Modeling lightning impact on the upper atmospheres of Venus and giant gaseous planets

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TRAPPA group
TRANSIENT PLASMAS IN PLANETARY ATMOSPHERES

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Introduction: Lightning in the Solar System beyond the Earth

Planet	E-M evidence	Chemical evidence
Jupiter and Saturn	✓ HF, SED, VLF	✓ Optical evidence
Uranus and Neptune	✓ UED, VLF	×
Venus	VLF?	✓ TEXES: NO_x lines

Table: Lightning evidence

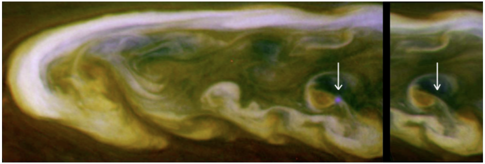

Figure: Saturnian storm *[Cassini spacecraft, NASA]*

Introduction: Transient Luminous Events

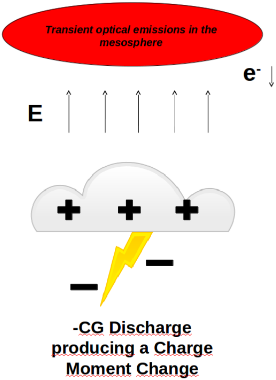

Figure: Halos are produced by quasielectrostatic fields.

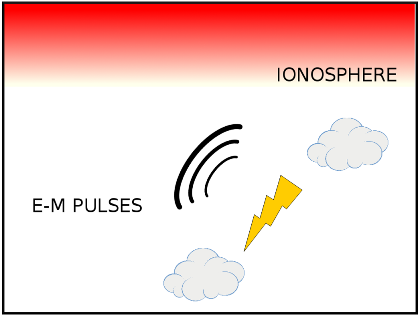

Figure: Elves are generated by EMPs.

Introduction: The case of Venus

- Electromagnetic signals from lightning or plasma instabilities?

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- Electromagnetic signals from lightning or plasma instabilities?
- Lack of optical signals. Lightning optical emissions attenuated by a dense cloud deck?
- Optical emissions from TLEs as an indirect lightning detection?
- Temporal and spatial variability in the nightglow emissions from the 557.7 nm atomic oxygen line, between 0 and **136 R**. Connection with lightning?

Introduction: The case of Giant Gaseous Planets

- Very energetic strokes: Total energy released by intra-cloud (IC) lightning discharge around $10^{12} - 10^{13}$ J.

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- Lightning discharges evidence, but... possible TLEs?
- Lightning and TLEs study as a source of information about the atmosphere composition?

Missions

- Japanese Akatsuki probe (JAXA), equipped with cameras to detect fast 777.4 nm (**lightning**) and 557.7 nm (**nightglow**) emissions.

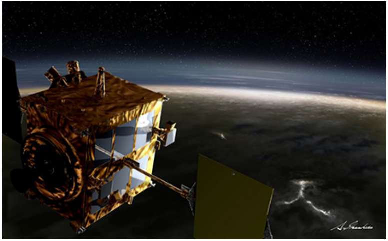

Figure: Akatsuki probe *[JAXA webpage, Courtesy of Akihiro Ikeshita]*

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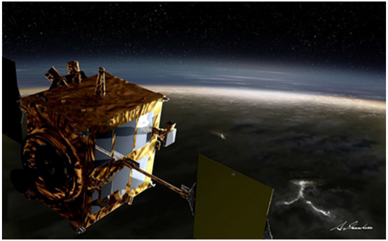

Figure: Akatsuki probe *[JAXA webpage, Courtesy of Akihiro Ikeshita]*

- Juno spacecraft (NASA), equipped with IR and UV spectrometer, plasma detectors and a vector magnetometer.

General models: Halos

$$\nabla^2\phi = -\frac{\rho}{\varepsilon_0} \tag{1}$$

$$J_{e,z} = -D_i\frac{\partial N_e}{\partial z} - \mu_e E_z N_e \tag{2}$$

$$J_{e,r} = -D_i\frac{\partial N_e}{\partial r} - \mu_e E_r N_e \tag{3}$$

$$\frac{\partial n_e}{\partial t} + \nabla \cdot \mathbf{J}_e = G_e - L_e \tag{4}$$

$$\frac{\partial n_i}{\partial t} = G_i - L_i \tag{5}$$

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Approach: The system of equations is solved using a Runge-Kutta method.

General models: Elves

$$\nabla \times \mathbf{E} = -\mu_0 \frac{\partial \mathbf{H}}{\partial t} \quad (1)$$

$$\nabla \times \mathbf{H} = \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \mathbf{J} \quad (2)$$

$$\frac{d\mathbf{J}}{dt} + \nu \mathbf{J} = \varepsilon_0 \omega_p^2(\mathbf{r}, t)\mathbf{E} + \omega_b(\mathbf{r}, t) \times \mathbf{J} \quad (3)$$

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- (1) and (2): 3-D Maxwell equations in time domain.

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  Approach: The system of equations is solved using a Finite Differences Time Domain scheme.

Model: Cosmic ray ionization in Venus

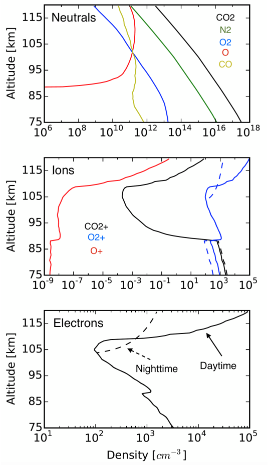


Figure: Equilibrium profile at initial conditions under the influence of cosmic ray radiation *[Pérez-Invernón et al., 2016]*.

Results: Venus

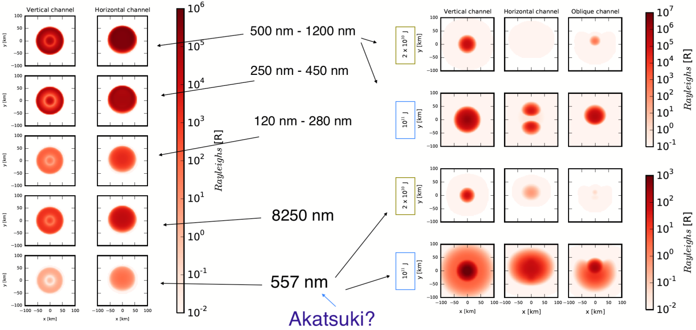


Figure: Main emission brightness, in Rayleighs, in the atmosphere of Venus 0.3 ms and 1 ms after the initiation of a discharge with different total released energies *[Pérez-Invernón et al., JGR, 2017, submitted]*.

Results: Saturn

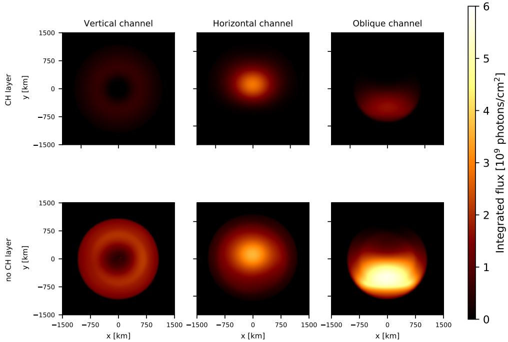


Figure: Integrated flux of total emitted photons from the radiative decay of $H_2(d^3\Pi_u)$ and $H_2(a^3\Sigma_g^+)$ molecules *[Pérez-Invernón et al., JGR, 2017, submitted]*.

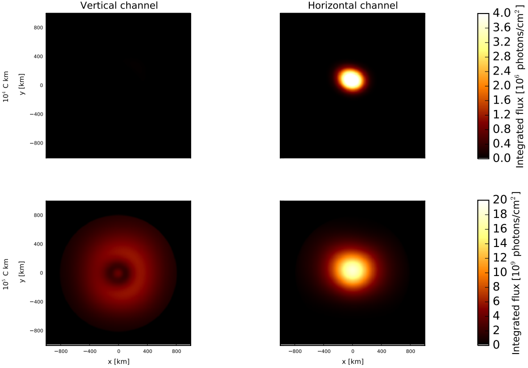
Results: Saturn

Table 1: Total number of emitted photons from the Saturnian ionosphere produced 5 ms after an IC lightning:

Profile and CMC	Vertical channel	Horizontal channel	Oblique channel
CH_x - 10^4	0	0	-
CH_x - 10^5	2×10^{25}	3×10^{25}	1×10^{25}
non CH_x - 10^4	4×10^{23}	1×10^{25}	-
non CH_x - 10^5	4×10^{25}	6×10^{25}	8×10^{25}

Electron profile and lightning channel inclination are decisive in the number of total emitted photons.

Results: Jupiter



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- Elves shape depends on the lightning channel inclination.
- Latitude can influence TLEs characteristics in planets with an intrisic magnetic field.