Ground-based search for lightning with GTC/OSIRIS fast photometry

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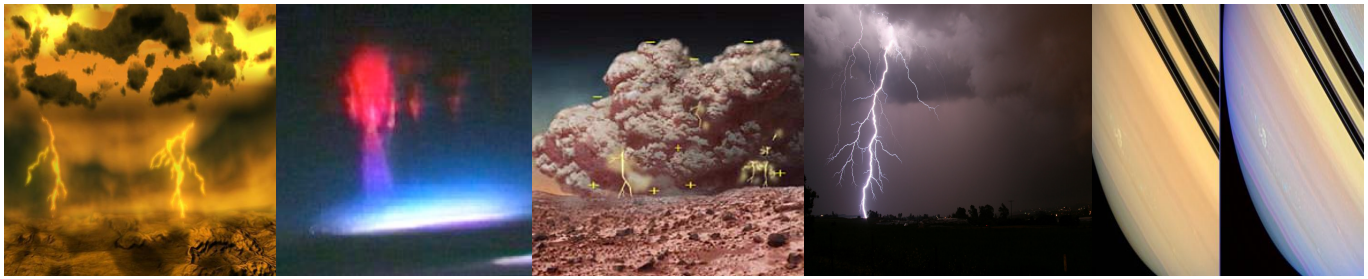
vazquez@iaa.es

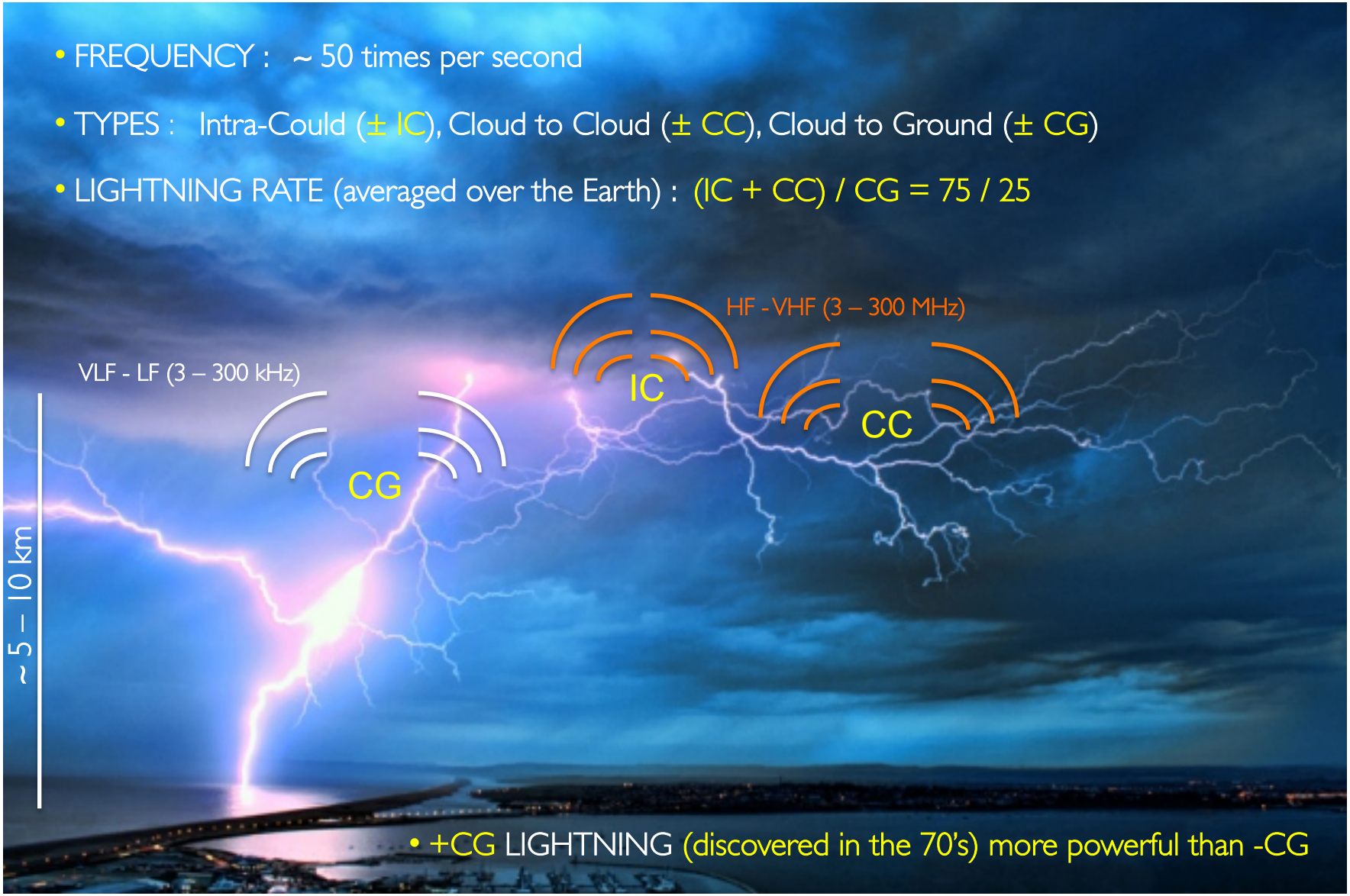
http://ww.trappa.iaa.es/



Outline

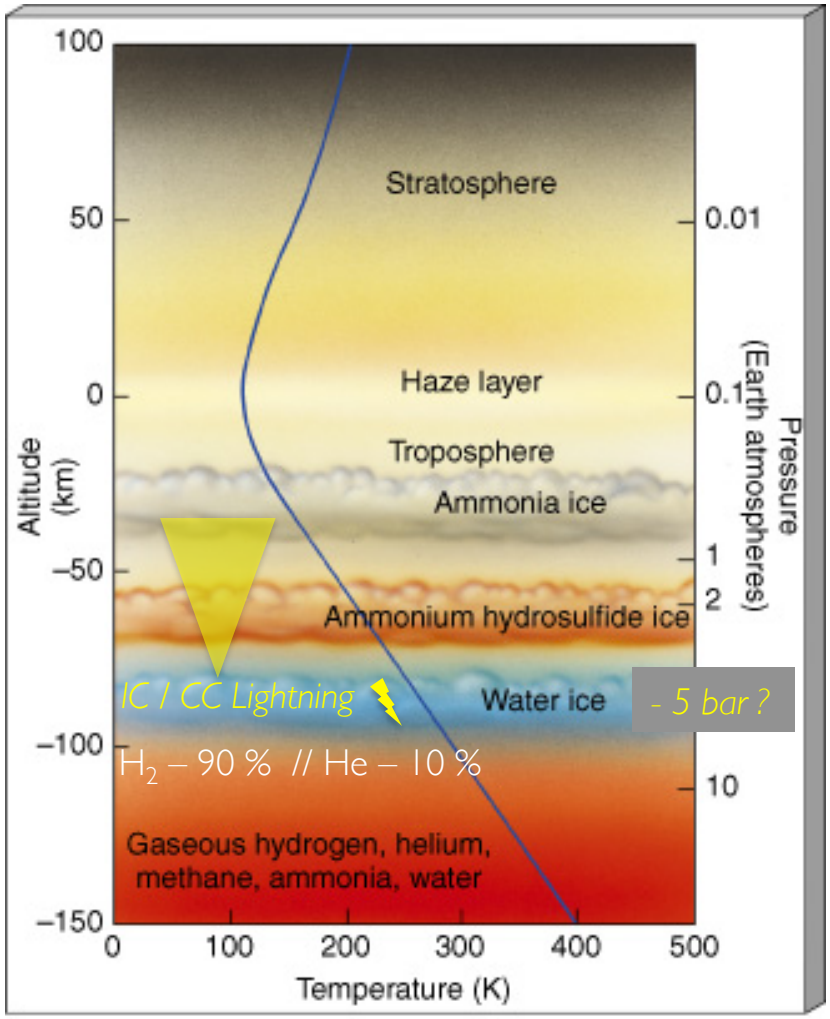
- Lightning on Earth
- Lightning in Jupiter
- Lightning-driven coupling between atmospheric layers
- Brief group overview

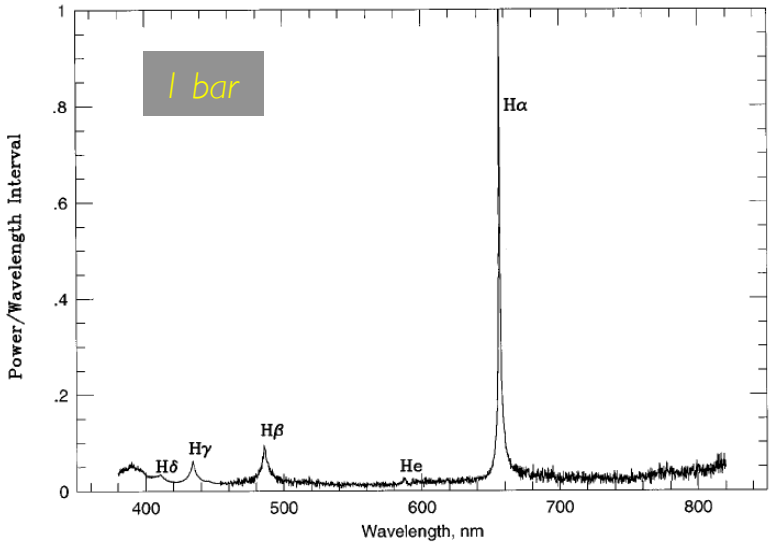
Lightning on Earth

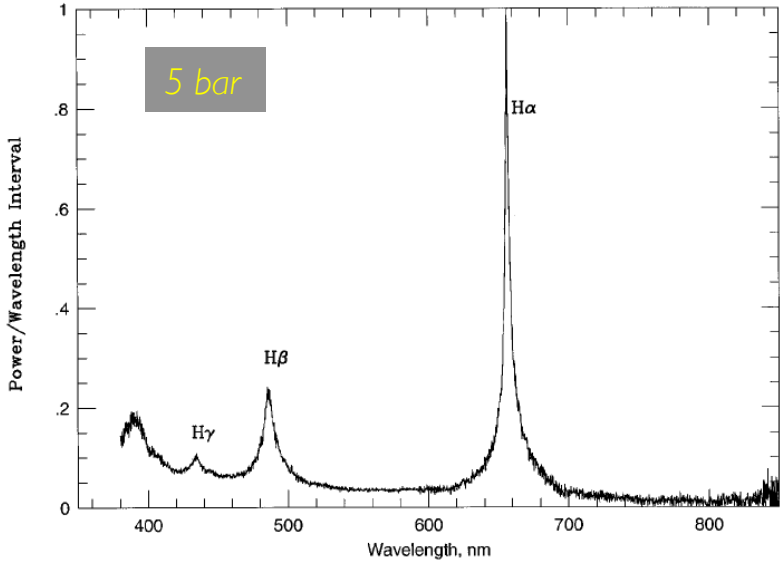


Lightning in Jupiter

Laboratory simulated Jovian lightning Spectra







W. J. Borucki *et al.*, *Icarus, 1996*

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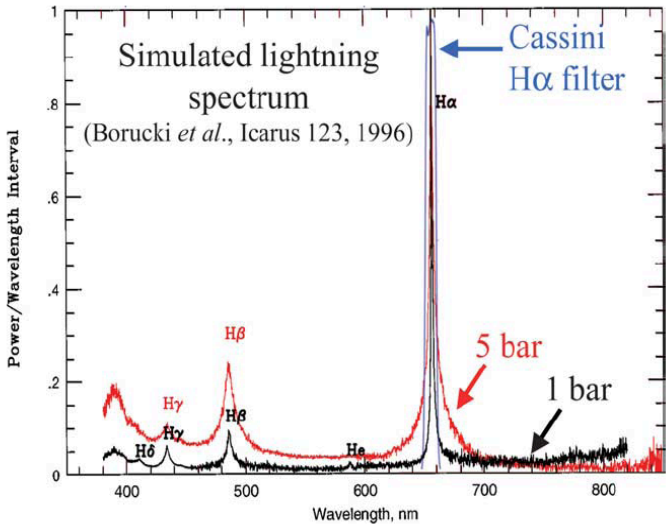
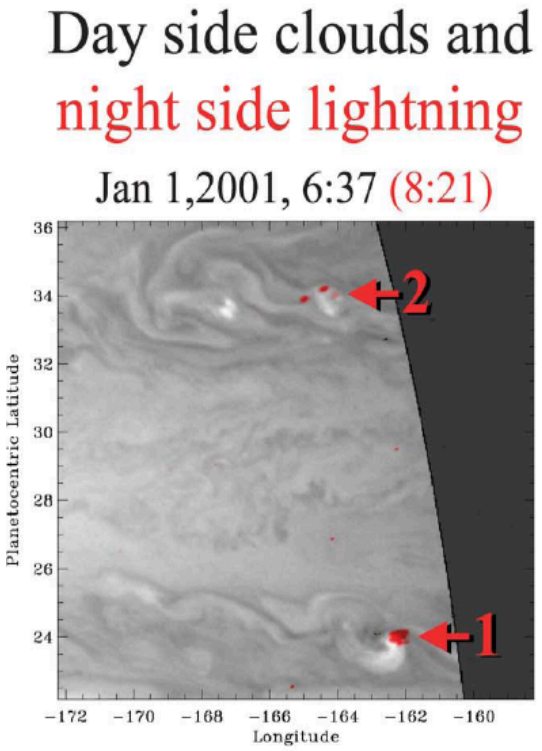
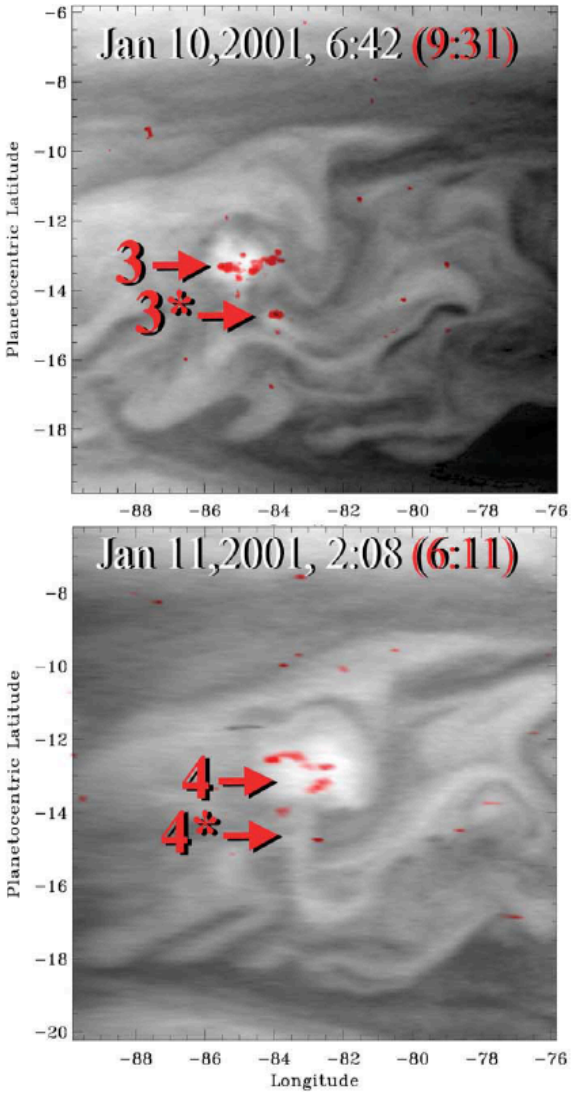
Lightning in Jupiter

Lightning optical emissions by the Cassini ISS camera with H_{alfa} filter and 10 nm waveband



U. A. Dyudina *et al.*, *GRL, 2004*





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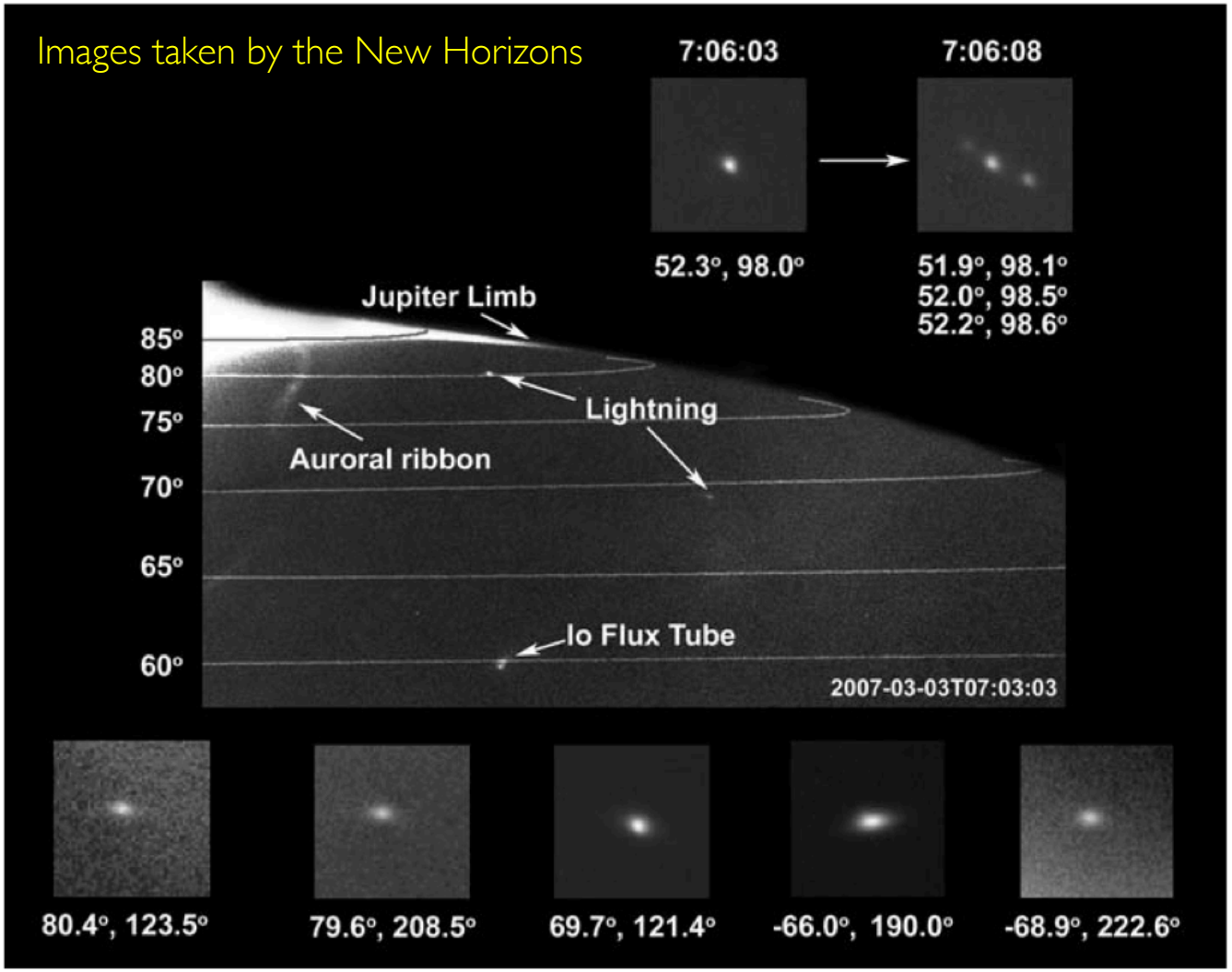
Lightning in Jupiter

Optically observed by *every* probe that has approached it.

No HF (> 1 MHz) radio emission detected



K. H. Baines *et al.*, Science, 2007

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Lightning in Jupiter

Ground-based search for lightning in Jupiter with GTC/OSIRIS fast photometry and tunable filters (March, 2014)

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Astronomy & Astrophysics

Ground-based search for lightning in Jupiter with GTC/OSIRIS fast photometry and tunable filters
(Research Note)

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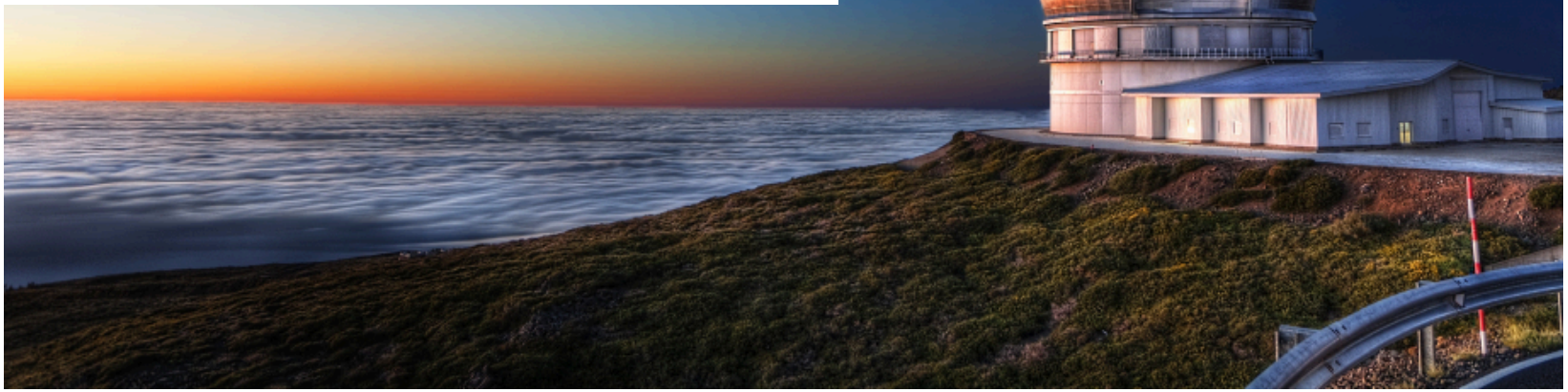
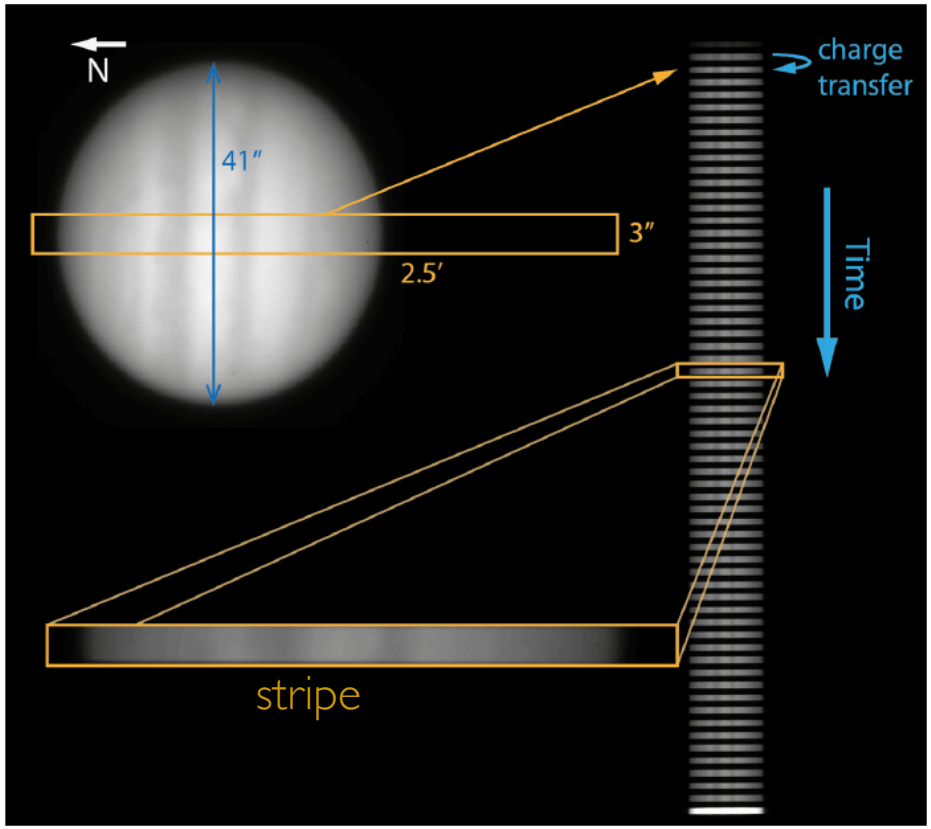


Lightning in Jupiter with GTC/OSIRIS

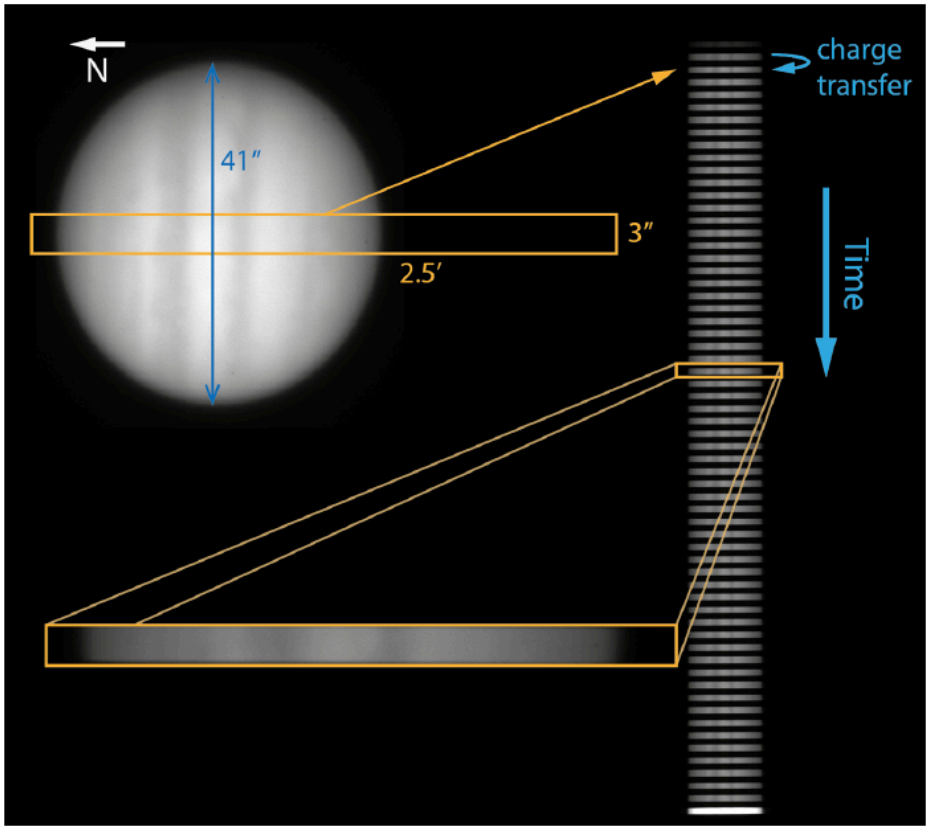
SETUP



- Narrowband (1.2 nm) filter around H_α (656.3 nm)
- 50 ms exposure time
- 208 images with 58 stripes each
- 12064 frames (603.2 s total exposure)

Lightning in Jupiter with GTC/OSIRIS

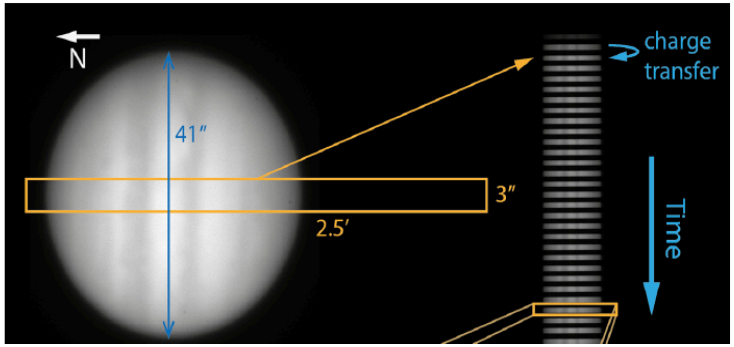
REASONS for signal variations between frames within a single series/image (of 58 frames)

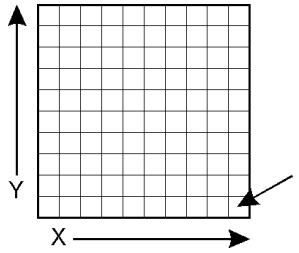


1. Shot noise
2. Variations in the terrestrial atmosphere
3. Spurious signals (cosmic rays)
4. Lightning flashes

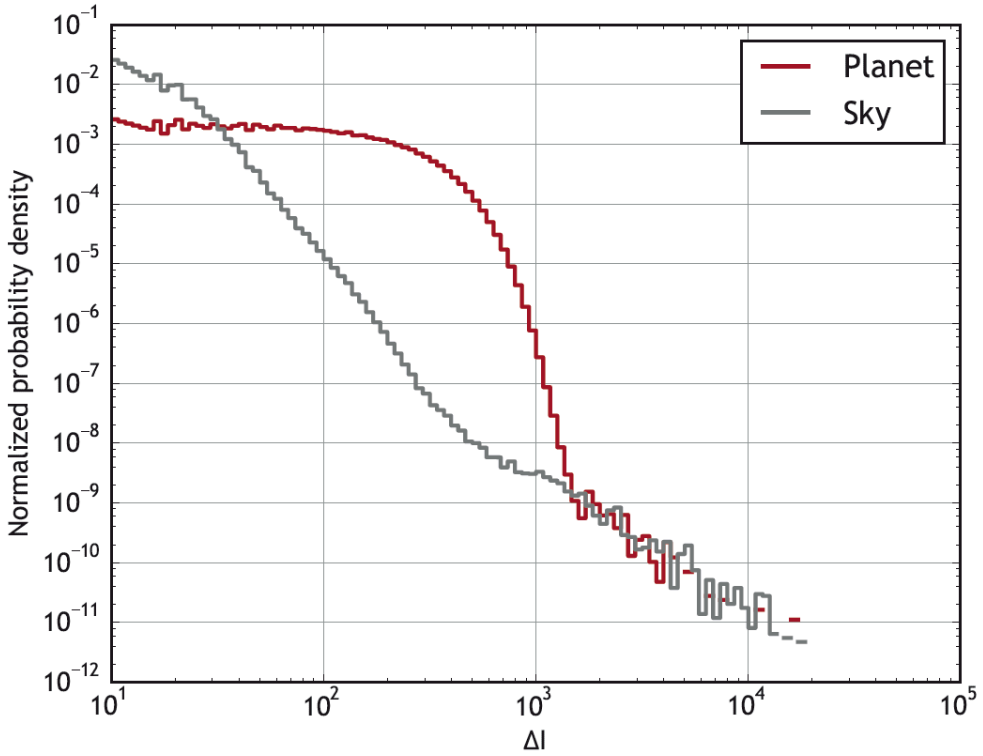
Lightning in Jupiter with GTC/OSIRIS

DATA ANALYSIS





pixel i in frame j



Transient events cause variations of $I_{i,j}$ relative to frames immediately preceding (j-1) and following (j+1):

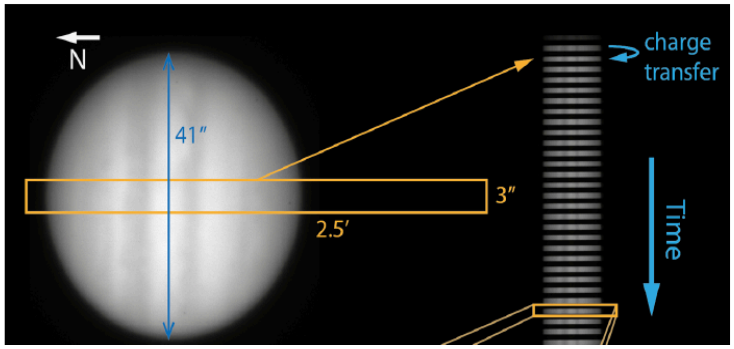
$$\Delta I = \Delta I_{i,j} = I_{i,j} - 0.5(I_{i,j-1} + I_{i,j+1})$$

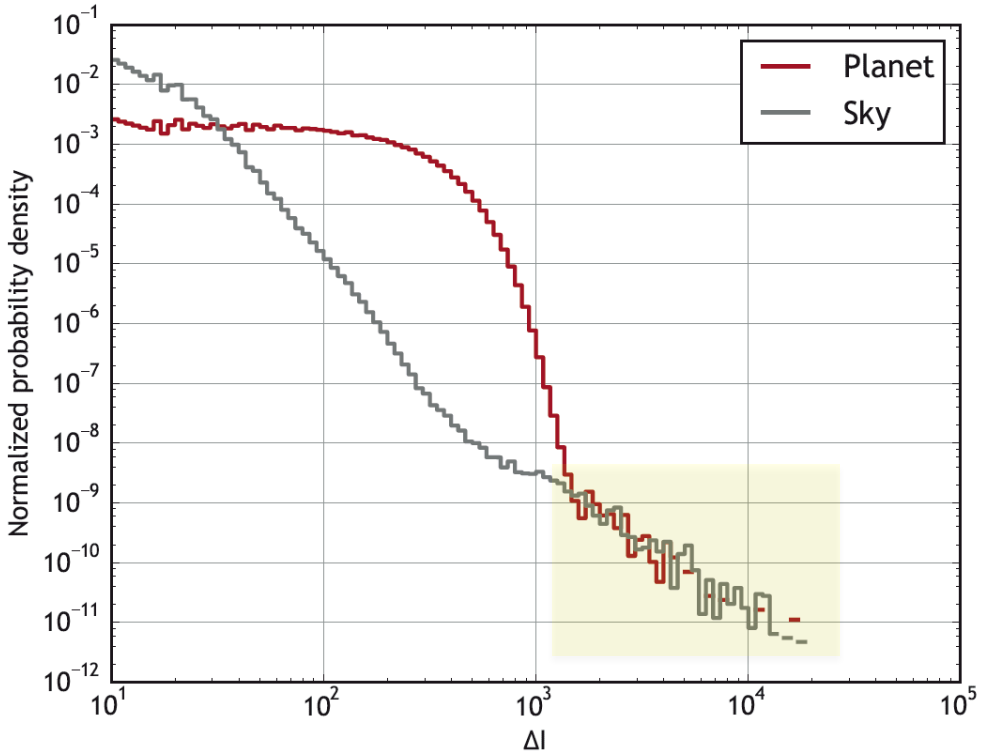
$1 \le i \le 1200 \times 19 = 22800$

$1 \le j \le 58$

Lightning in Jupiter with GTC/OSIRIS

DATA ANALYSIS: COSMIC-RAY tail (> 1500 counts)





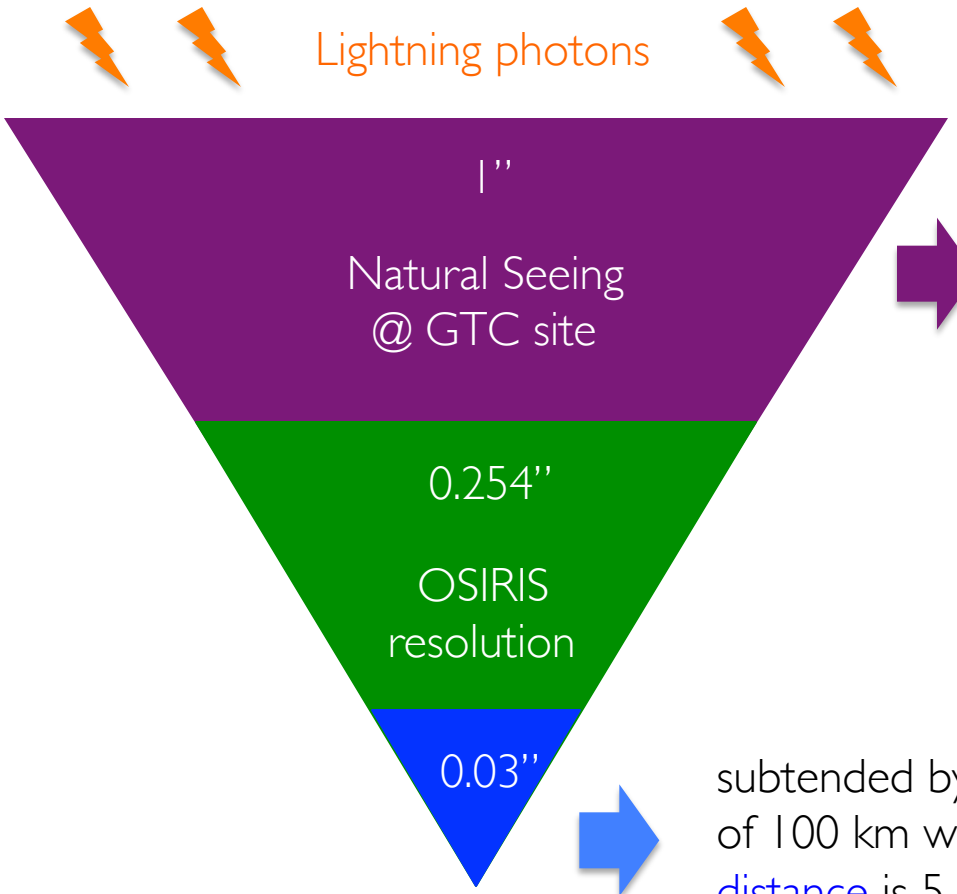
- Planet and Sky tail distributions not completely the same
- Transients hidden in Planet tail distribution ?
- Compare Planet tail distribution (PTD) with artificial distribution (AD) derived from Sky distribution (SD)

AD = SD + randomly chosen **Δ**I from PD

- A Kolmogorov-Smirnov test to PTD and AD indicates that both distributions are identical ➡ No statistically significant presence of flashes in PTD.

Lightning in Jupiter with GTC/OSIRIS

SEEING LIMITATIONS



Key limitation !

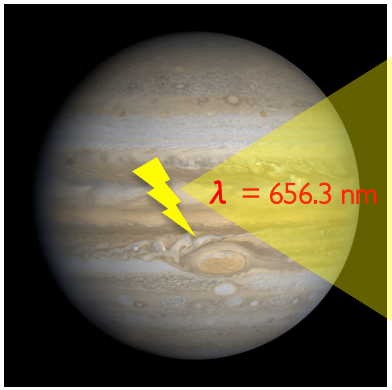
Possible mitigation with:

- Adaptive Optics
- Lucky Imaging

subtended by lightning on a scale of 100 km when Earth – Jupiter distance is 5 AU

Lightning in Jupiter with GTC/OSIRIS

LIGHTNING PHOTONS …



Lightning Optical Energy (10^9 – 10^{10} J)

L ≈ 5 AU

A_{GTC} ≈ 73 m^2

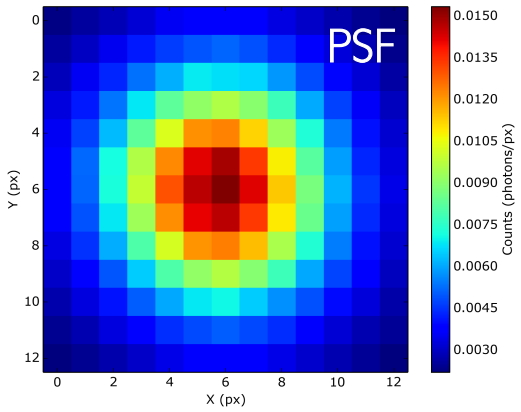
4×10^4 to 4×10^5 photons per FLASH

GTC / OSIRIS

PSF = 0.015

1.2 nm FILTER only collects ≈ 3 % of 656.3 nm

18 to 180 counts/pixel at GTC/OSIRIS detector



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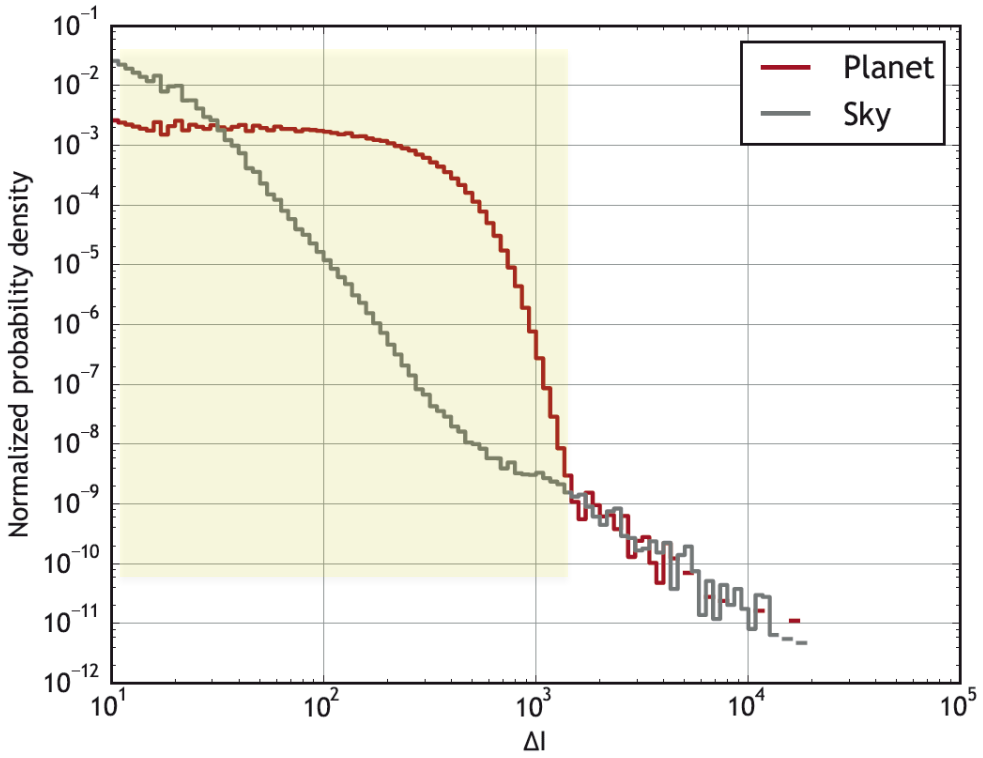
Lightning in Jupiter with GTC/OSIRIS

DATA ANALYSIS: BULK distribution (< 1500 counts)



$I_{i,j}$

Principal Component Analysis

$I_{i,j} = \mu_{i,j} + r_{i,j}$

atmospheric

shot noise

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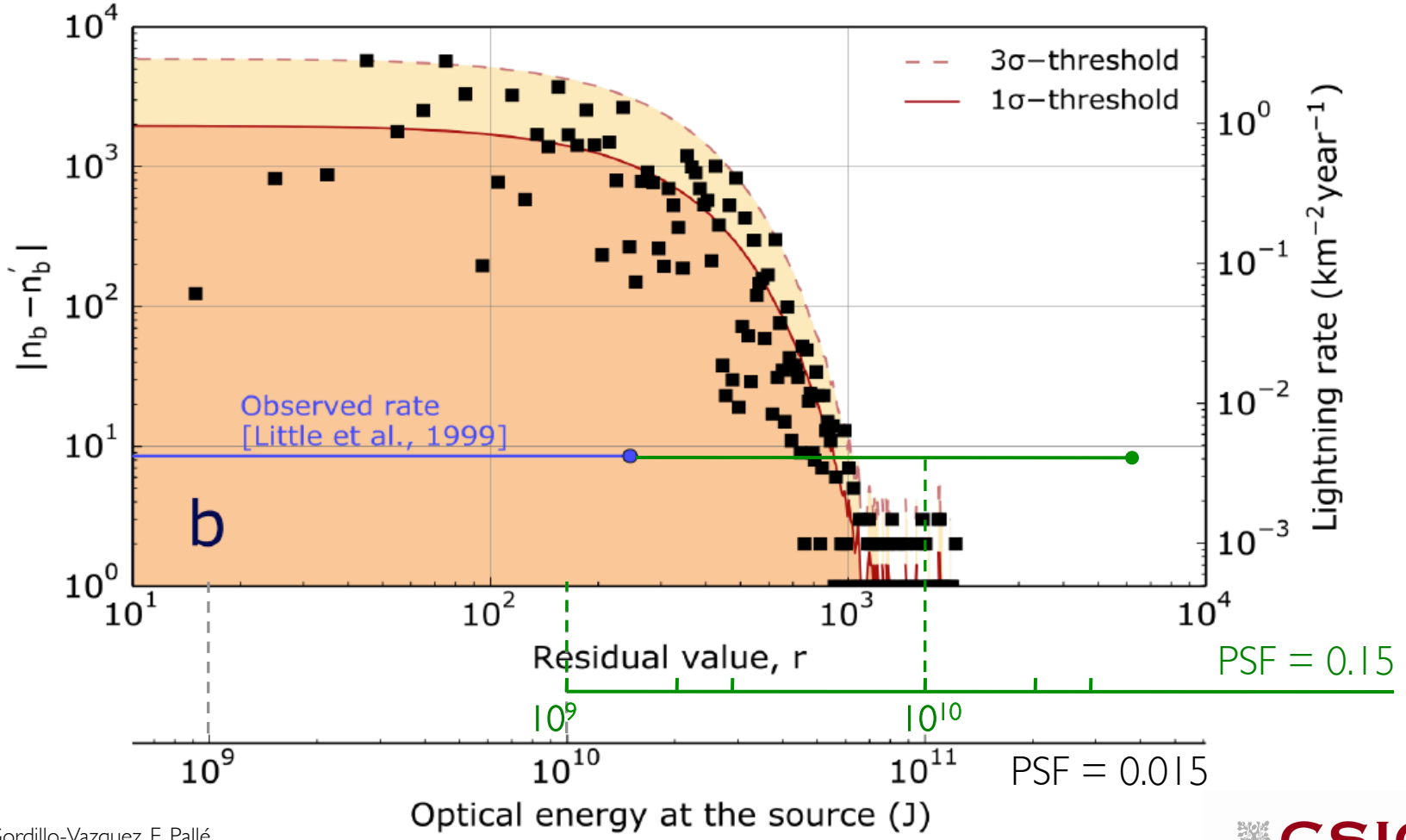
Lightning in Jupiter with GTC/OSIRIS

DATA ANALYSIS: BULK distribution (< 1500 counts)



A. Luque, F. J. Gordillo-Vazquez, E. Pallé
Astronomy & Astrophysics, 577, 2015

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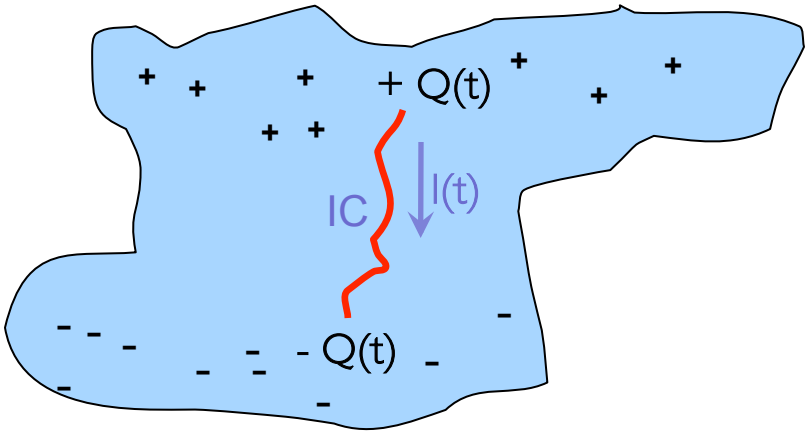
Outline

- Lightning on Earth
- Lightning in Jupiter
- Lightning-driven coupling between atmospheric layers
- Brief group overview

Lightning-driven atmospheric coupling

- Lightning couples atmospheric layers on Earth
- May it do similarly in other planets?
- If so, are there similar sprite, halos and elves?

Electric field of a radiating dipole



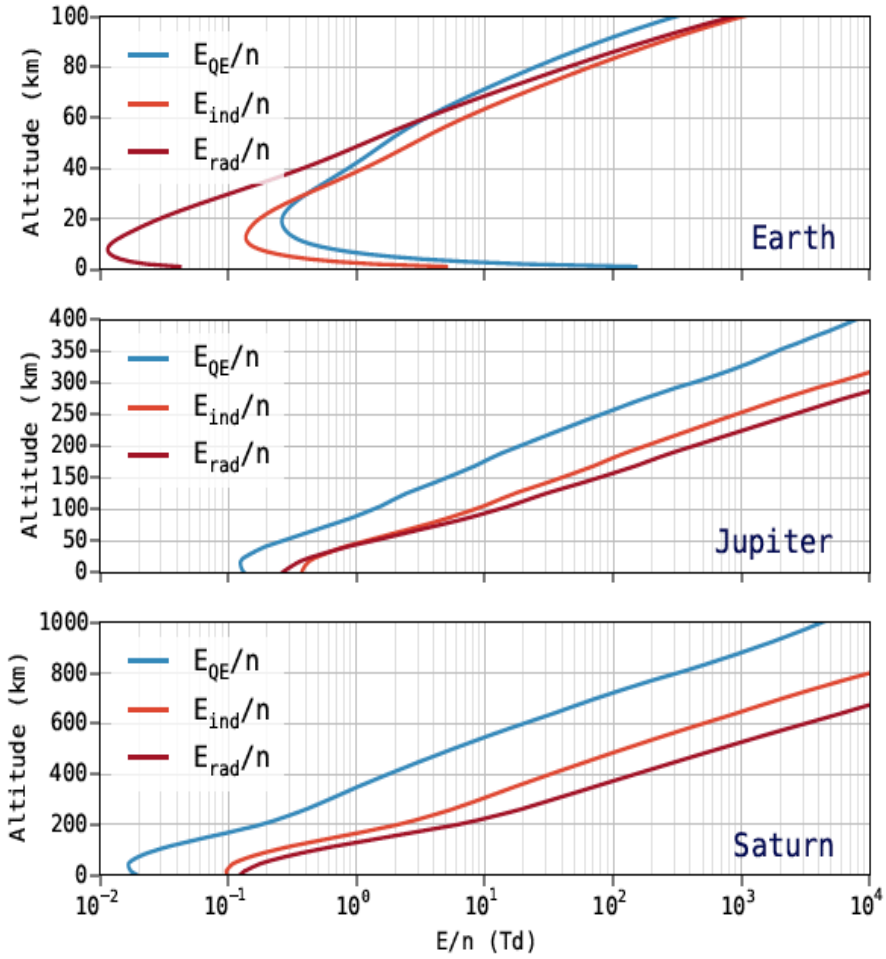
$$E_{QE} = \frac{M}{\pi\epsilon_0(z - z_P)^3},$$

$$E_{ind} \approx \frac{M}{\pi\epsilon_0 c\tau(z - z_P)^2},$$

$$E_{rad} \approx \frac{M \sin 2\alpha}{4\pi\epsilon_0 c^2\tau^2(z - z_P)},$$

Electric field of a radiating dipole

(Earth, Saturn, Jupiter)



A. Luque, D. Dubrovin, F. J. Gordillo-Vazquez, et al.
JGR, 119, p. 8705 (2014)

$$E_{QE} = \frac{M}{\pi\epsilon_0 (z - z_P)^3},$$

$$E_{ind} \approx \frac{M}{\pi\epsilon_0 c\tau (z - z_P)^2},$$

$$E_{rad} \approx \frac{M \sin 2\alpha}{4\pi\epsilon_0 c^2 \tau^2 (z - z_P)},$$

$z_P =$ 0 km (Earth)
$z_P =$ - 150 km (Saturn) (relative to 1 bar level)
$z_P =$ - 85 km (Jupiter) (relative to 1 bar level)

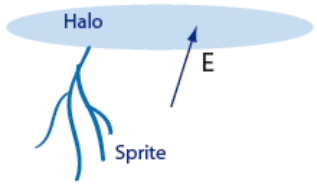
Scaling that affects Electrical Activity

(Earth, Saturn, Jupiter)

Saturn vs **Earth**

- Charge moment $Q\ell$: $\times 10^3$.
- Distance cloud-TLE, R: $\times 10$.
- Discharge time τ: about the same.

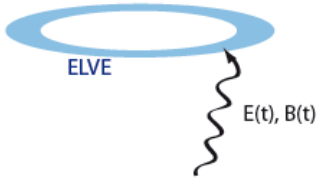
Quasi-electrostatic



$$E \sim \frac{Q\ell}{R^3}$$

$\sim$ about as strong as on Earth.

Radiative



$$E \sim \frac{Q\ell}{R\tau^2}$$

$\sim$ 100 times **stronger** than on Earth!.

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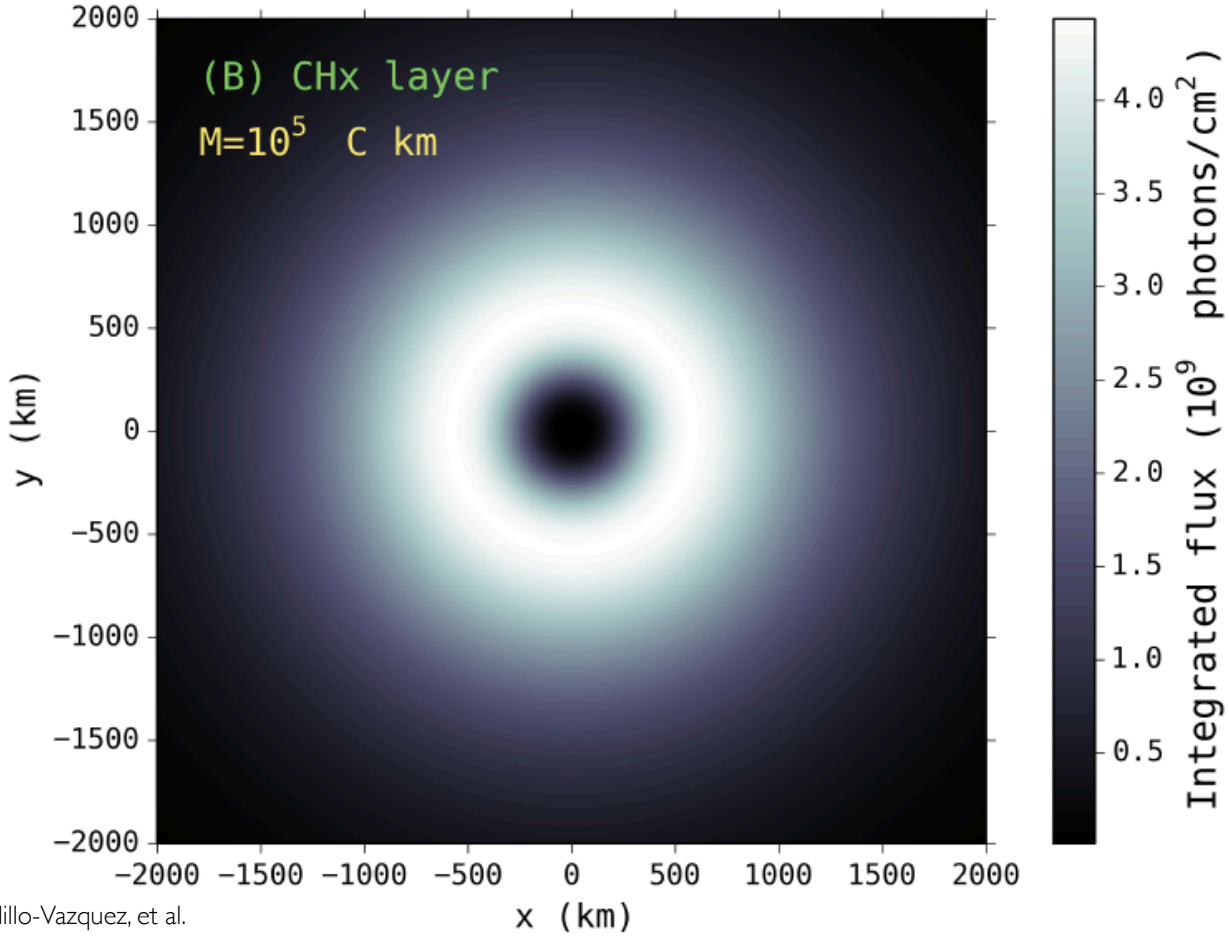
Effects of lightning EMPs

(Saturn)

Predicted shape of an ELVE (column integrated) optical emissions due to IC lightning as seen from an orbiter from the nadir



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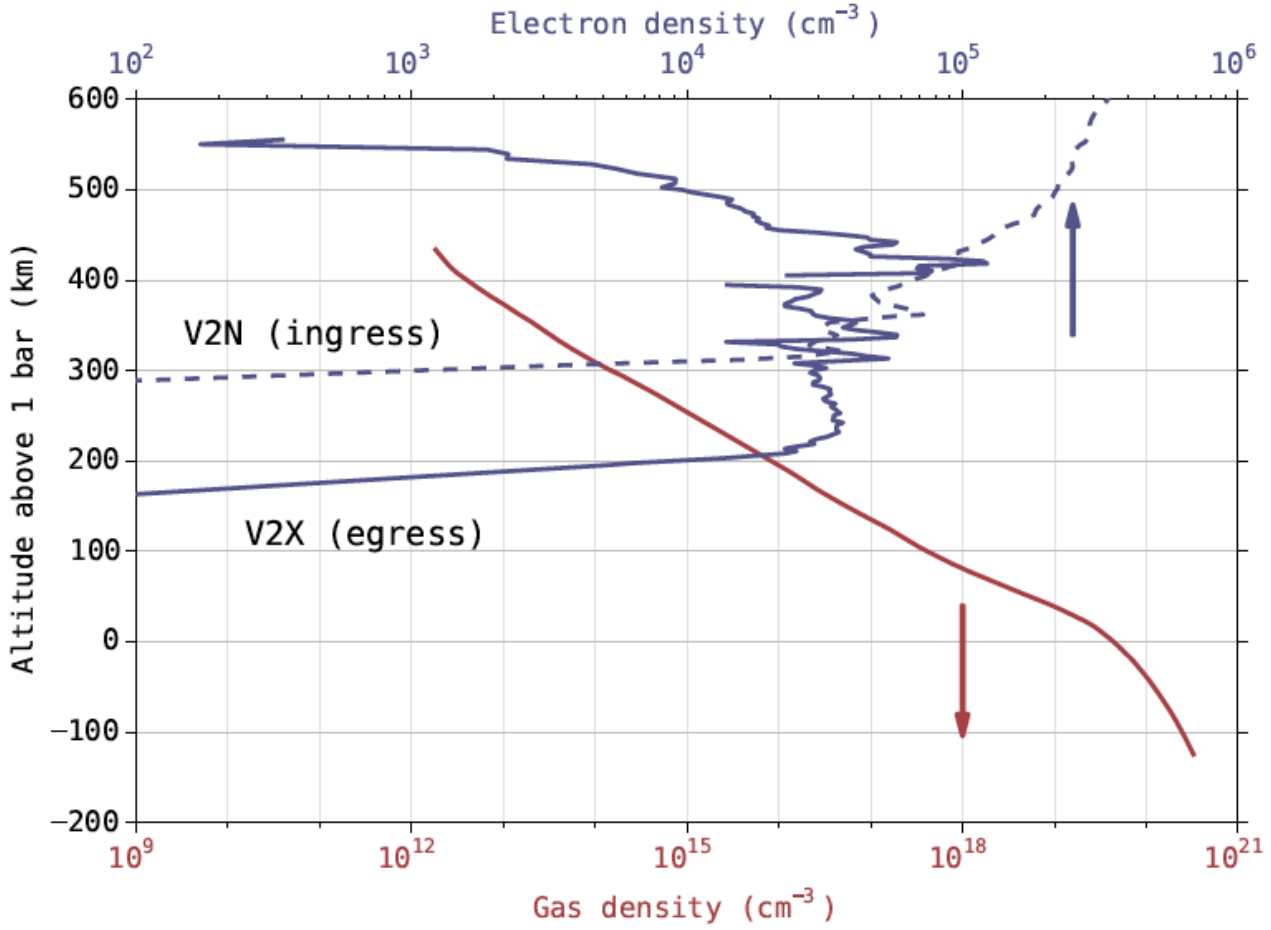
Electron density profiles

(Jupiter)



Electron density profiles from Voyayer 2 radio occultation Measurements (Hinson et al, JGR, 1998)

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Effects of lightning EMPs

(Jupiter)

A. Luque, D. Dubrovin, F. J. Gordillo-Vazquez, et al.
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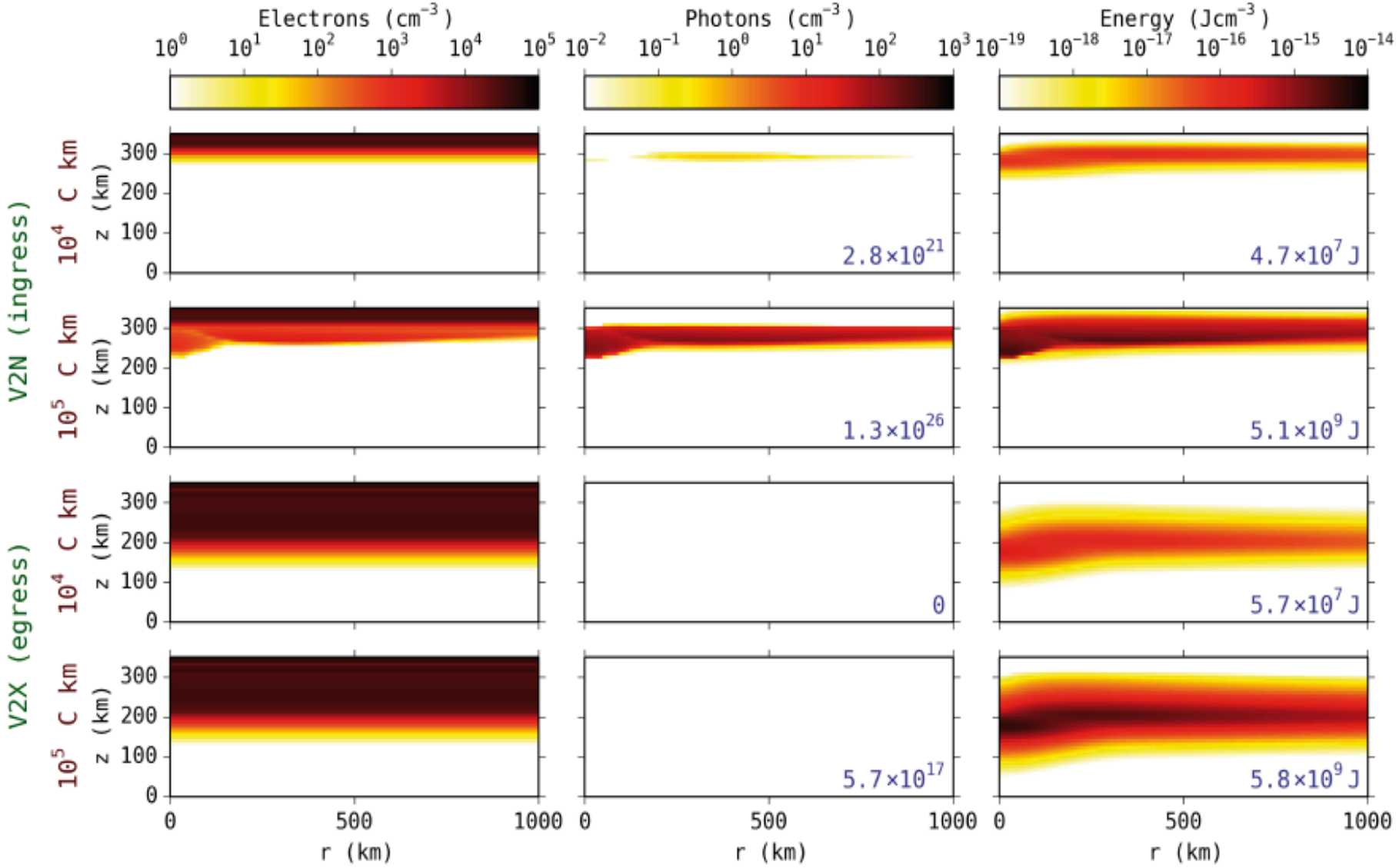
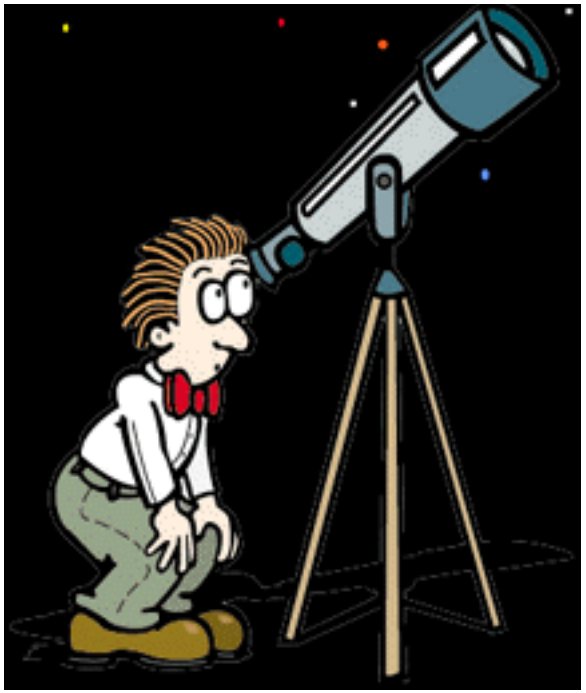
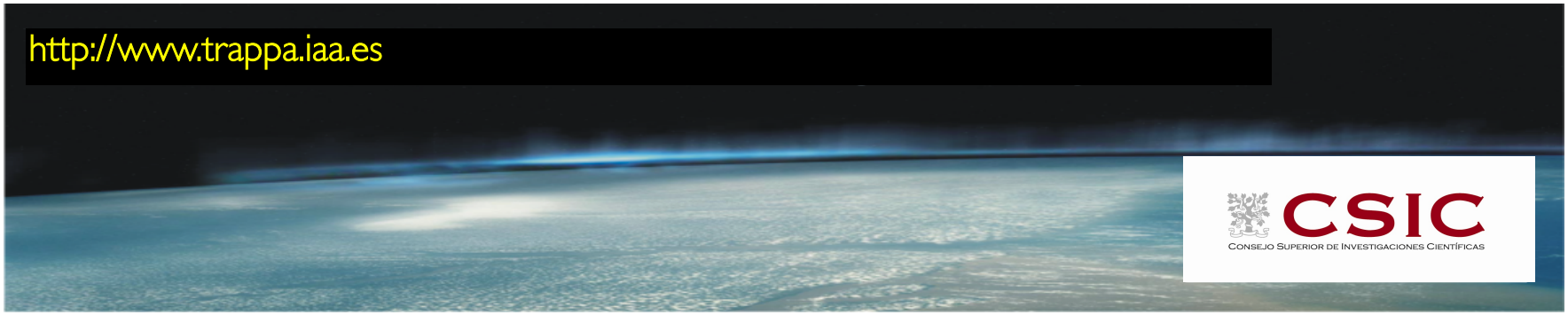


Possibilities for observing lightning induced upper atmosphere emissions



- Find a donought pattern in Saturn/Jupiter lightning images
- Perform sensitive spectroscopy
- Study the radio fingerprint as observed from Earth

El grupo TRAnsient Plasmas in Planetary Atmospheres del IAA



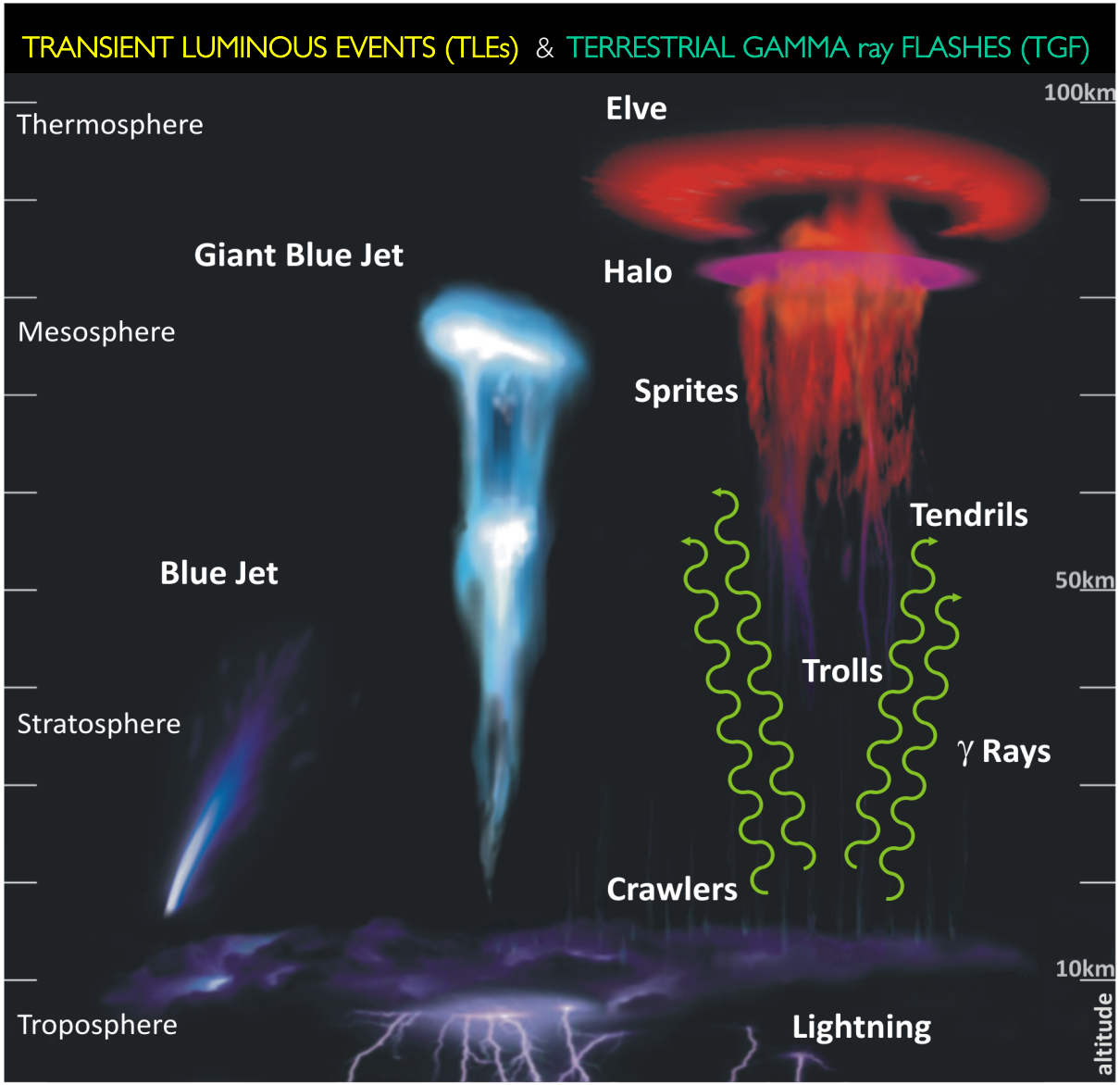
- El grupo se formó en noviembre de 2008 en el IAA – CSIC, Granada

- Formado por **5 miembros**

- Nuestra principal línea de investigación es el estudio de fenómenos relacionados con la ELECTRICIDAD ATMOSFÉRICA en atmósferas planetarias (Tierra, Venus, Jupiter, Saturno, … Exoplanets)

Lightning on the Earth upper atmosphere

(associated with intense tropospheric electric storms / lightning)



TLEs

DISCOVERED by chance

in 1989

(Franz *et al.*, Science, 1990)

TGFs

DISCOVERED by chance

in 1994

(Fishman *et al.*, Science, 1994)

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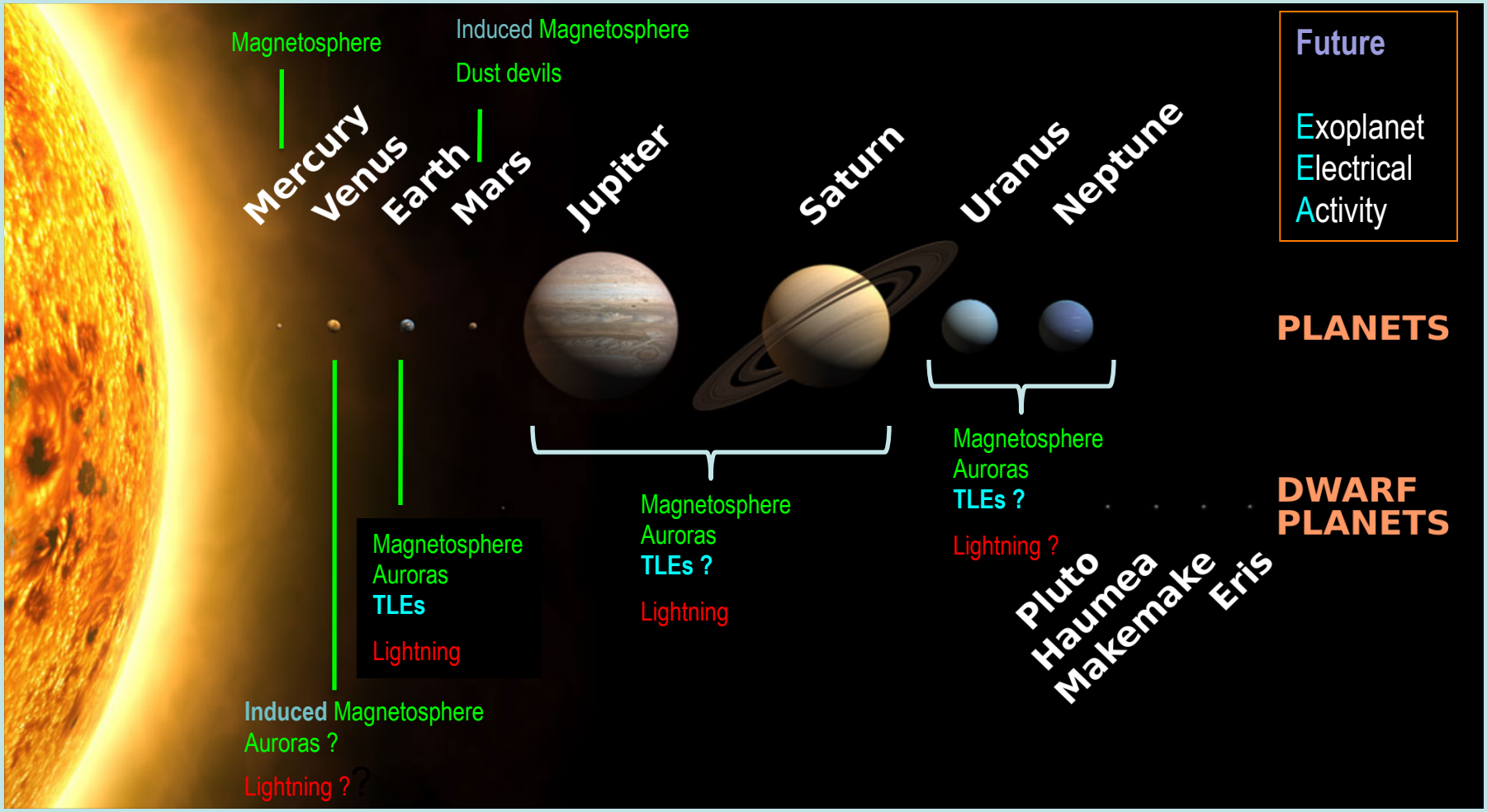

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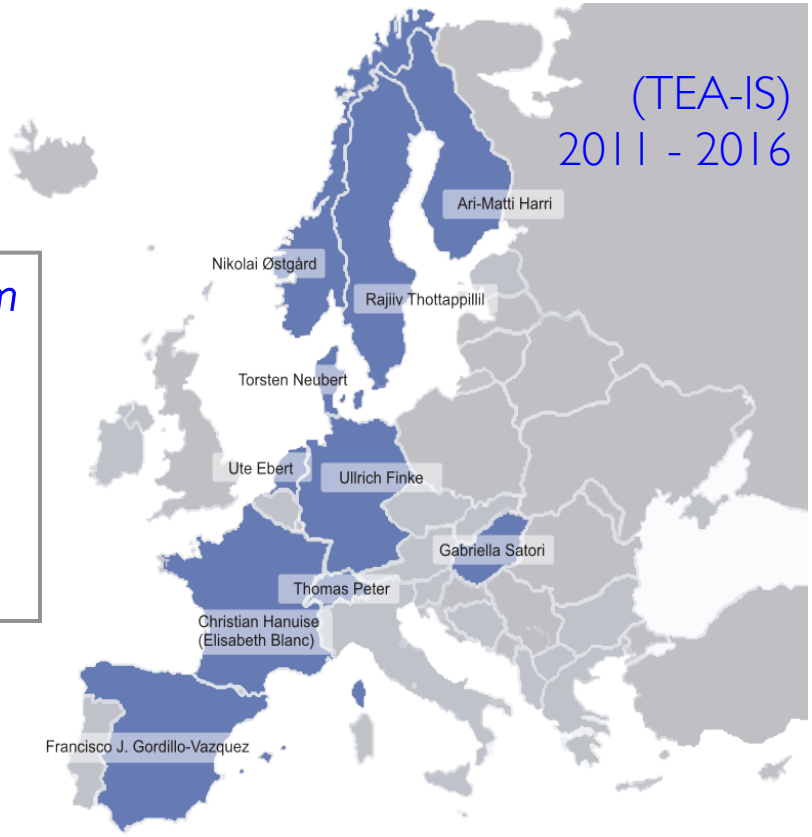
El grupo TRAnsient Plasmas in Planetary Atmospheres del IAA

- 3 Proyectos Nacionales del MICINN / MINECO
- 1 Proyecto Excelencia Junta Andalucía
- Proyectos solicitados a H2020

EUROPEAN SCIENCE FOUNDATION

(TEA-IS)
2011 - 2016



- El grupo co-lidera la red internacional *Thunderstorm Effects on the Atmosphere – Ionosphere System* (TEA-IS)

  10 países europeos
  > 100 investigadores

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El grupo TRAnsient Plasmas in Planetary Atmospheres del IAA

El **grupo** forma parte del **equipo científico** de futuras misiones espaciales europeas

The Atmosphere Space Interaction Monitor

Instrumento ESA para el módulo COLUMBUS de la ISS (350-400 km). Lanzamiento previsto en 2016. Duración mínima prevista de dos años

Microsatélite del CNES con 130 Kg de peso y lanzamiento previsto en 2017 a una órbita a 650 km de altura durante dos años

The Tool for the Analysis of RAdiations from lightNIngs and Sprites

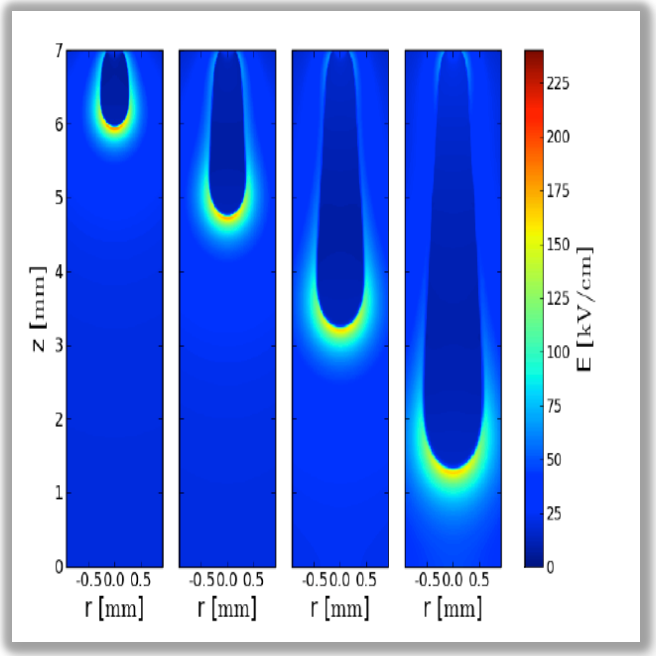
OBJETIVOS

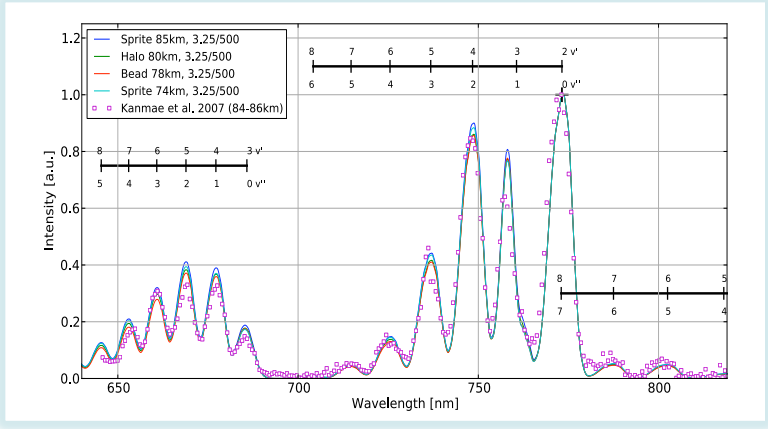
- Siguimiento global de TLE y TGF
- Física de TGF y TLE
- Acoplamiento con la ionosfera
- Influencia sobre el cinturón de radiación
- Perturbación de la dinámica atmosférica
- Circuito eléctrico atmosférico
- Efectos químicos sobre la atmósfera
- Estudios de NO_x y O_3 sobre tormentas

El grupo TRAnsient Plasmas in Planetary Atmospheres del IAA

(Different Approaches to Research in Planetary Atmospheric Electricity)

THEORY and MODELING





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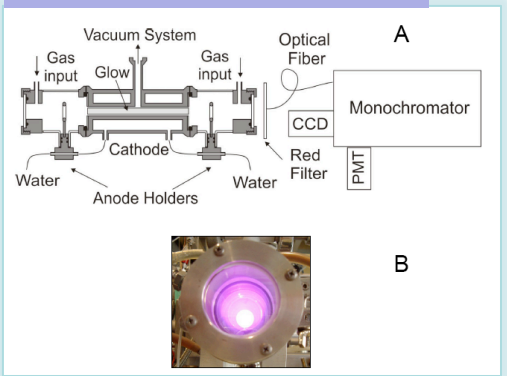
El grupo TRAnsient Plasmas in Planetary Atmospheres del IAA

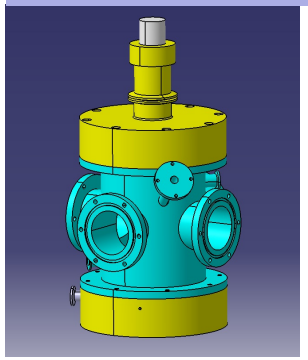
(Different Approaches to Research in Planetary Atmospheric Electricity)

LAB EXPERIMENTS

Glow-like structures of TLEs



Streamer-like structures of TLEs



In collaboration with:

IPP – Praga
IEM – CSIC - Madrid

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El grupo TRAnsient Plasmas in Planetary Atmospheres del IAA

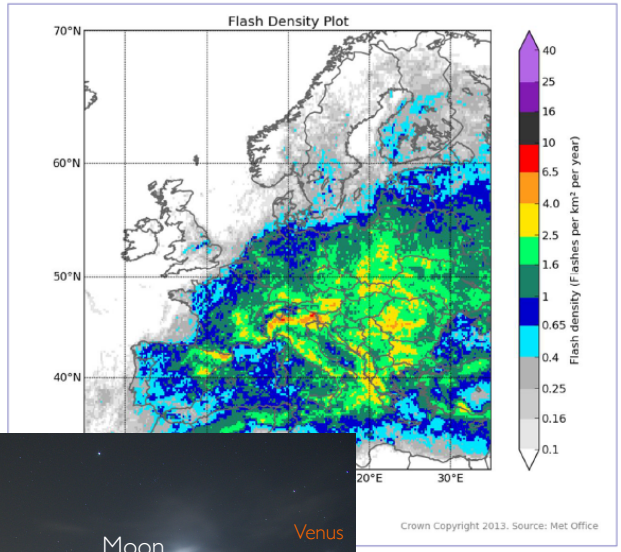
(Different Approaches to Research in Planetary Atmospheric Electricity)

OBSERVATIONS

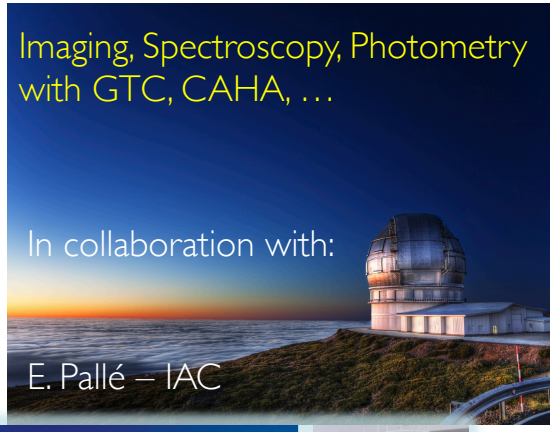
Lightning on EARTH

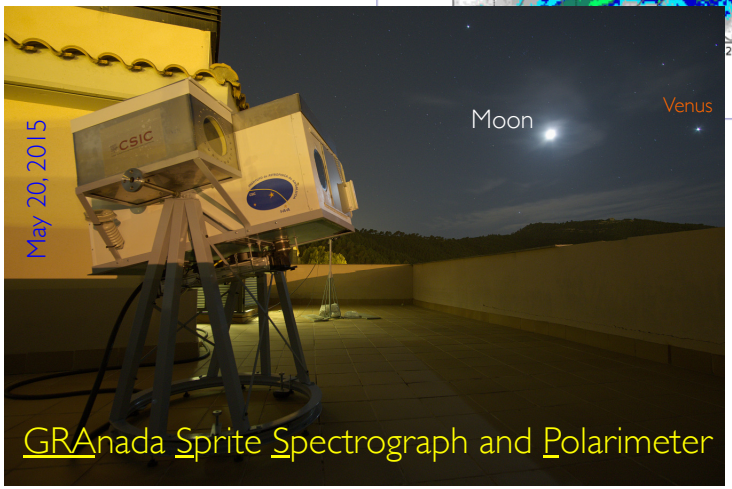
Met Office

Lightning Density in EUROPE (2008 – 2012)



Lightning on other planets





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