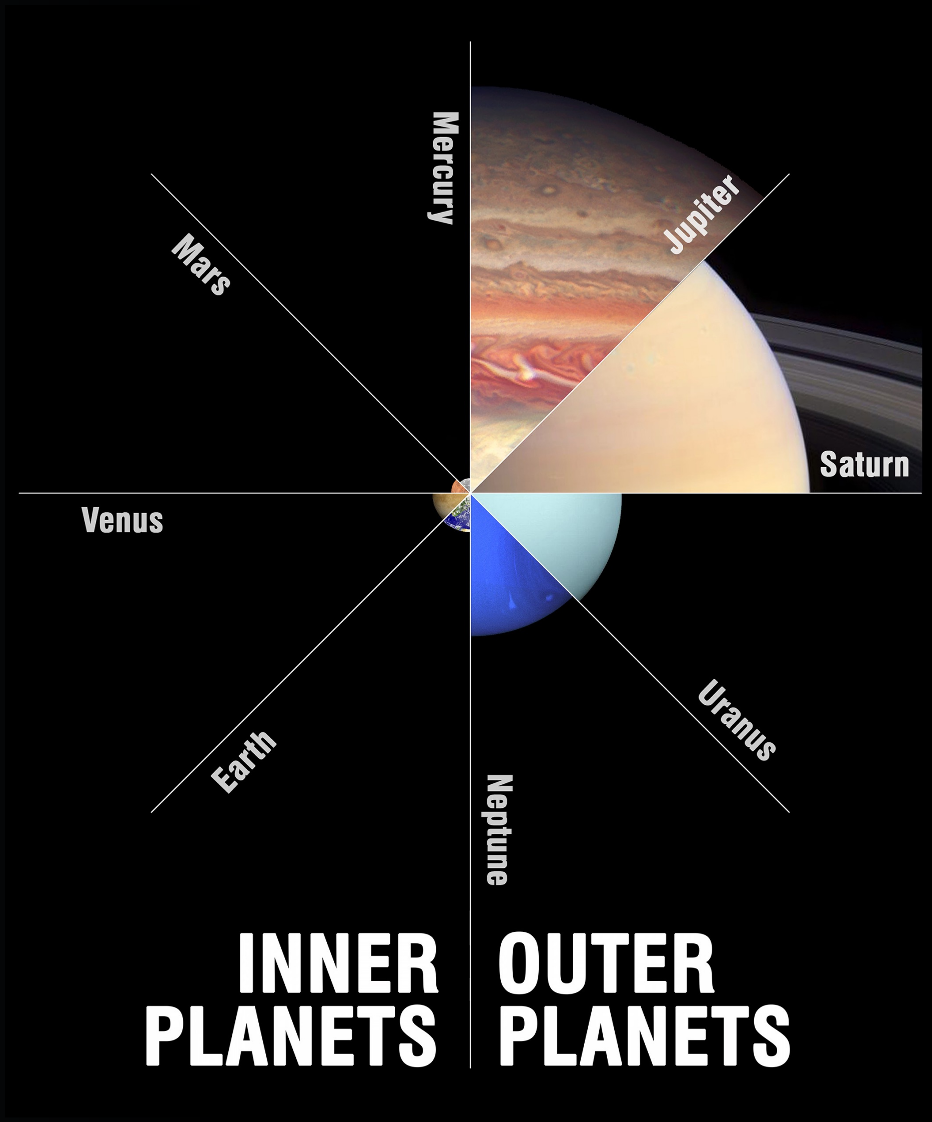
Comparative Planetary Magnetospheric Processes

George Clark[1], Wen Li[2], Dan Gershman[3], Peter Delamere[4], Bob Marshall[3] , Shannon Curry[6]

[1]Johns Hopkins Applied Physics Laboratory
[2]Boston University
[3]NASA Goddard Space Flight Center
[4]University of Alaska, Fairbanks
[5]University of Colorado, Boulder
[6]University of California, Berkeley

Special thanks to Sasha Ukhorskiy, Margret Kivelson, Shin Ohtani, Barry Mauk, Joachim Saur, Fran Bagenal, and Bob Lysak for their fruitful discussions



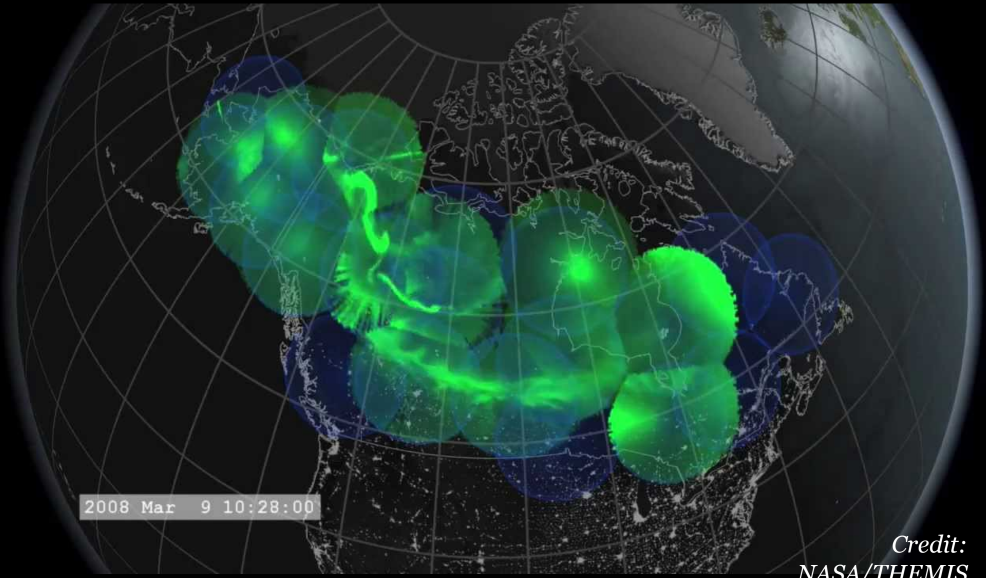
Credit: NASA/JPL

Can we apply the physical insight gleaned from comprehensive measurements at Earth to other systems?

Sounding rockets

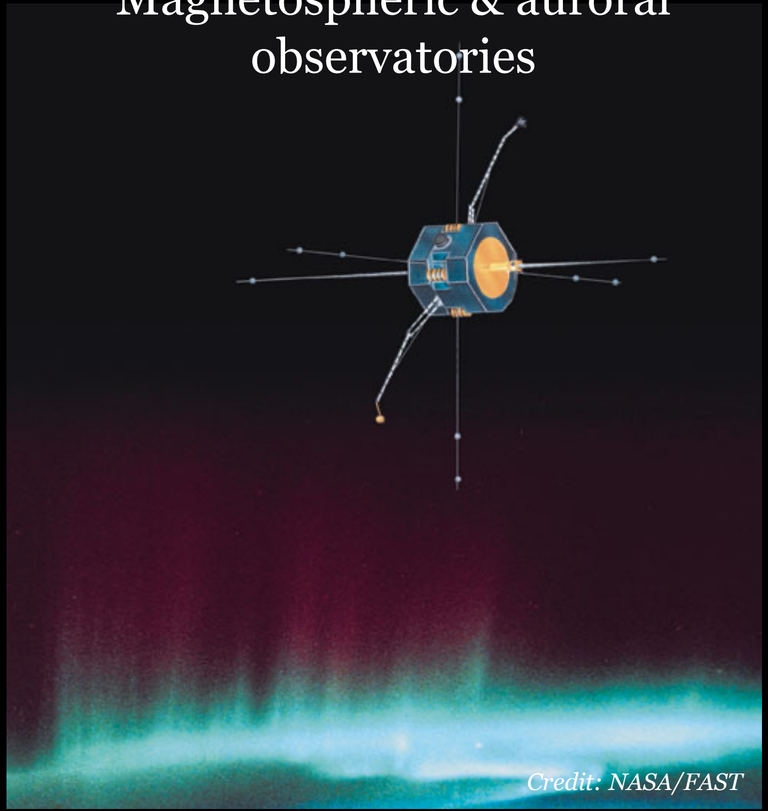
Credit: NASA/GREECE

Network of all sky imagers



Credit: NASA/THEMIS

Magnetospheric & auroral observatories



Credit: NASA/FAST

Why study other space environments? (M. Kivelson 2010)

- As Margy Kivelson noted in her 2010 GEM talk, *we are physicists*. And as physicists there is a driving desire to change the parameters governing the system (e.g., Earth's magnetosphere) in order to test whether behavior varies as predicted.

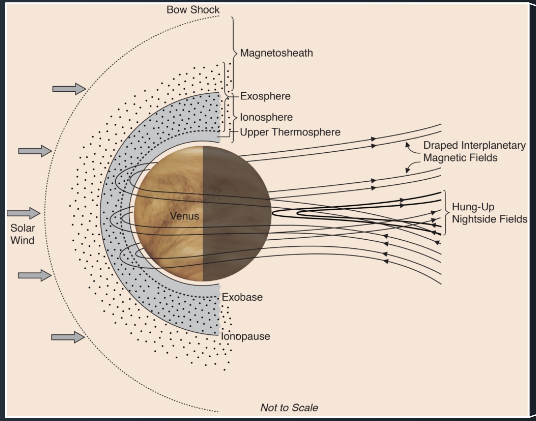
- Earth's magnetosphere experiences varying solar wind input, but other parameters, which are important for understand magnetospheres, such as plasma sources, rotation rate, magnetic field magnitude, size of magnetosphere change only very little or not at all.

- In contrast, elsewhere in the Solar System there are environments sourced by active moons that tap into the vast rotational energy of the planet, magnetospheres filled with neutrals and dust, and magnetic configurations that exhibit extreme tilts (e.g., Uranus) to the induced variety (Mars and Venus).

- Studies of planetary magnetospheres can be considered our experiments.

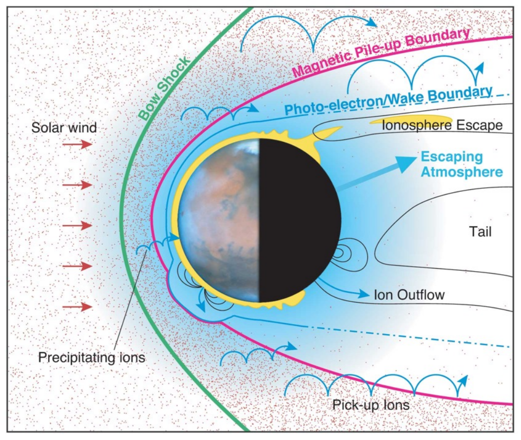
Magnetospheres

Induced Field

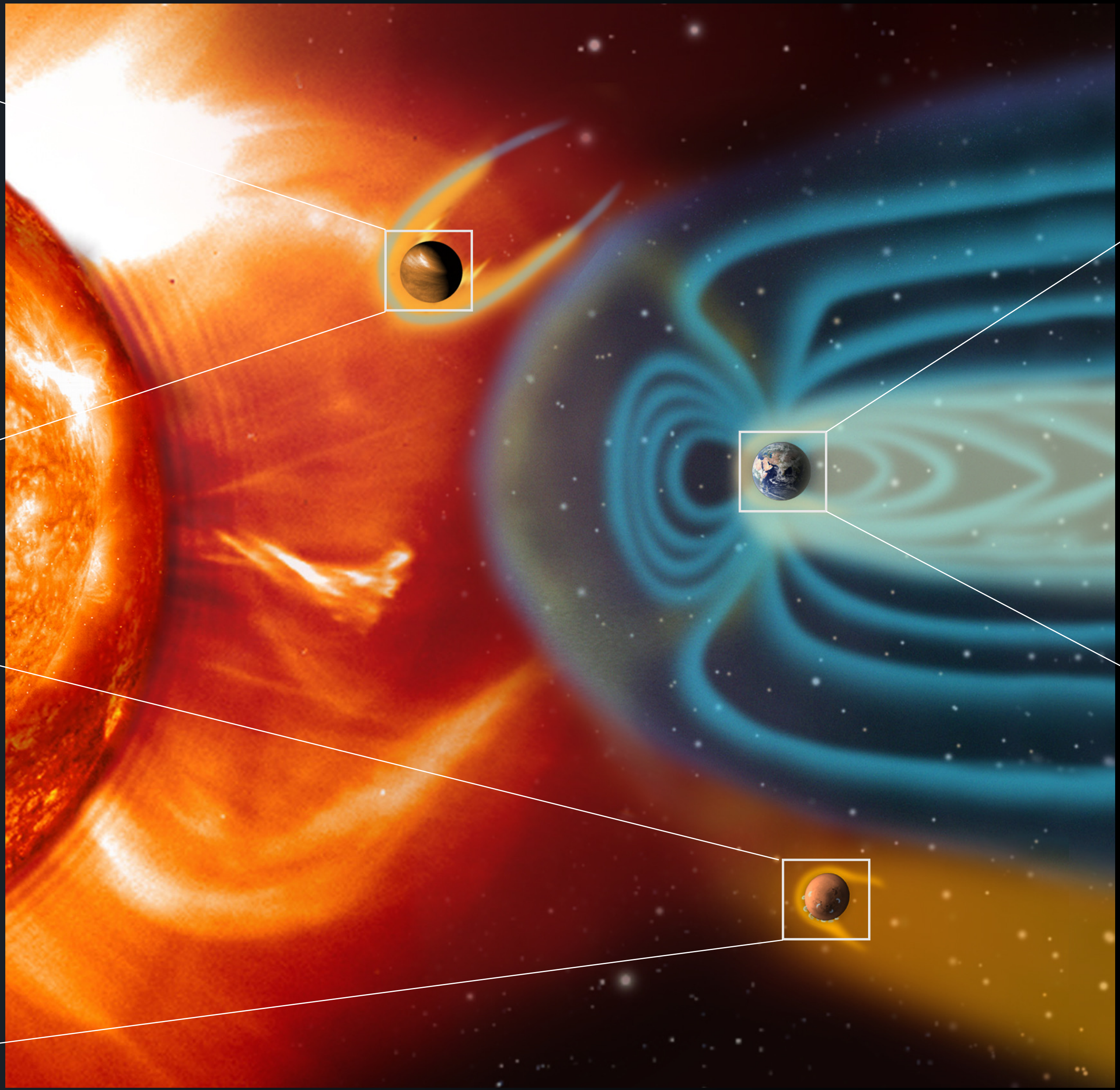


Credit: Richard Hart adapted from Russel et al. (2007)

Induced Field (+ crustal fields)

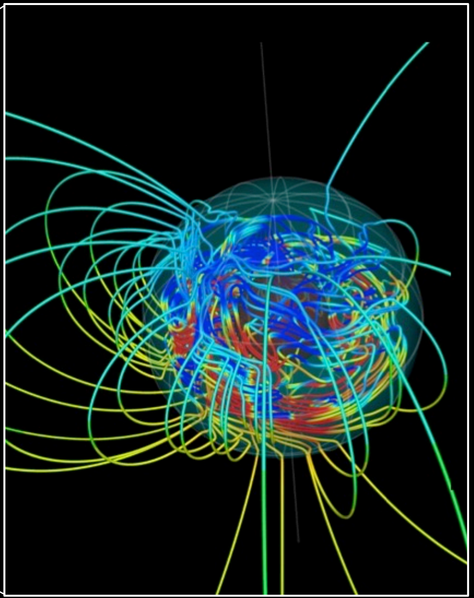


Credit: Fran Bagenal & Steve Bartlett



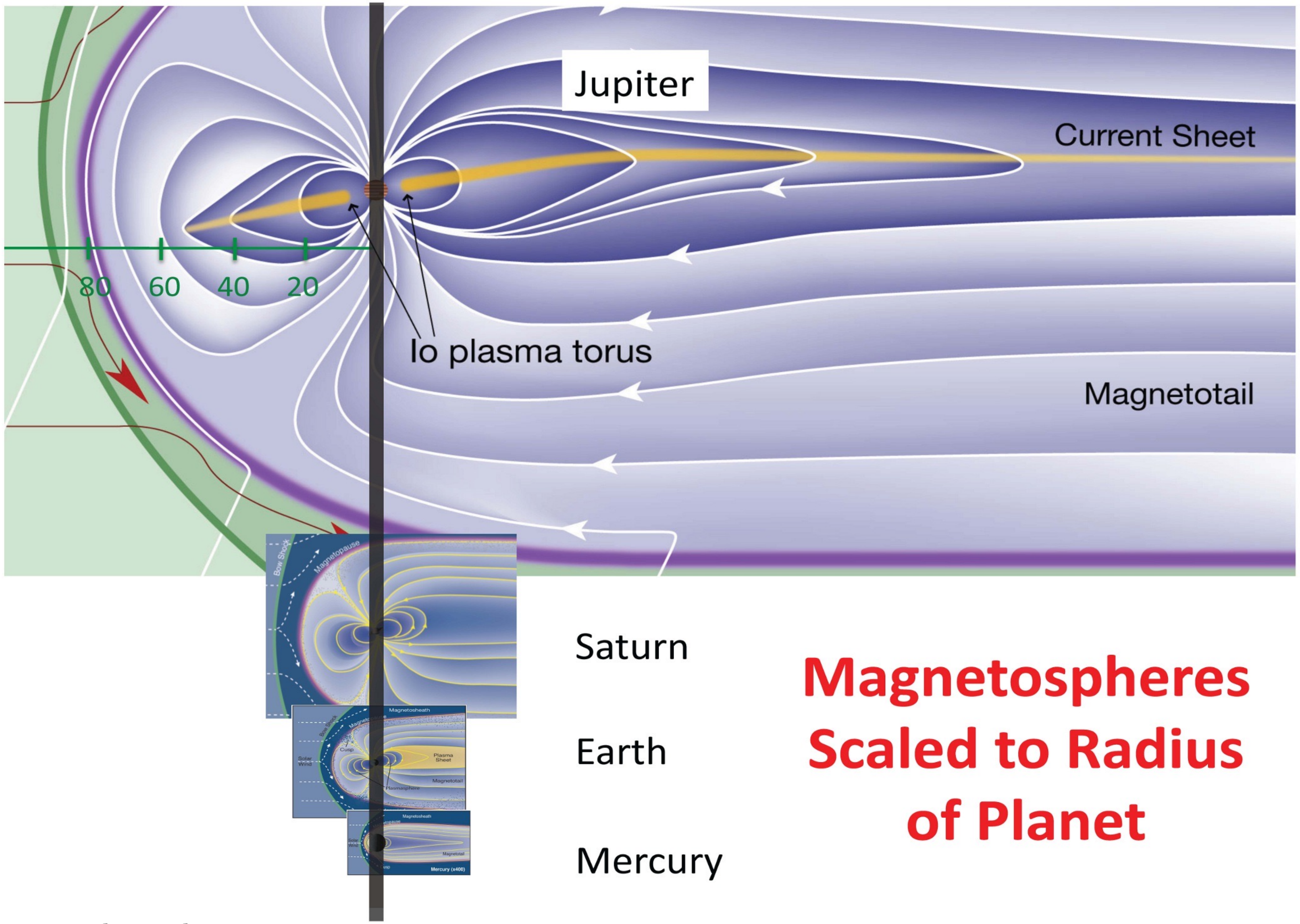
Credit: ESA

Dynamo



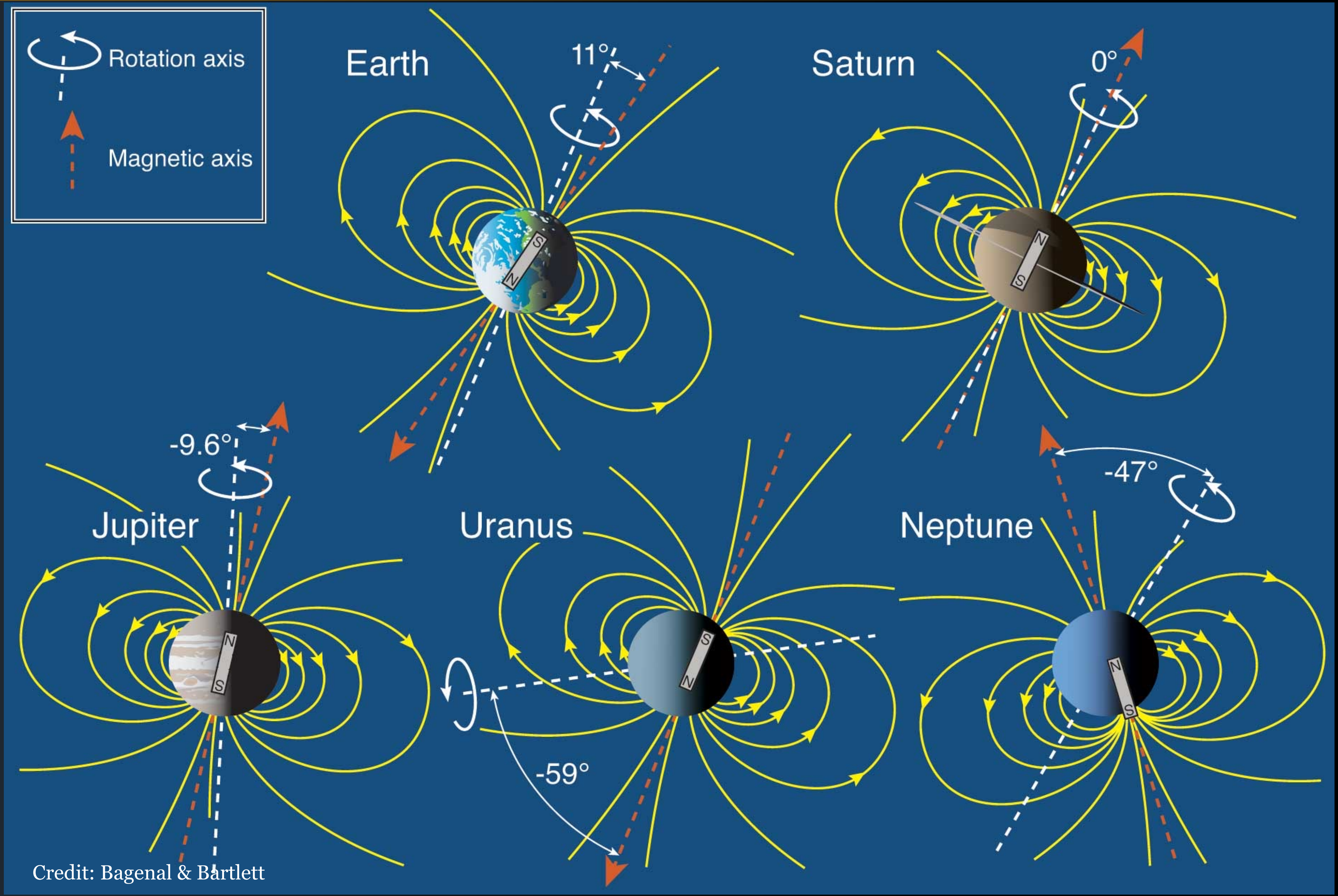
Credit: NASA

Magnetospheric scaling to planetary radius



Credit: Bagenal & Bartlett

Planetary magnetic field configurations



Credit: Bagenal & Bartlett

Magnetospheres throughout the Solar System

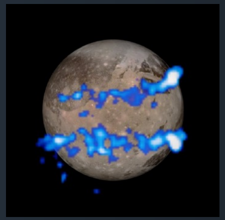
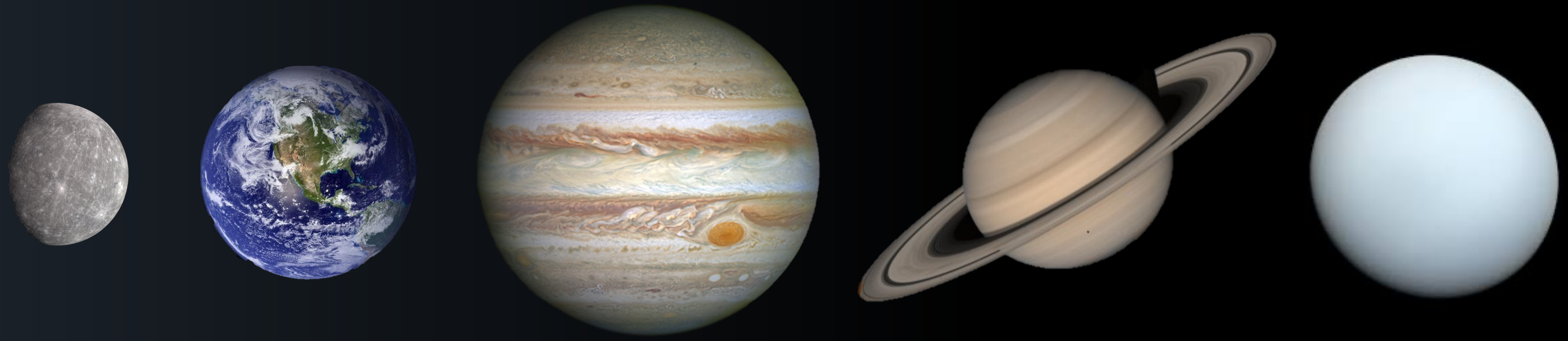


Image Credit: NASA/ESA/J. Saur/University of Cologne

Ganymede too!

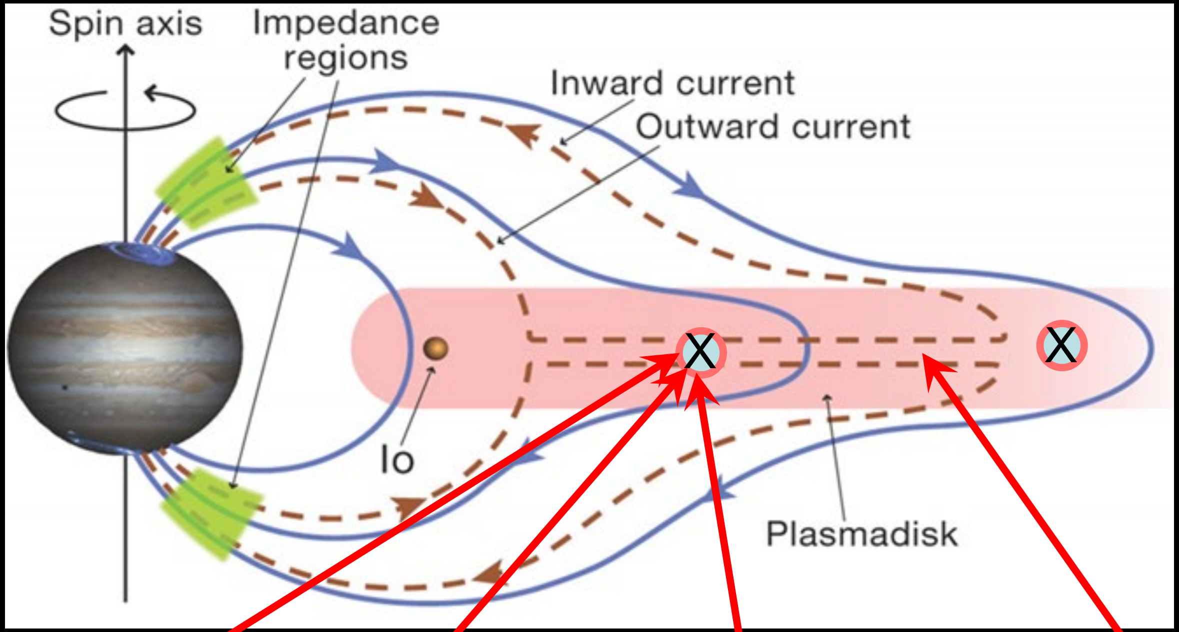


Characteristics	**Mercury**	**Earth**	**Jupiter**	**Saturn**	**Uranus**
Plasma Density [cm^{-3}]	~1	4000	>3000	~100	~3
Composition	H^+	H^+, O^+	H^+, O^{n+}, S^{n+}	H^+, O^+, H_2O^+, OH^+	H^+ (?)
Source	Solar Wind (SW)	Ionosphere + SW	Io (heavies), ionosphere (H^+)	Enceladus, Rings	Atmosphere? Moons?
Plasma motion	SW driven	SW + rotation driven	Rotation driven	Rotation driven	Rotation (+SW?)
Magnetic field @ surface [nT]	~300	31,000	428,000	22,000	23,000

Credit: Kivelson & Bagenal (2014)

Current sources in SW vs rotationally driven systems (credit: Barry Mauk)

$$\boldsymbol{J}_\perp = \frac{\boldsymbol{b}}{B}\, x\, \nabla_\perp (P_\perp) + (P_\parallel - P_\perp)\frac{\boldsymbol{b}\ x\ (\boldsymbol{b}\cdot\nabla)\boldsymbol{b}}{B} + (m\cdot n)\frac{\boldsymbol{b}}{B}\, x\, \frac{dV}{dt}$$



Pressure Gradient

Pressure Anisotropy

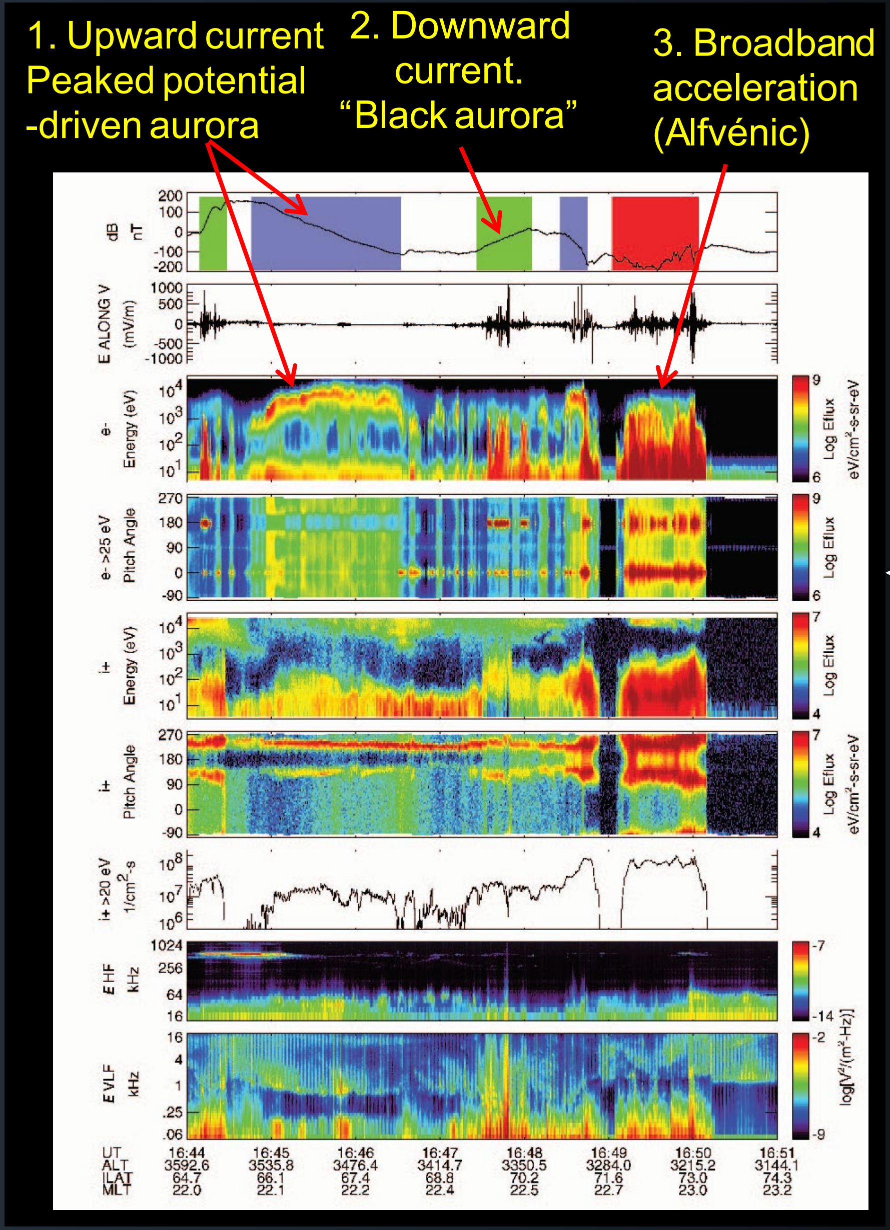
Centrifugal

Coriolis driven

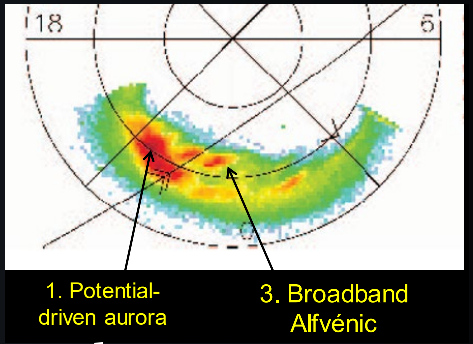
$$\boldsymbol{J}_\perp = \frac{\boldsymbol{b}}{B}\, x\nabla_\perp (P_\perp) + (P_\parallel - P_\perp)\frac{\boldsymbol{b}x(\boldsymbol{b}\cdot\nabla)\boldsymbol{b}}{B} + (m\cdot n)\frac{\boldsymbol{b}}{B}x\left(\boldsymbol{\Omega}_{pl}x\left(\boldsymbol{\Omega}_{pl}x\boldsymbol{R}\right)\right) + (m\cdot n)\frac{\boldsymbol{b}}{B}x\left(2\cdot\boldsymbol{\Omega}_{pl}x\boldsymbol{U}_{rad}\right)$$

Exploring the parameter space within our solar system

Expectations based on Earth auroral observations vs reality (at Jupiter)

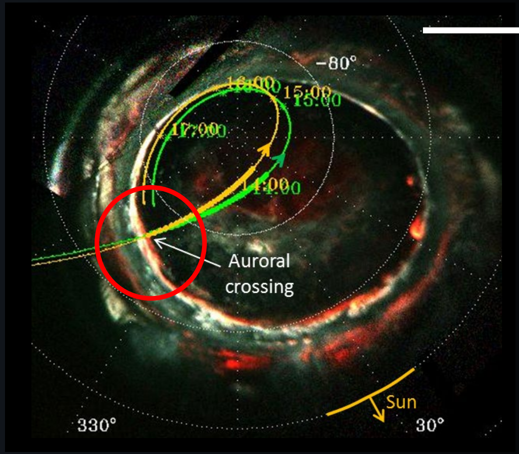


Paschmann (2002)

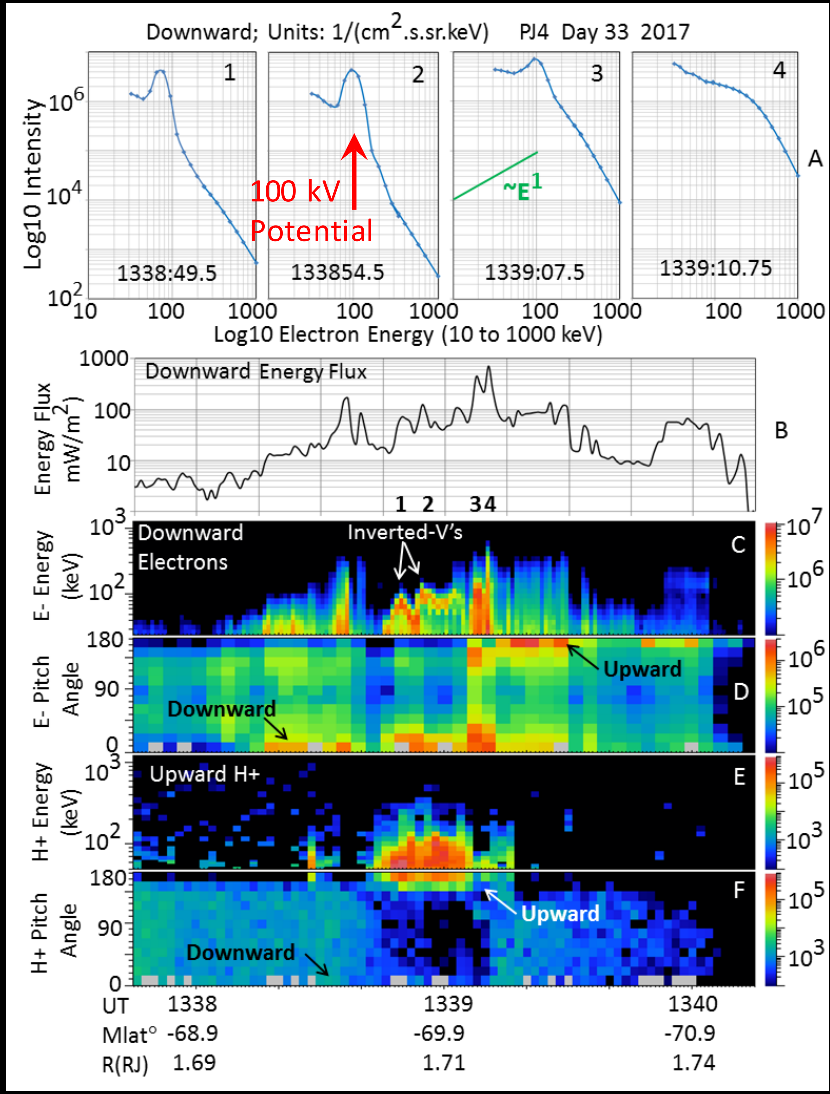


Earth

Jupiter

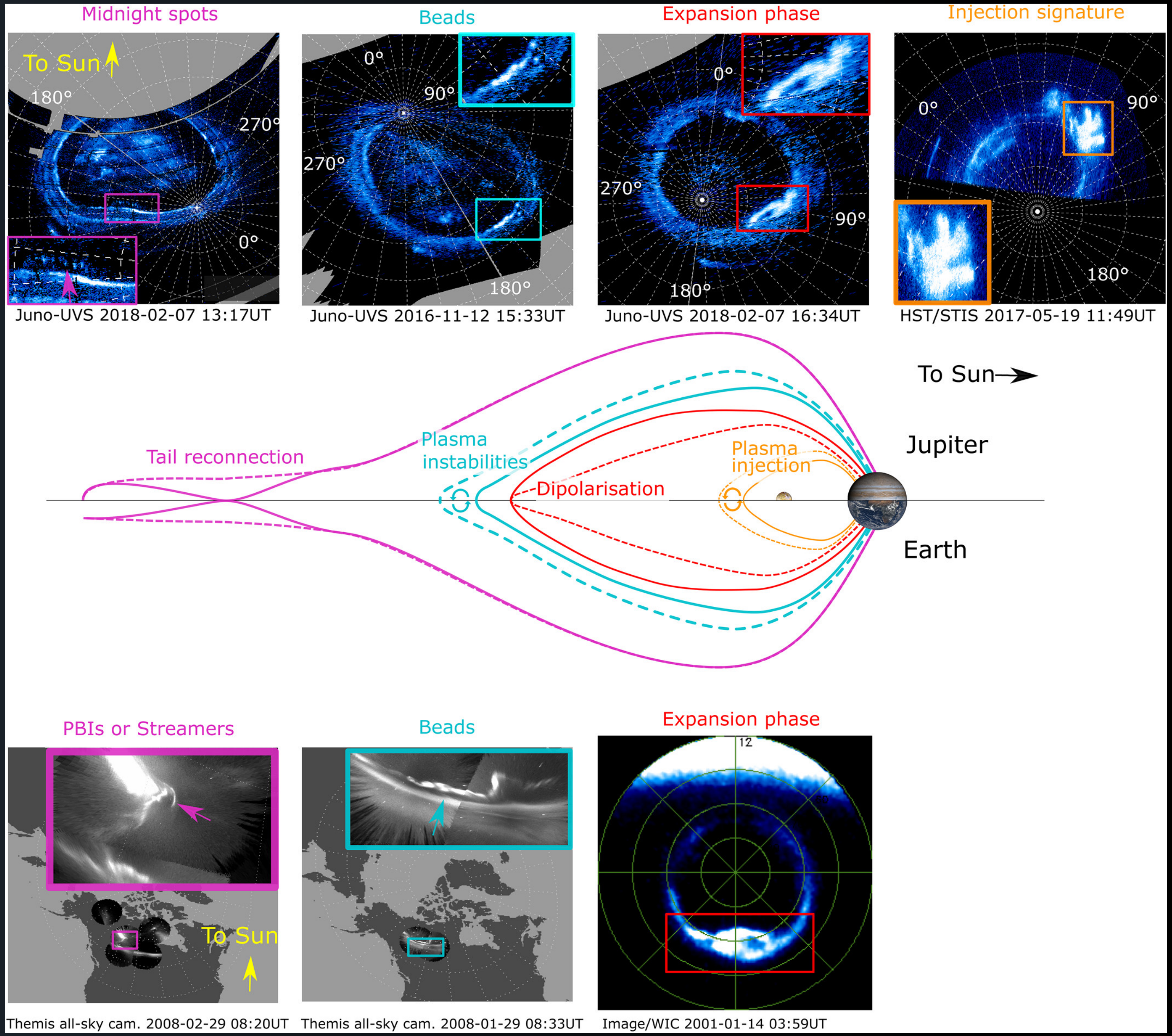


Credit: Juno UVS

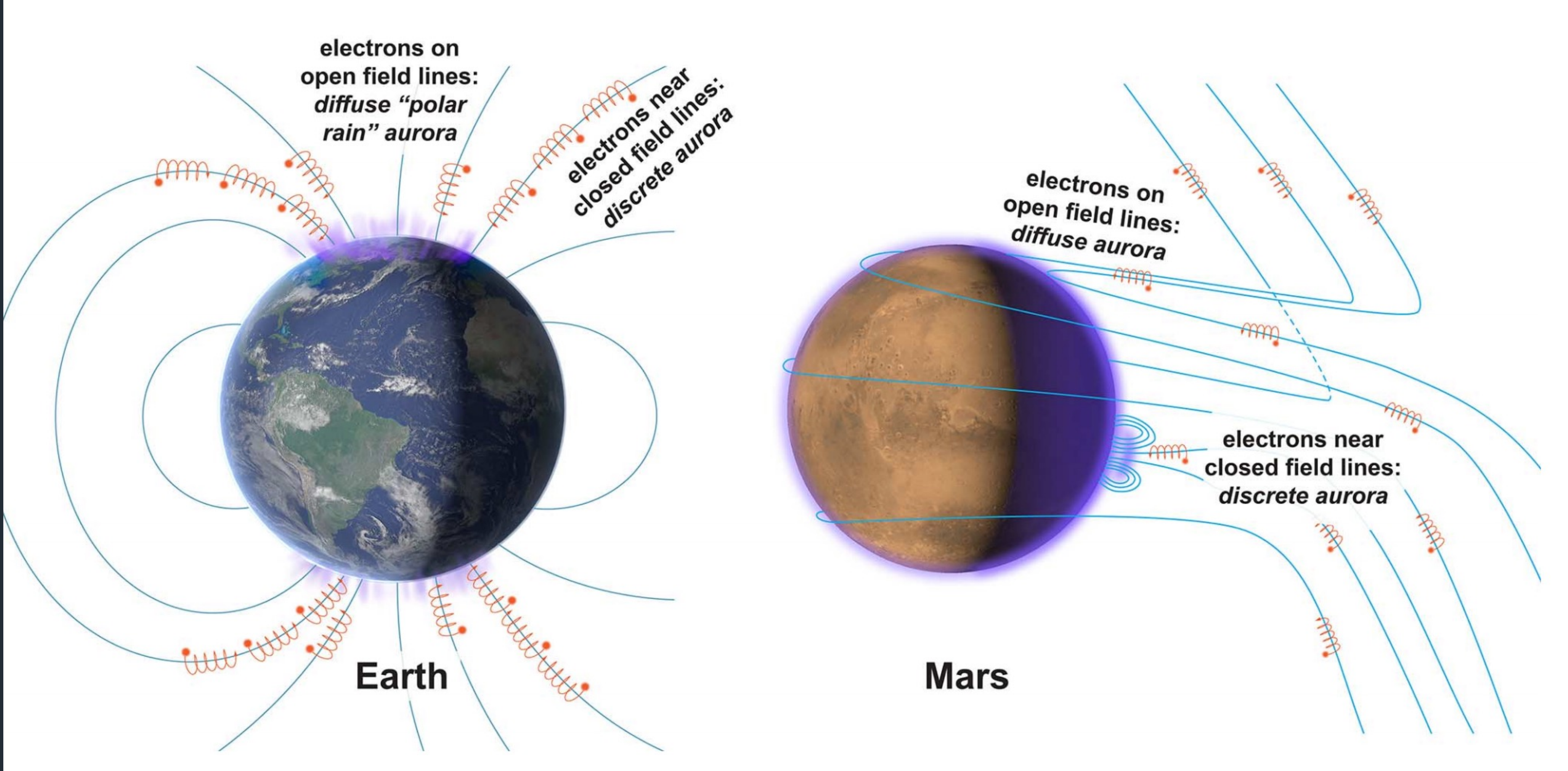


Mauk et al. (2018)

Unexpected similarity between Jupiter's dawn storms and Earth's auroral substorms (Bonfond et al, 2021)

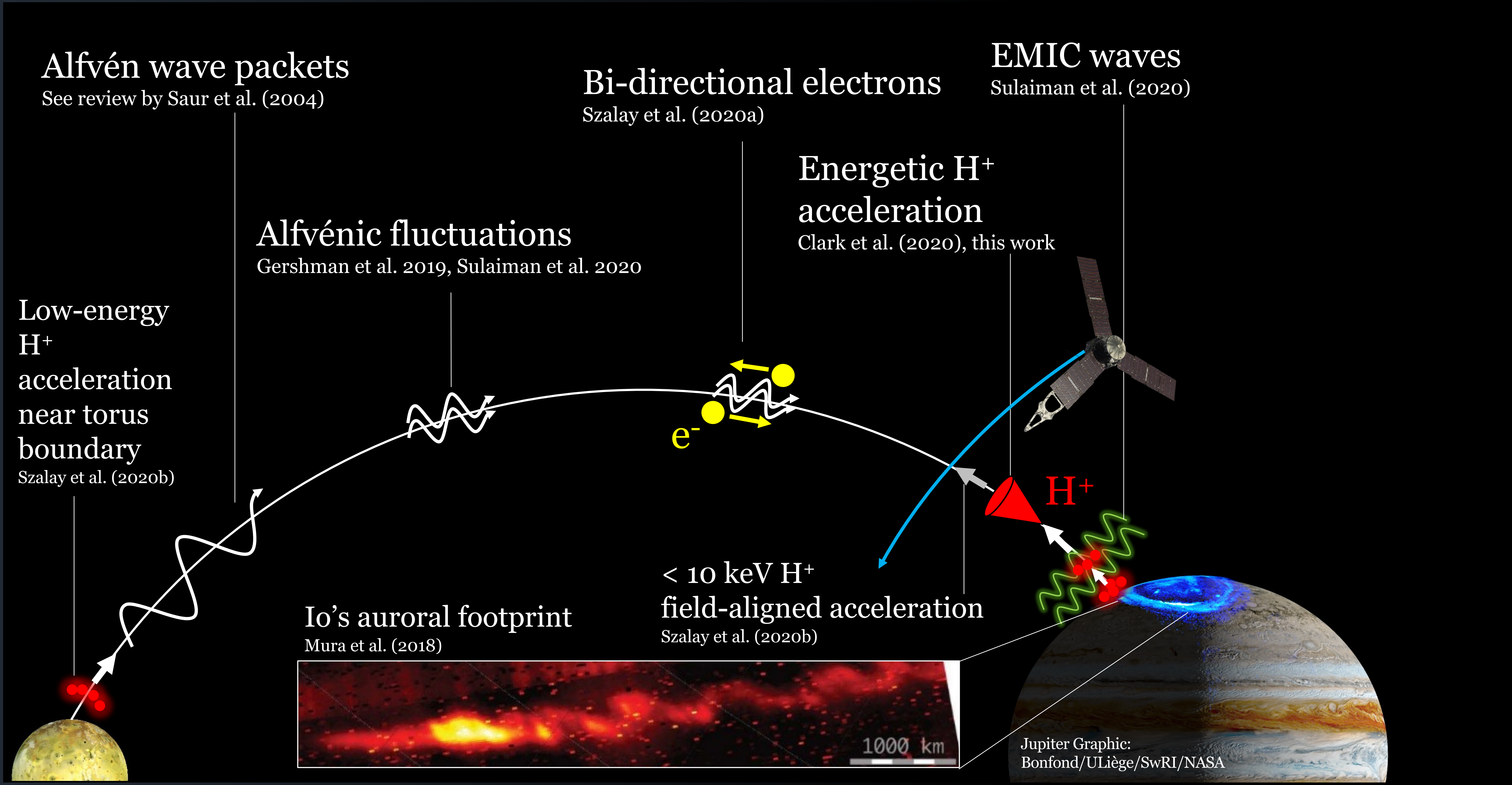


Discrete and diffuse aurora: comparisons between Earth and Mars

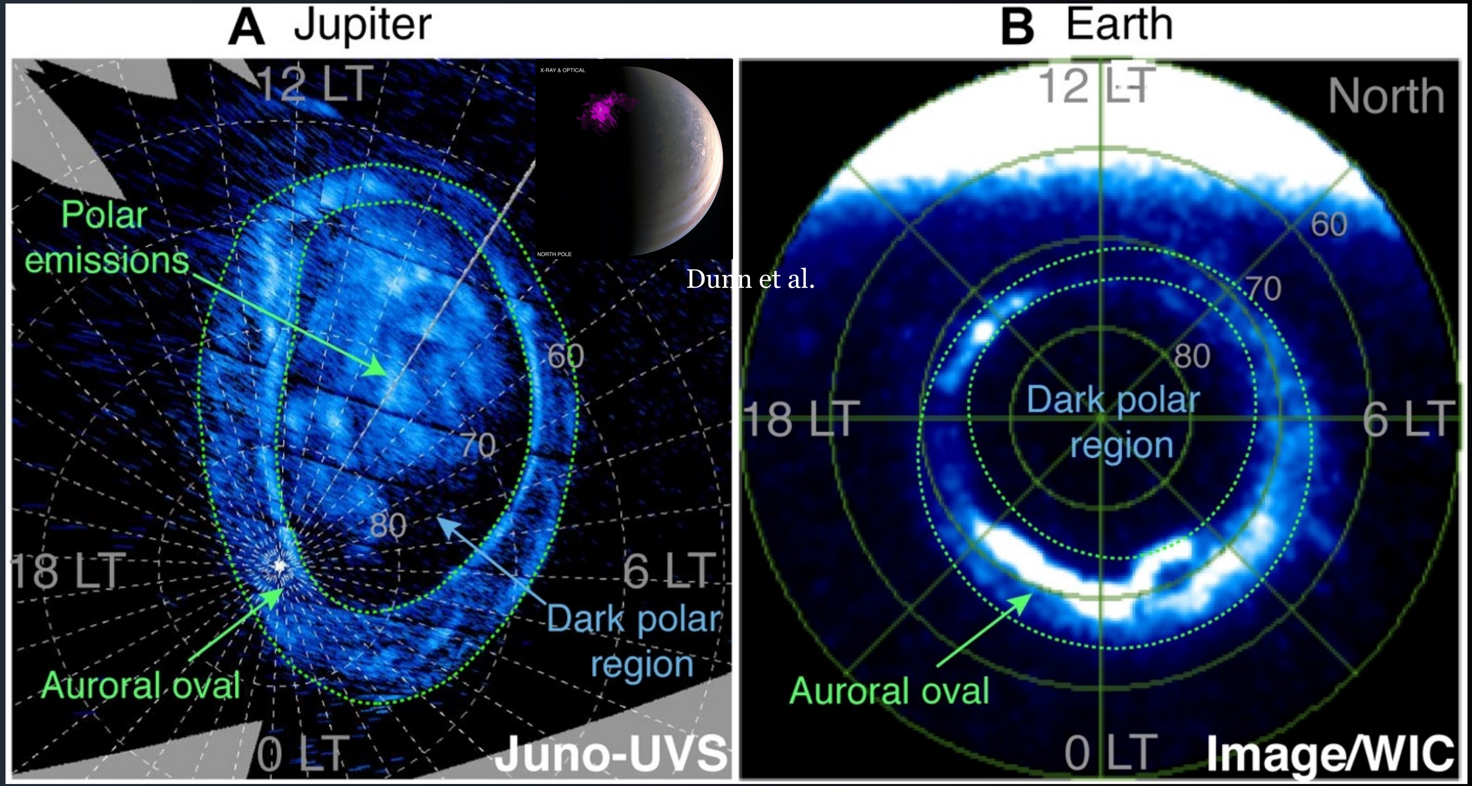


Credit: N. Schneider et al. (2015)

Intense ion outflow associated with moon-planet interactions

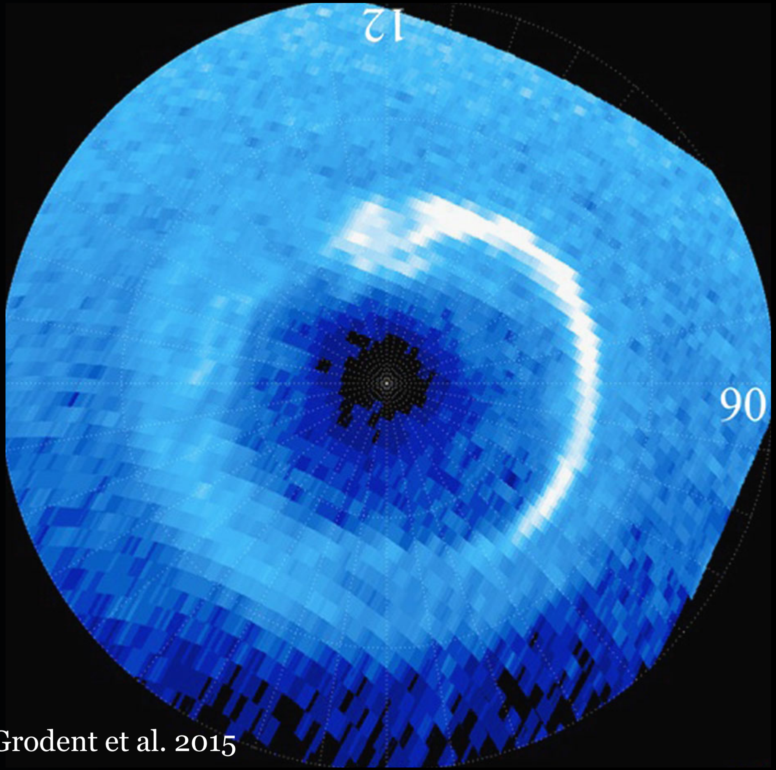


Polar auroral region



Zheng et al. 2021

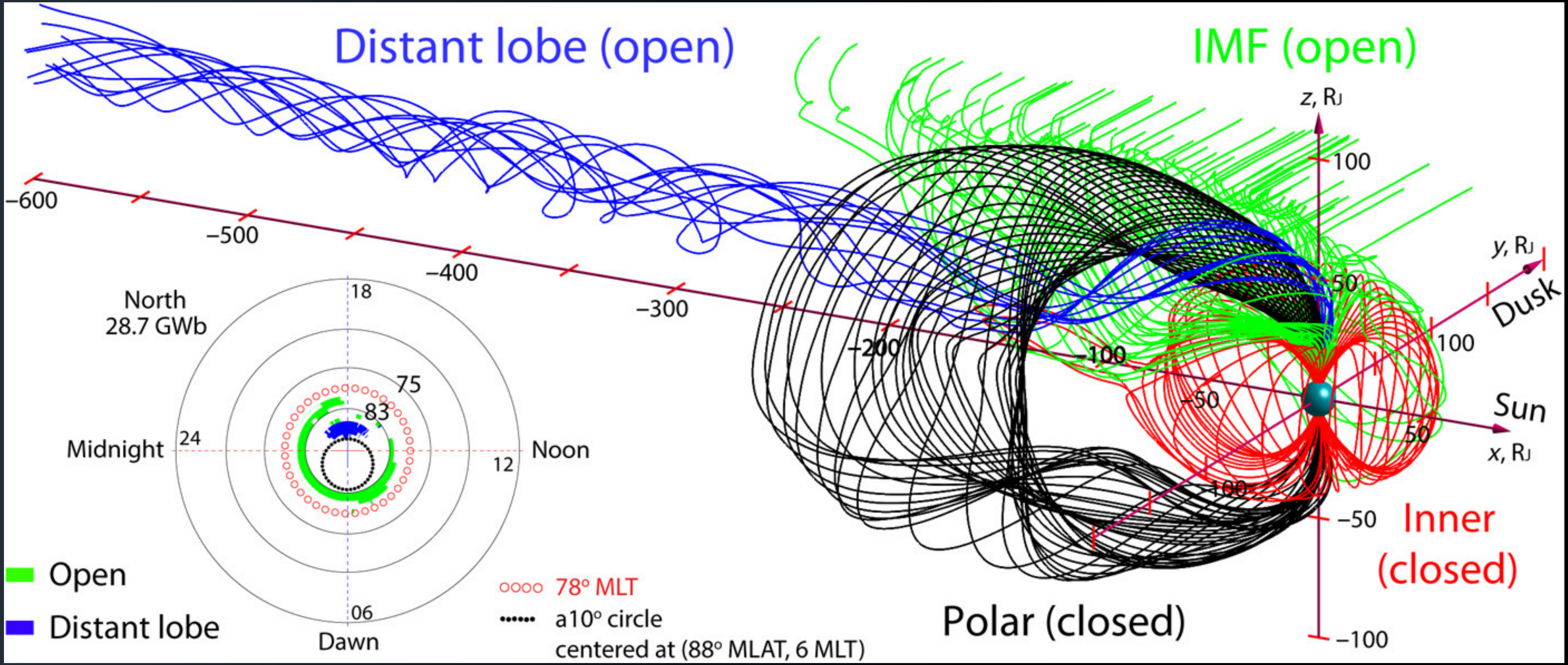
Saturn



Grodent et al. 2015

- Jupiter’s “polar cap” region is of high interest because it is unlike the other planets. Additional, it is filled with electric potential structures that reach to > 1 megavolt → accelerating electrons upward and ions downward.
- Studies have also shown that Jupiter’s auroral regions are dominated by “broadband” processes (perhaps Alfvénic?) and they create the most energetic and likely brightest auroral features.
- Unlike Earth, Saturn’s and Jupiter’s moons also play a role in scattering ions and electrons into the atmosphere

Jupiter’s unusual magnetic topology



Zhang et al. (2021)

Summary

- We're gifted with a diverse set of planetary environments in our cosmic backyard, making it possible to probe fundamental physics across a large parameter regime.

- Similar physical processes found at Earth operate across the solar system, but in some environments they're not masked by competing mechanisms. E.g., localized wave environments found near the moons of Jupiter or the multi-species and –charge state plasma found in the Gas Giant magnetospheres.

- Workshop style meetings (like GEM & CEDAR) that facilitate a collaborative format is perfect for developing interest & consensus on the big open auroral/magnetospheric questions that can be pursued with current datasets and modeling capabilities