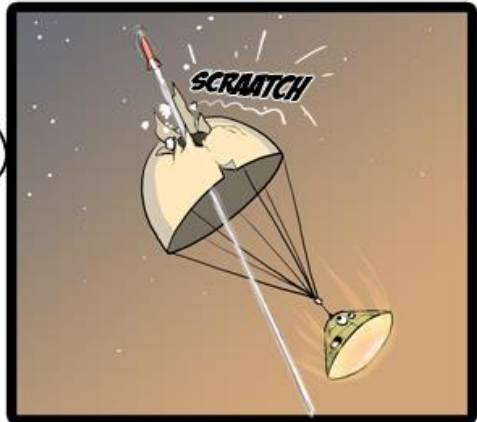
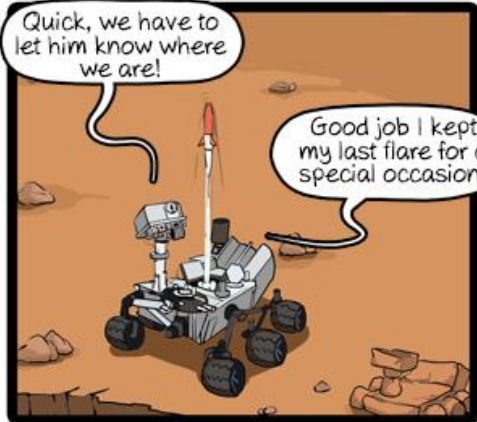
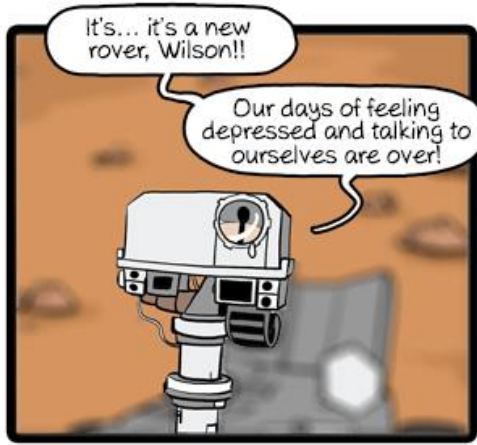


PIC approach future developments

26

- ▶ Simulate **positive** AND **negative** ions
- ▶ Electrons are **NON-negligible** on Mars
 - ▶ Collision rate for **electrons** very (too much ?) large $\approx 10^9$ collisions/sec
 - ▶ Possible to simulate through PIC ?
 - ▶ Hybrid approach ? (PIC + statistical/Monte carlo approach)
- ▶ Use a **complete** geometry
- ▶ Implement a **representative** electrical circuit





Thank you
for your attention
Any questions ?