Imperial College London

Science & Technology Facilities Council

COMPARATIVE "PLANETARY" AURORAS

Marina GALAND
(*Imperial College London, UK; m.galand@imperial.ac.uk*)

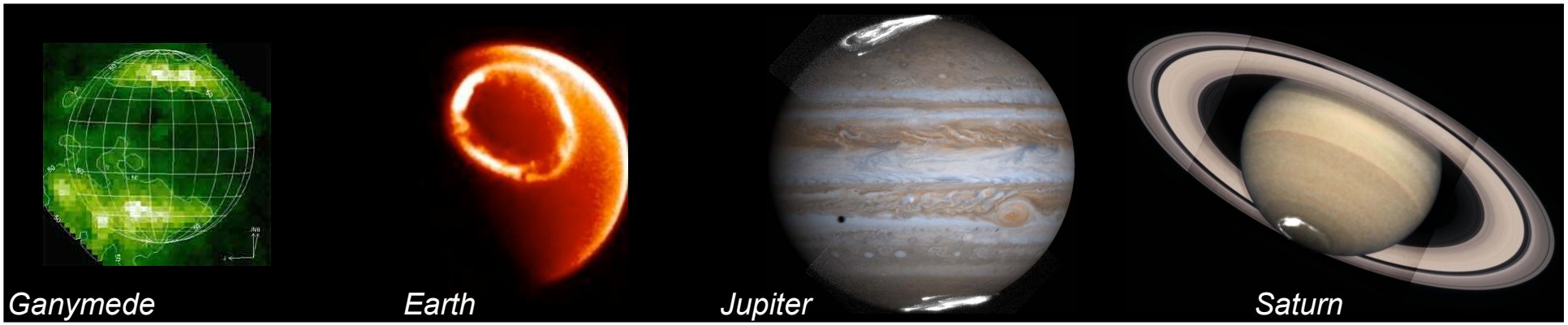
Anil BHARDWAJ
(*Vikram Sarabhai Space Centre, India*)

1. Overview of auroral emissions
2. Soft X-ray aurora
3. FUV aurora
4. Conclusion and discussion

Is aurora a universal process? After Jo Davila:

→ Has aurora been observed under different settings?

→ Has its analysis provided a deeper, physical understanding through a comparative approach?



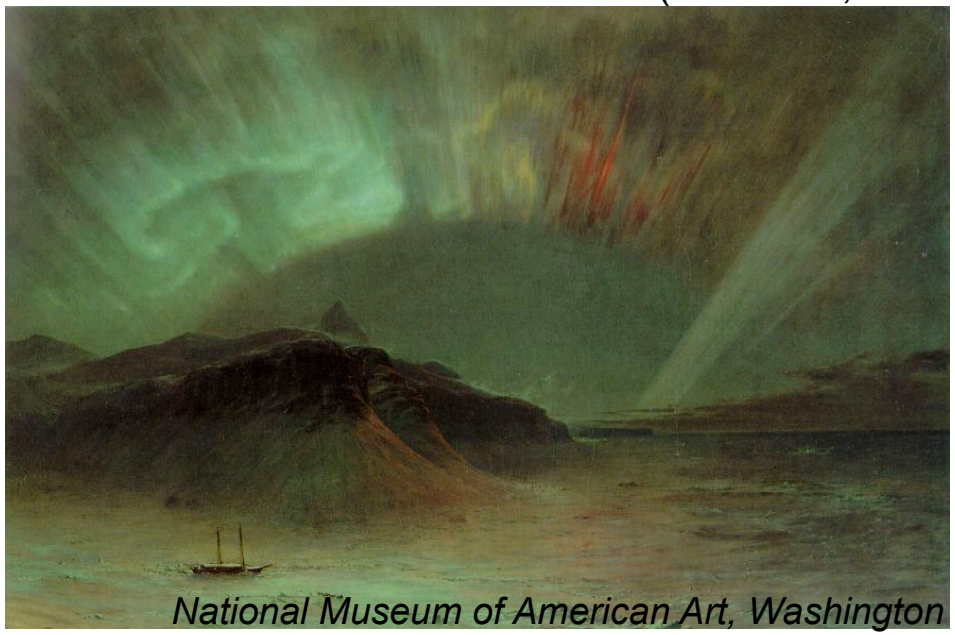
(1) Overview of auroral emissions

Auroral emissions have been observed at Earth from many centuries…

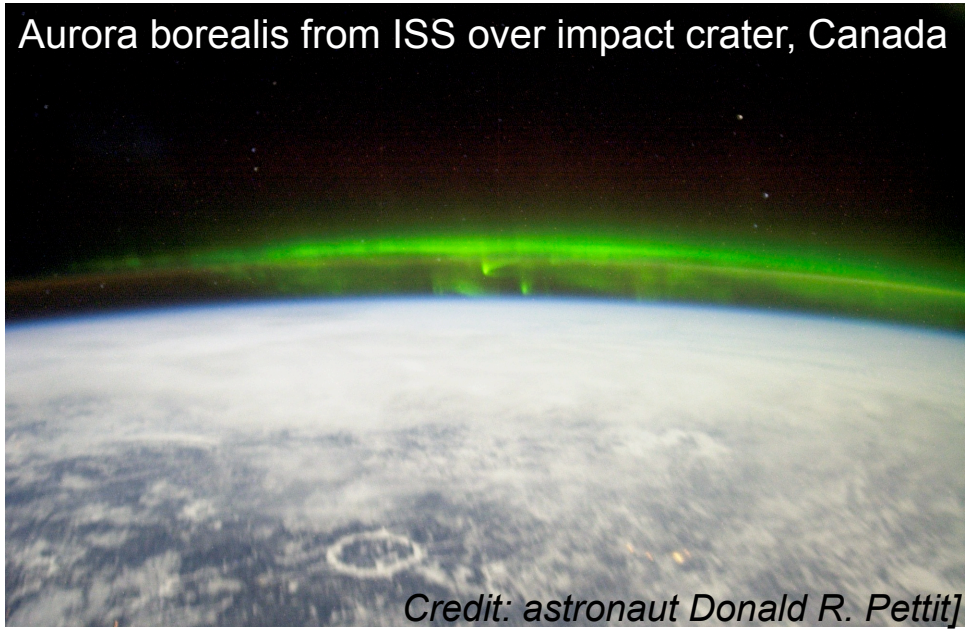
Aurora borealis over Nüremberg, Germany (1591)

Aurora borealis over Kulusuk, Greenland

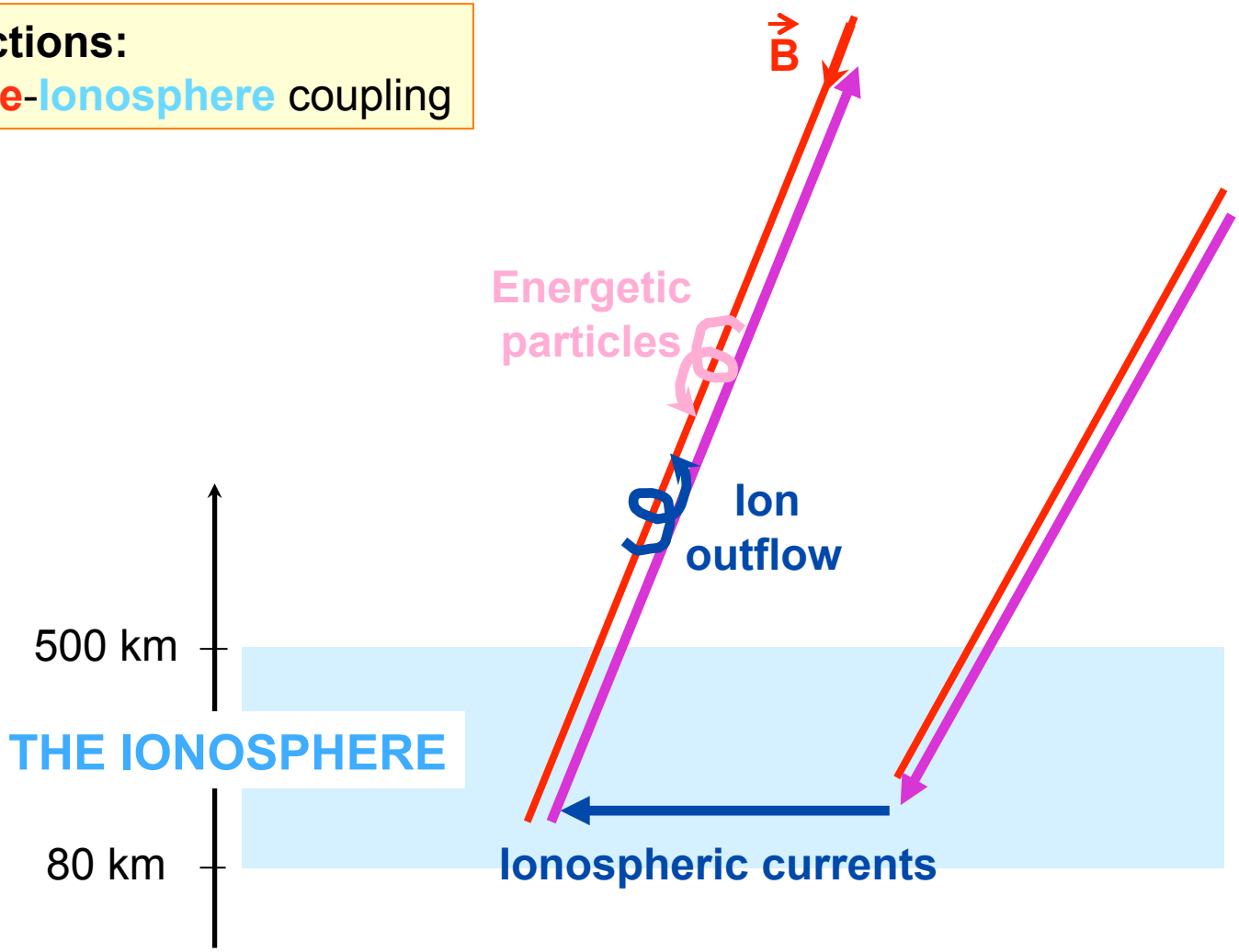
Aurora borealis from Newfoundland (F. Church, 1865)



Aurora borealis from ISS over impact crater, Canada



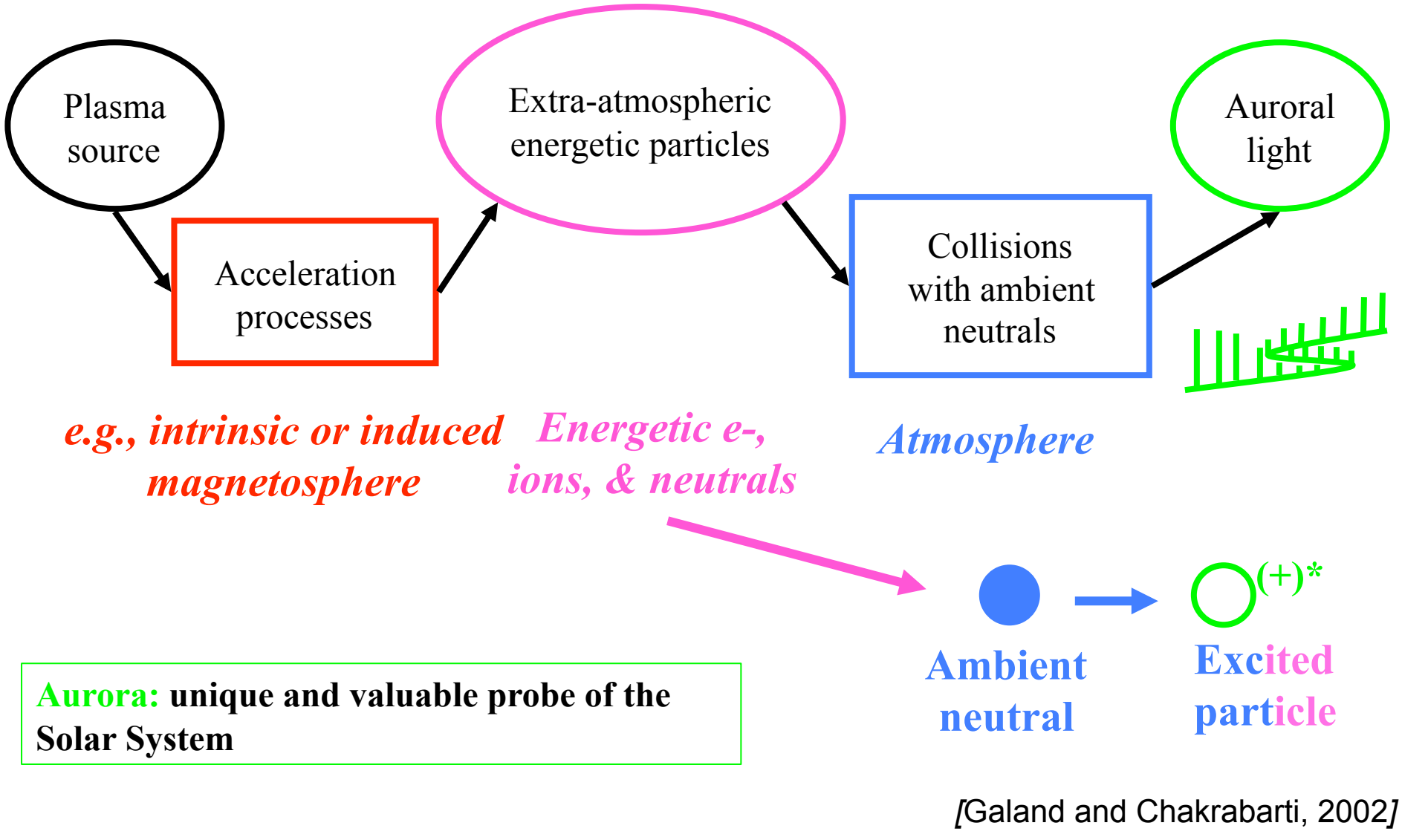
Plasma interactions:
Magnetosphere-**Ionosphere** coupling



Dynamic interchange of:

- particles (**particle precipitation** into, **ion outflow** from the ionosphere)
- electrodynamic energy (through **field-aligned currents**)

Aurora: *photo-manifestation of the interaction of energetic extra-atmospheric electrons, ions, and neutrals with an atmosphere.*



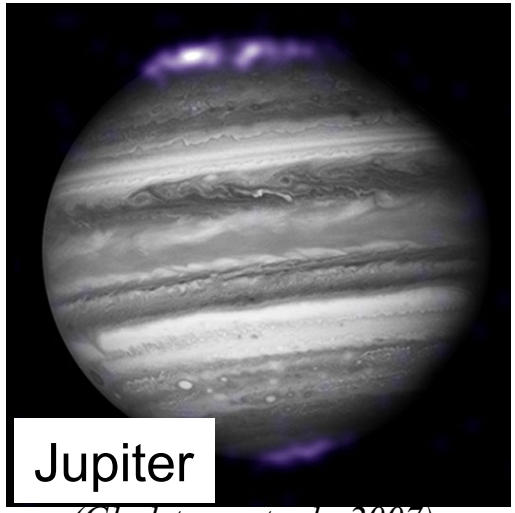
Aurora: unique and valuable probe of the Solar System

*[*Galand and Chakrabarti, 2002*]*

(2) Analysis of auroral soft X-rays

Auroral soft X-ray emissions in the Solar System

Key production mechanism for Jupiter/comets:
Charge-exchange (capture) of highly ionized ions with neutrals



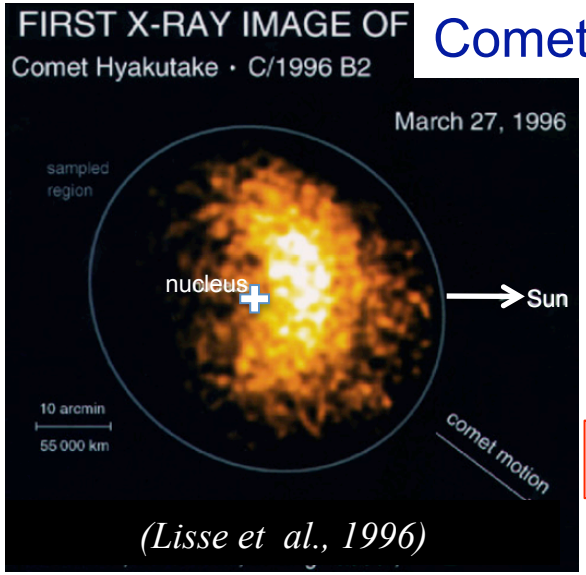
(Gladstone et al., 2007)

Jupiter: MeV heavy ions O^+ and S^+ from the magnetosphere (Io) which become highly charged through e- stripping with atmospheric neutrals and/or highly charged solar wind ions

Jovian atmospheric neutrals (H, H_2)

$$A^{q+} + M \rightarrow A^{(q-1)+*} + M^+$$

Soft X-ray photons produced: K-shell lines (O, S, C, Ne ions) have been identified



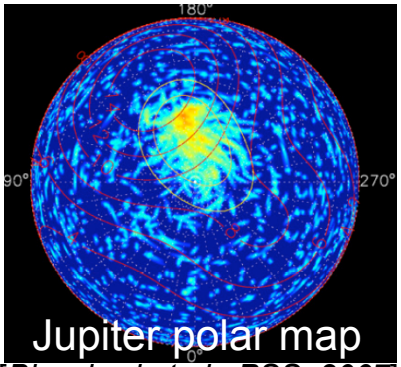
Comet

(Lisse et al., 1996)

Cometary neutrals (H_2O, OH, O, H)

Comets: Highly charged solar wind ions (e.g., O^{6+},O^{7+})

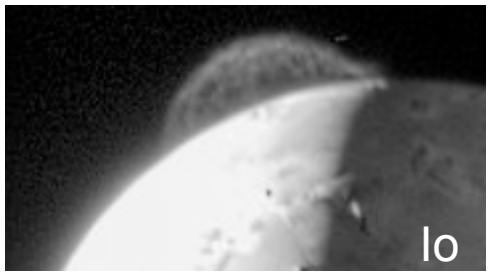
What do we learn from the auroral soft X-ray analysis?



[*Bhardwaj et al., PSS, 2007*]

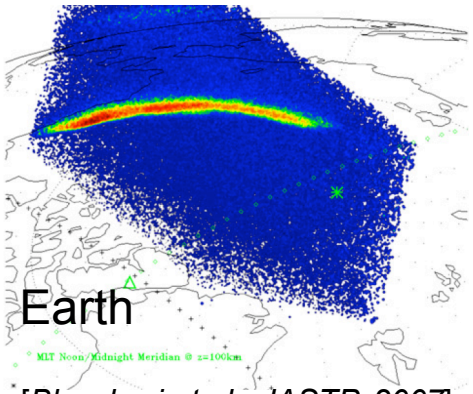
Jupiter

- *Plasma interaction and magnetospheric processes at Jupiter*
  - **Additional acceleration (E//)** from sw or magnetospheric source:
    - Comparison of spectra between Jupiter & comets highlights different charge state distributions → more energetic particles at Jupiter than at comets
  - Hot spot located **poleward** of the main oval:
    - Source: Outer magnetosphere or cusp
  - Still opened questions:
    - Magnetospheric or solar wind origin?
    - If magnetospheric source, missing link from Io's volcanos to the high latitude jovian atmosphere
    - Origin of the pulsation of ~45 min?



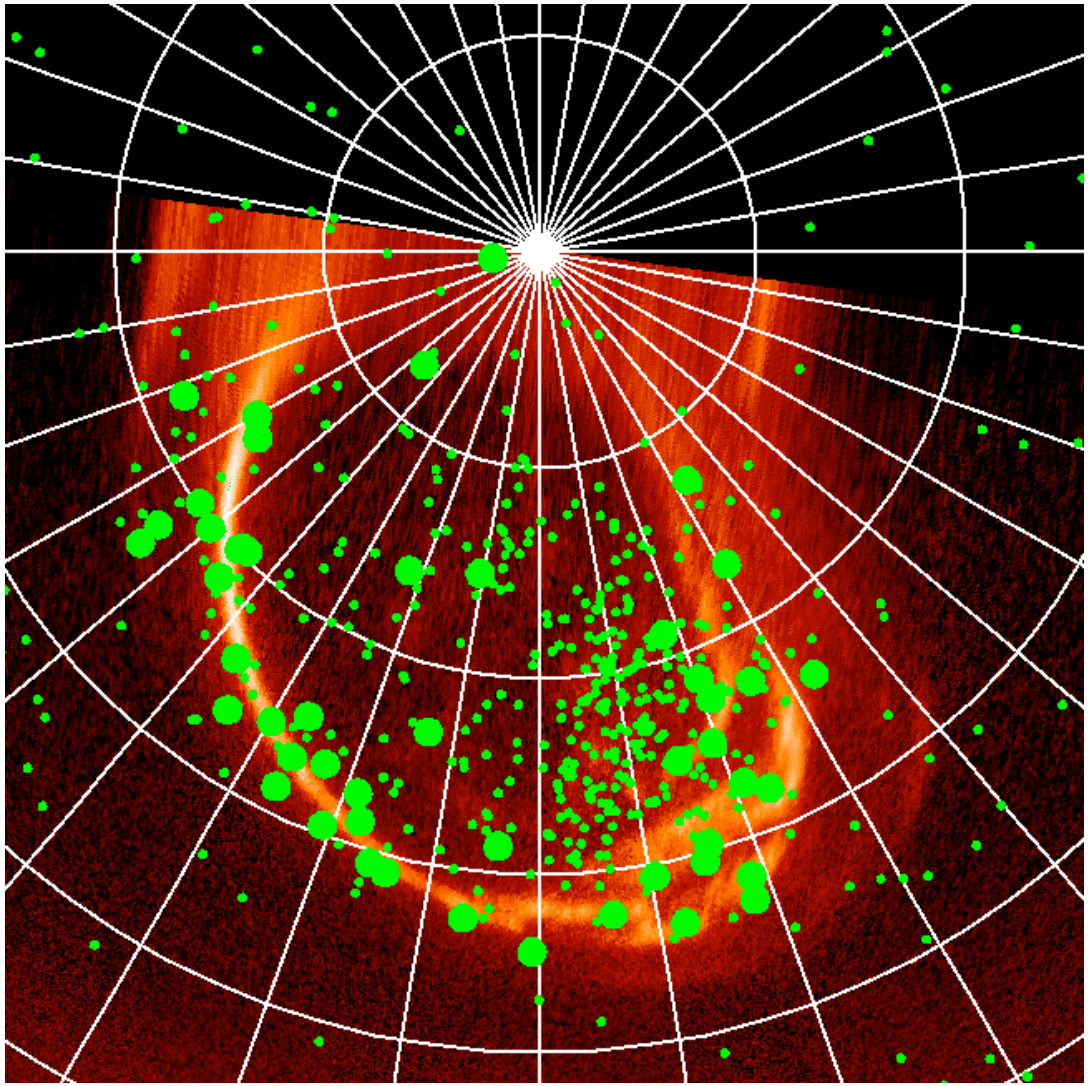
NASA/NH, Gladstone, 2007]

- *Prompted a dedicated search for soft X-ray auroral emissions at Earth*
  - Highly variable
  - Strong K-shell lines of nitrogen and oxygen by auroral e-
  + bremsstrahlung e-
  + possible solar wind contribution in the cusp
  → Need for high spectral resolution



[*Bhardwaj et al., JASTP, 2007*]

Aurorae in UV and X-rays [Jupiter]



Hubble STIS *FUV* image of Jupiter's northern auroral oval (polar projection) (e-)

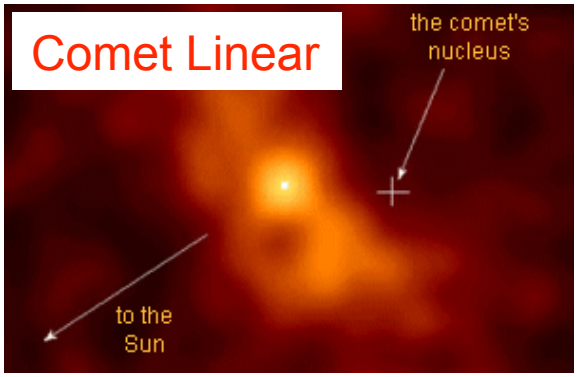
Chandra X-rays observations:

- > 2keV X-rays (e-)
- < 2keV X-rays (ions)

[Branduardi-Raymont et al., JGR, 2008]

What do we learn from the auroral soft X-ray analysis?

WHAT DO WE LEARN FROM THESE AURORAL SOFT X-RAY OBSERVATIONS?



Comets

- *Nature of the cometary coma* (outgassing rate, dust level):
  - extent of the X-ray emission (*10^4-10^6 km*),
  - location of the X-ray brightness peak (displaced or not),
  - X-ray total luminosity

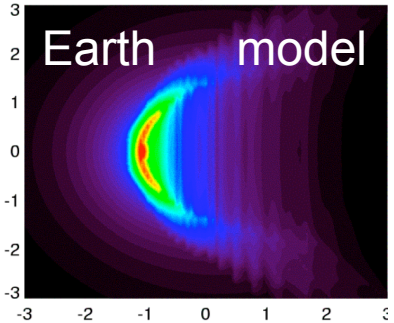
- *Characteristics of the solar wind* (oxygen ion flux, composition, fast/slow):
  - X-ray brightness variability (strongly correlated to O ion flux),
  - Line ratio → composition + energy of particles through charge state distribution

- *Prompted the search of soft X-ray emissions elsewhere in the Solar System*
  - observations + modeling

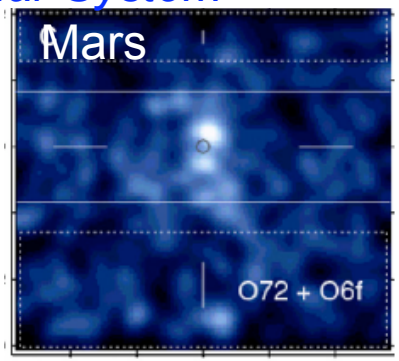
  → Geocorona and magnetosheath

  → Martian halo

  → Heliosphere

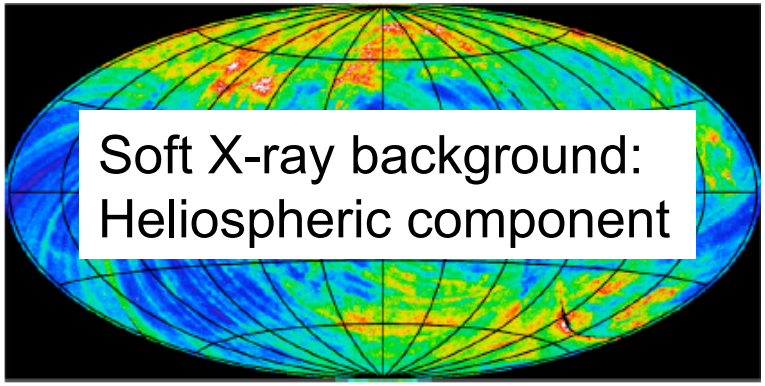


[*Robertson and Cravens*, 2003]



[*Dennerl et al.*, 2007]

What do we learn from the "auroral" soft X-ray analysis/modeling?



Highly charged ions from the solar wind

Interstellar neutrals entering freely the Solar System

$$O^{6+} + H \rightarrow O^{5+*} + H^{+}$$

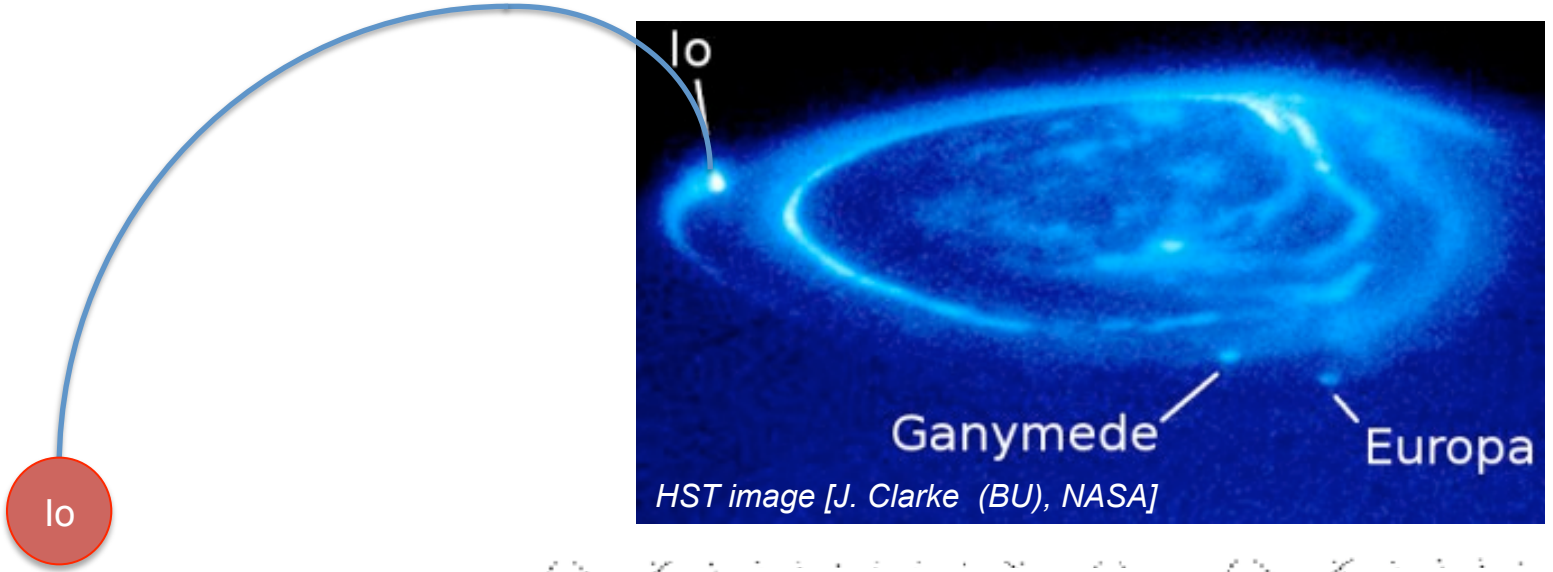
X-ray emission line

Heliospherical component to the soft X-ray background:

- Identification (*Cravens, 2000*):
  - Good correlation in time variation between soft X-ray backg and **solar H^+ flux**
- Quantitative estimation through modeling (*Koutoumpa et al., 2008*):
  - ¾ keV band: entirely heliospheric
  - ¼ keV band: significant contribution
  - Revision needed regarding the ***Local Bubble*** *(thermal plasma emission)*, its existence, its contribution to X-rays and its characteristics (hot→warm gas)
- Extrapolation to astropheres of other stars:
  - Detection of the mass-loss rate for stars (*Wargelin and Drake, 2001*)
  - Geometry of the stellar wind and size of the astrosphere through imaging the X-ray halo (future observatories)

(3) Analysis of auroral FUV emissions

Planetary magnetic field investigation using auroral emissions (Jupiter)

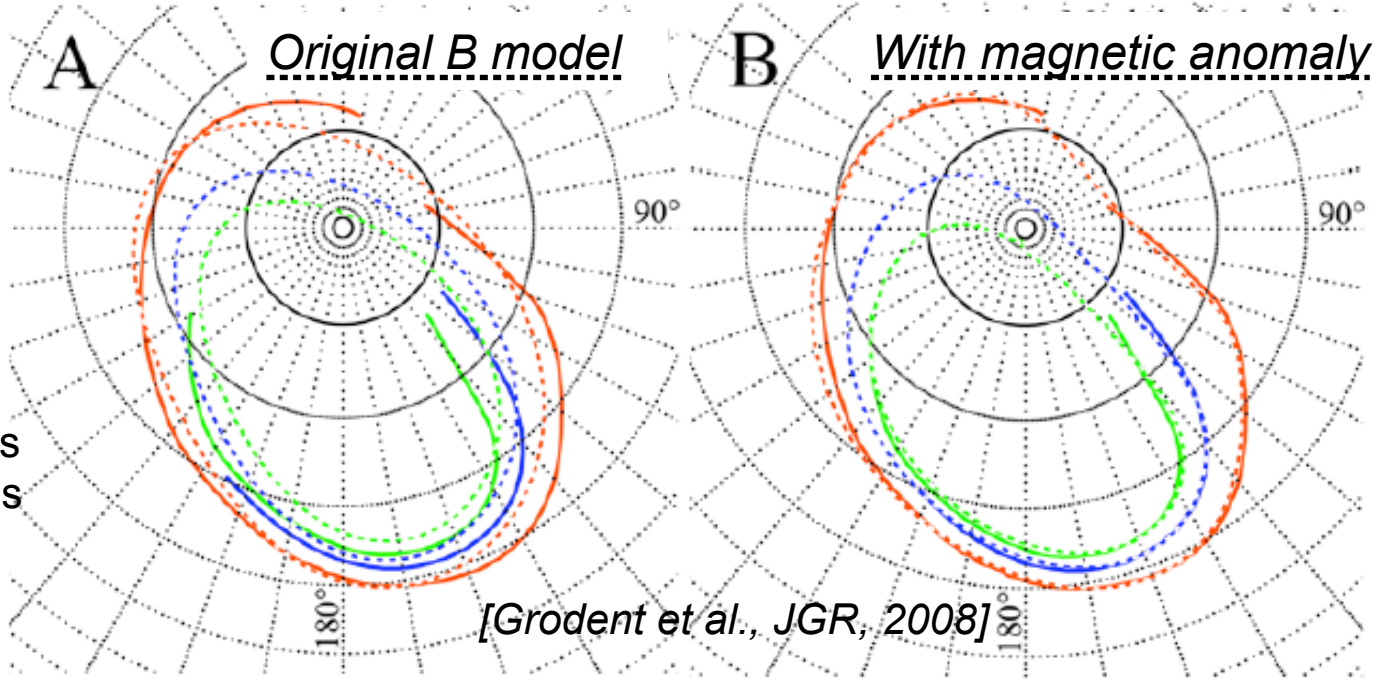


Galilean moon footprints

System III polar maps:

Io footprint
Europa footprint
Ganymede footprint

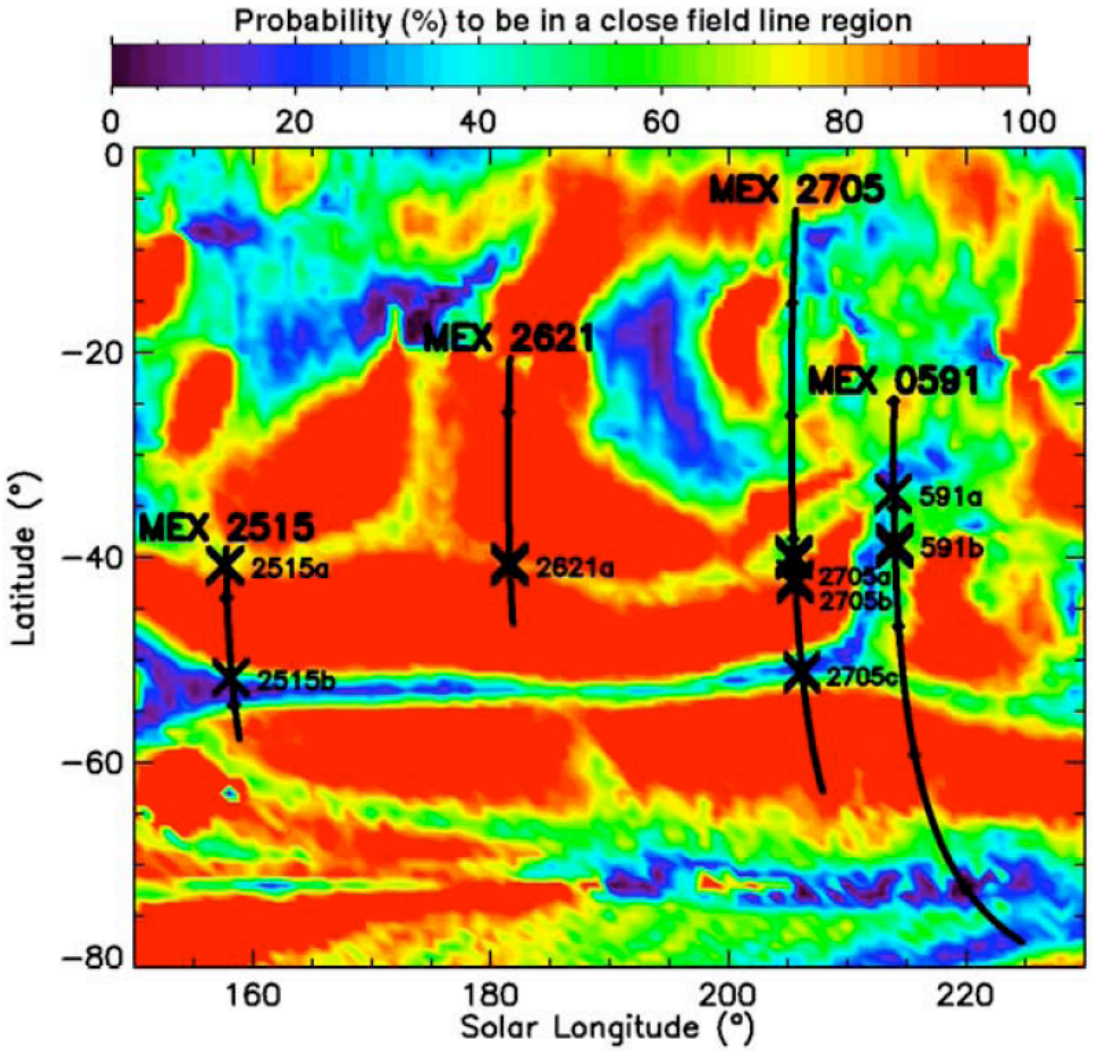
—— Observed UV contours derived from UV images
. . . . . Modeled contours



[Grodent et al., JGR, 2008]

➢ *Localized magnetic anomaly derived from auroral emission morphology*

Magnetic field topology associated with auroral emissions (Mars)



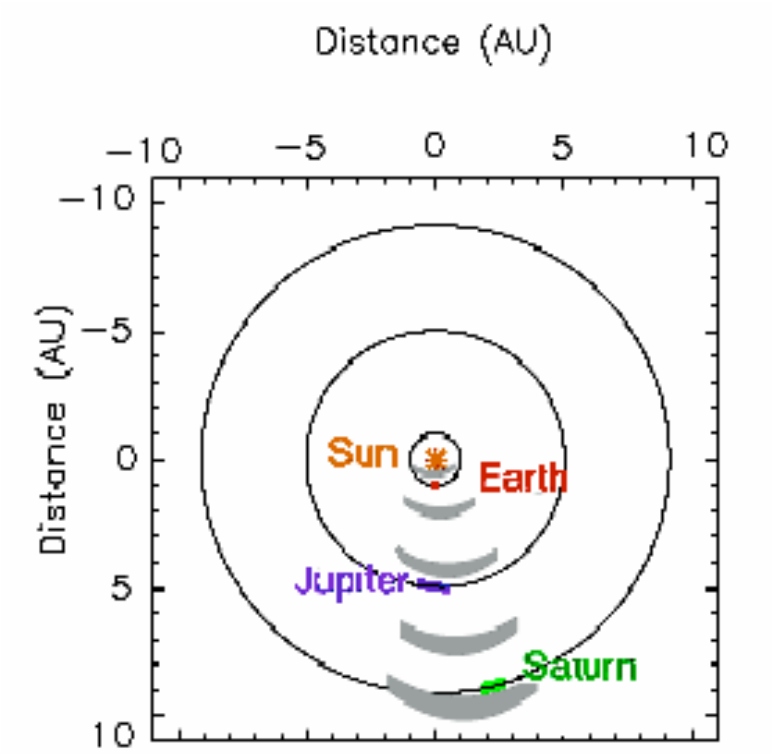
➢ ***Auroral emissions at Mars are located in cusp-like regions probably triggered by crustal magnetic fields***

[*Leblanc et al.*, *JGR*, 2008]

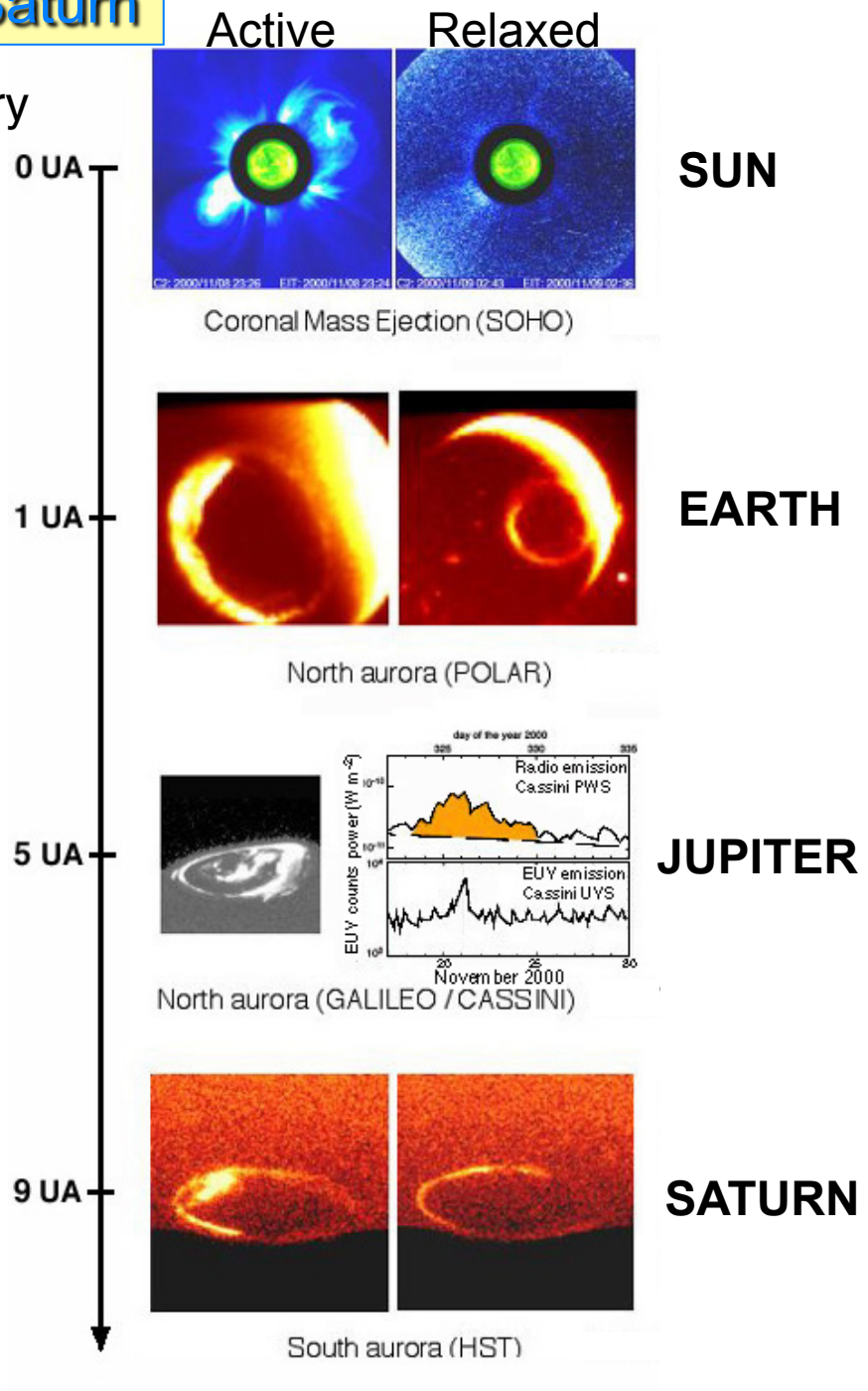
Interplanetary shock to Earth, Jupiter, Saturn

First synoptic view of a CME-driven interplanetary shock hitting the Earth, Jupiter and Saturn, triggering major – but different – auroral responses at all three planets

→ *Highlights the difference in setting and allows us to learn more about sw-MI coupling by comparing different responses*



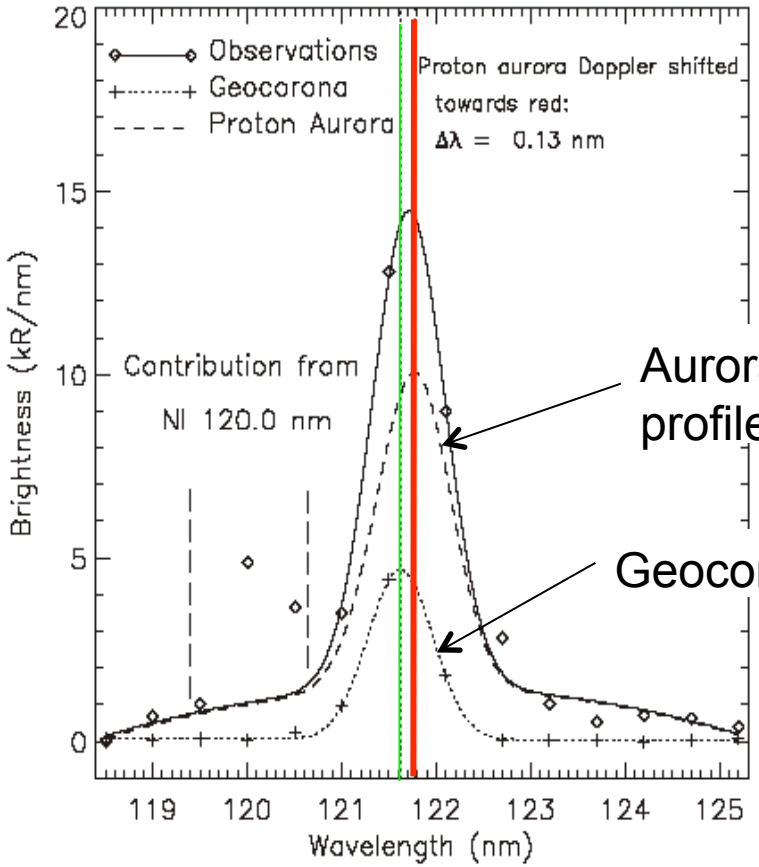
[Prangé et al., Nature, 2004]



Spectral analysis of H Lyman α auroral line profile

Earth

[Galand et al., *JGR*, 2002]



Terrestrial auroral H Ly α induced by precipitating keV **protons**: doppler-shifted

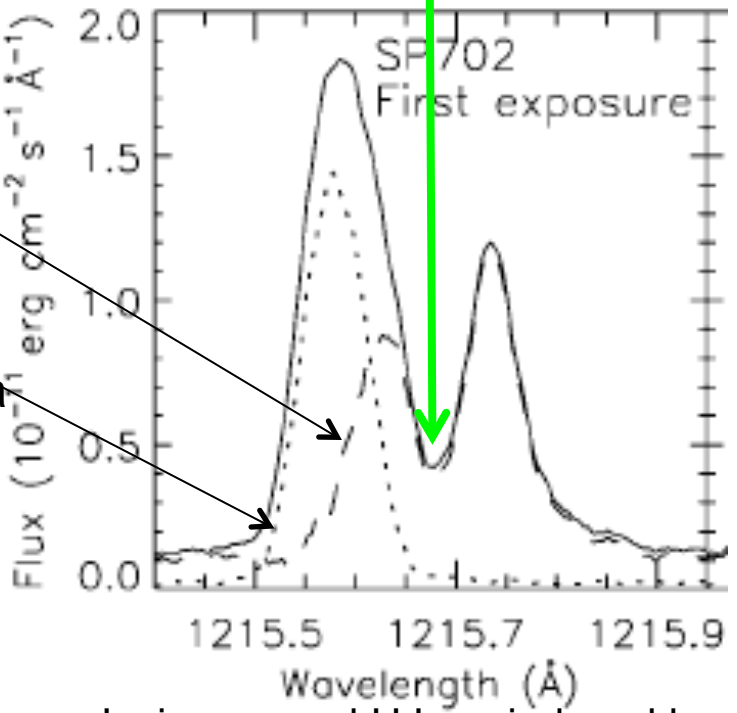
Auroral profile

Geocorona

Jupiter

Non-shifted in the Jovian rest frame

[Prangé et al., *Astrophys. J.*, 1997]



Jovian auroral H Ly α induced by precipitating keV **electrons**: deep core self-reversal

➢ ***Similar emissions used at various planets BUT different atmospheres + processes***
→ different physical quantities retrieved

CONCLUSION and DISCUSSION

✓ **Is aurora a universal process? YES!**

✓ Observed under different settings

✓ Comparative cross-body approach has helped to provide a deeper physical understanding of processes occurring in the Solar System:

- Has prompted observations yielding the discovery of new settings
- Is challenging our understanding under different settings
- Is providing an excellent step towards the aeronomy of extra-solar planets

✓ **Aurora is a unique and valuable probe of the Solar System:**

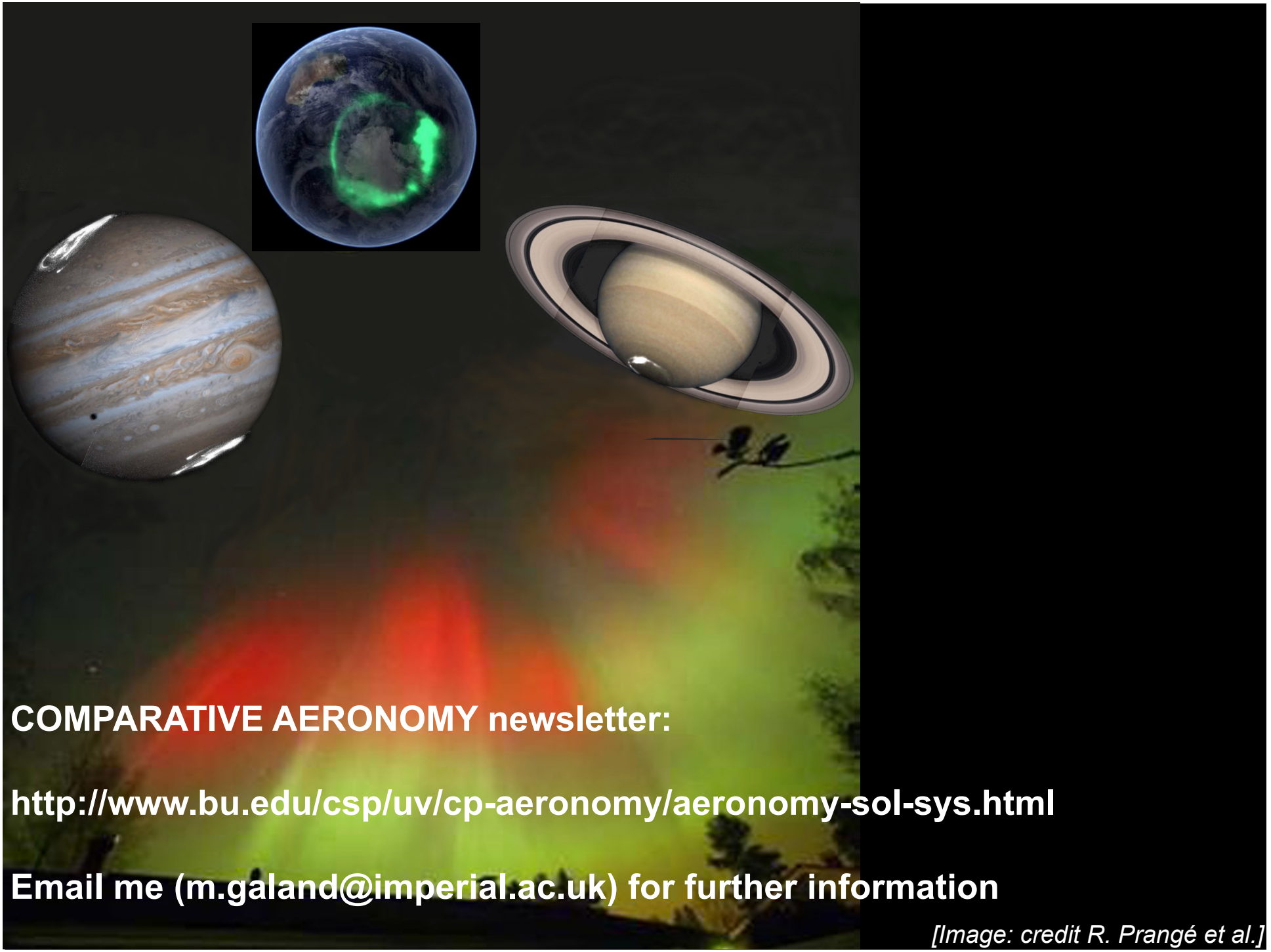
- Remote-sensing of magnetic field configuration
- Tracer of plasma interactions
- Indicator of energetic particle characteristics (e.g., type, energy) and source
- Fingerprint of the atmospheric constituents (e.g., H_3^+ & hydrocarbons in IR at Jupiter)
- **Multi-spectral** auroral analysis is a powerful approach (deeper understanding)

✓ **For studying the relationship between solar activity and aurora**

- Long term observations using planetary-dedicated Earth-orbiting platforms
- Orbiter at Solar System bodies → **for "ultimate" cross-body approach**

✓ **Quantitative auroral analysis at Earth:**

- Global "true" spectroscopic imaging in FUV from space!



COMPARATIVE AERONOMY newsletter:

http://www.bu.edu/csp/uv/cp-aeronomy/aeronomy-sol-sys.html

Email me (m.galand@imperial.ac.uk) for further information

[Image: credit R. Prangé et al.]