Solar system and ATHENA – JUICE synergy

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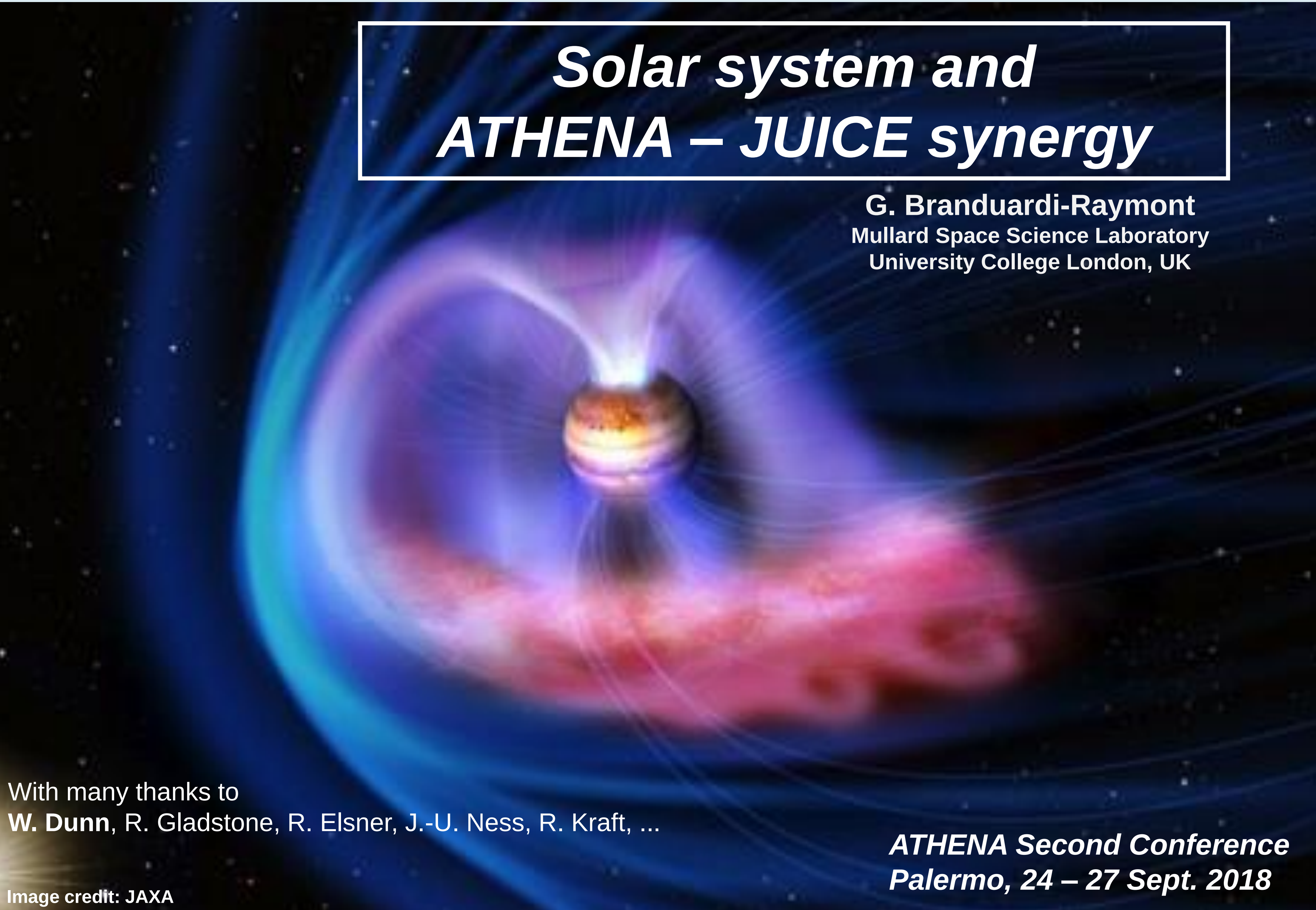
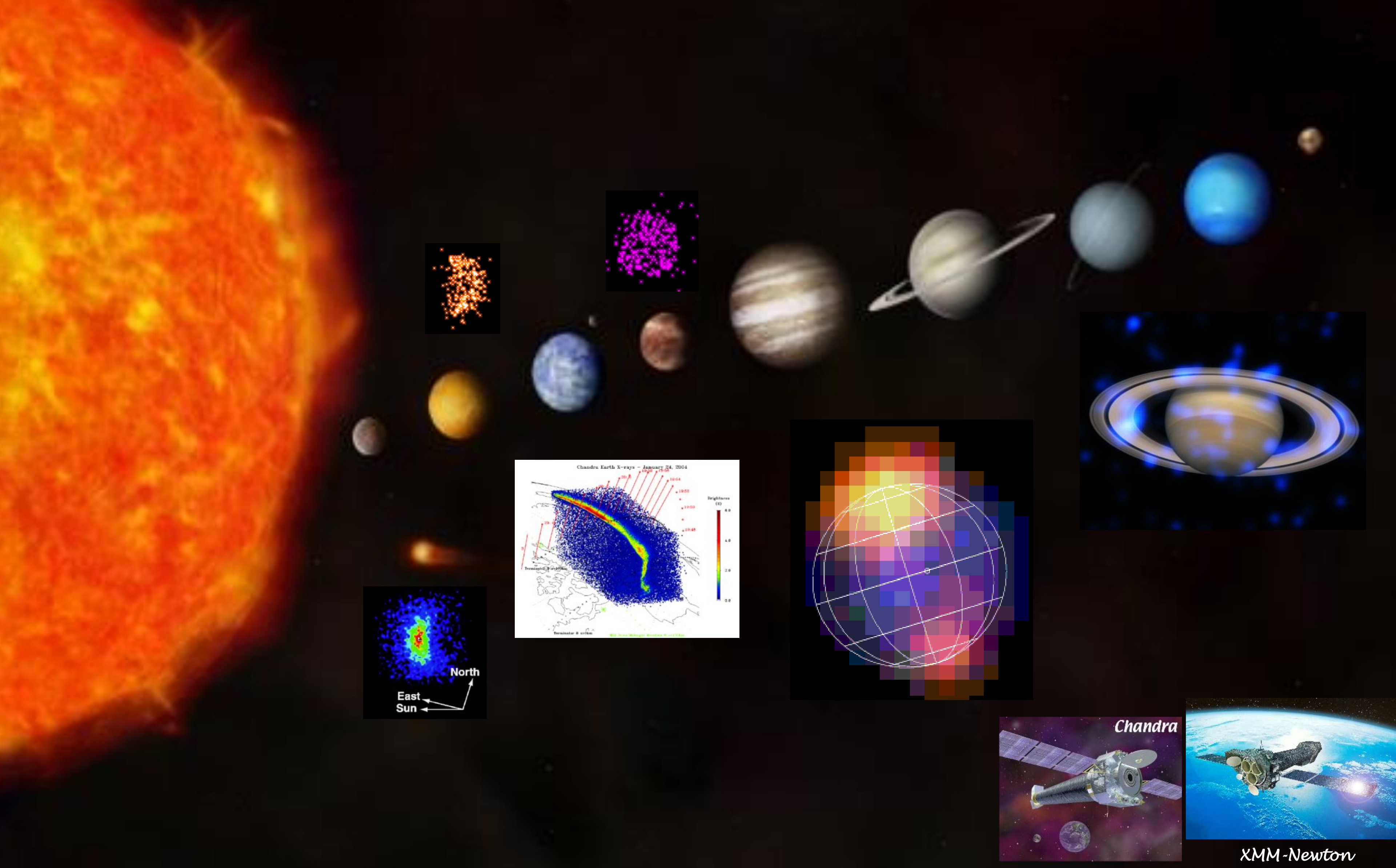


With many thanks to
W. Dunn, R. Gladstone, R. Elsner, J.-U. Ness, R. Kraft, ...

ATHENA Second Conference
Palermo, 24 – 27 Sept. 2018

Image credit: JAXA

X-ray sources in the solar system

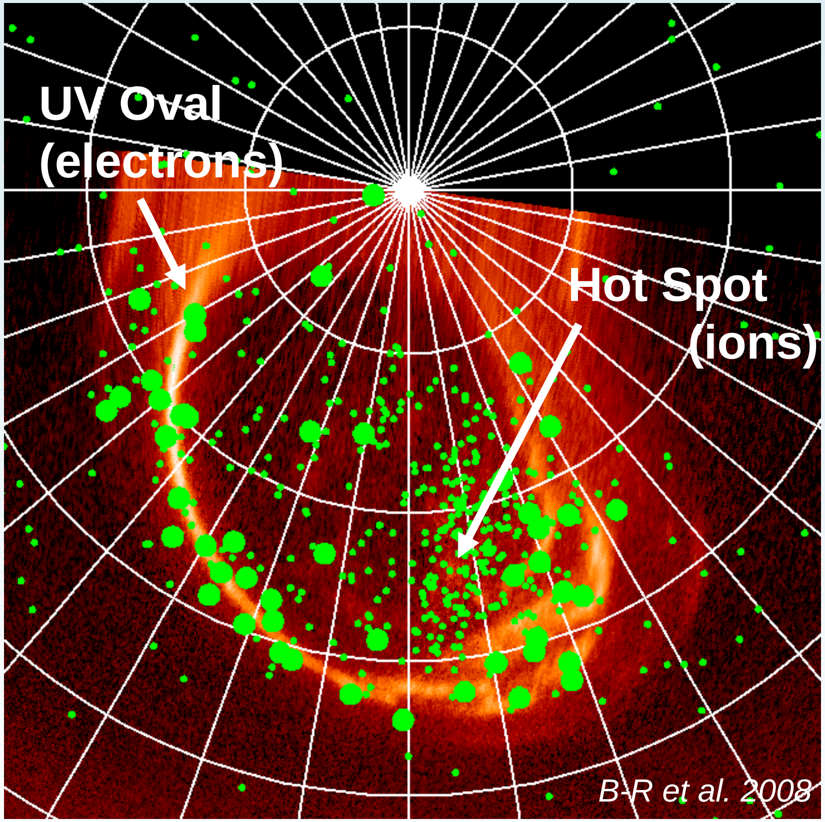


Jupiter – *Chandra* and *Hubble* STIS – 2003

Chandra ACIS reveals different spatial morphology of soft (< 2 keV, ion CX) and hard (> 2 keV, electron bremsstrahlung) X-ray events

→ CX X-ray events map far out from the planet

Simultaneous Hubble STIS images show > 2 keV events coincide with FUV auroral oval and bright features (FUV from excitation of atmospheric H_2 and H by 10 - 100 keV electrons)

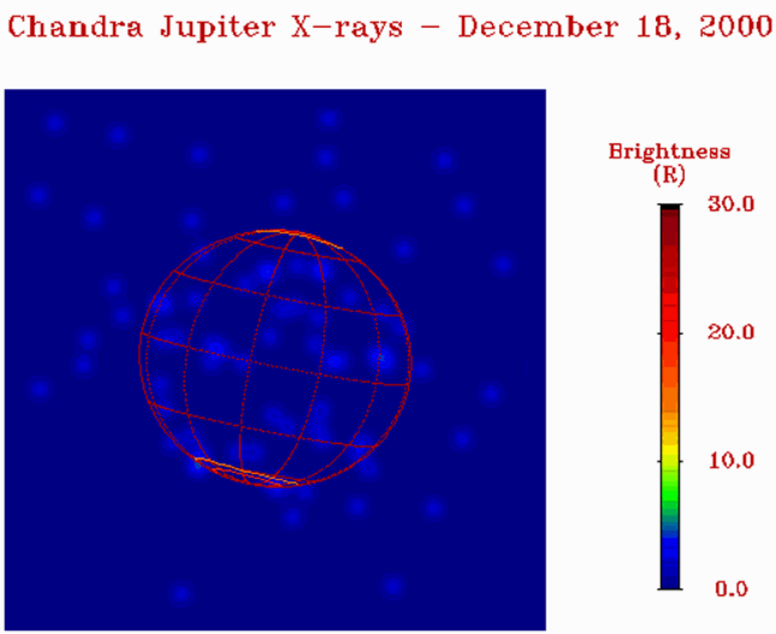


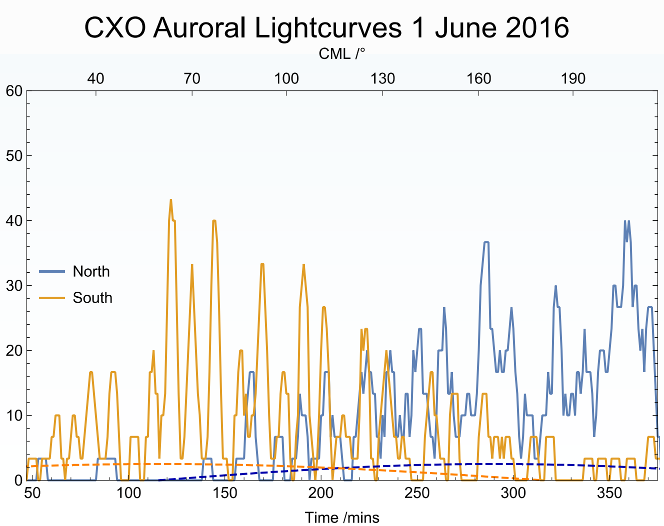
→ Same energetic electrons responsible for both, UV and X-rays

Charged particles from Io Plasma Torus or the solar wind (S and C dichotomy)

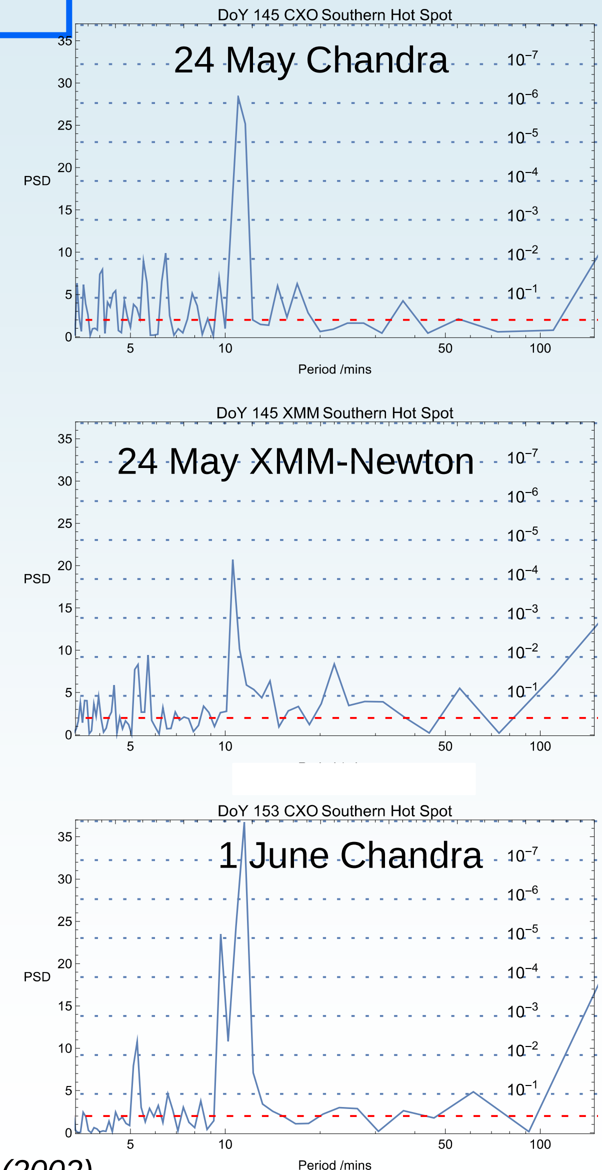
X-ray emission pulsates, on a variety of timescales (few - 10s of min)

Jupiter's pulsing X-ray Hot Spot





Southern Aurora Fourier Transform PSDs 2016



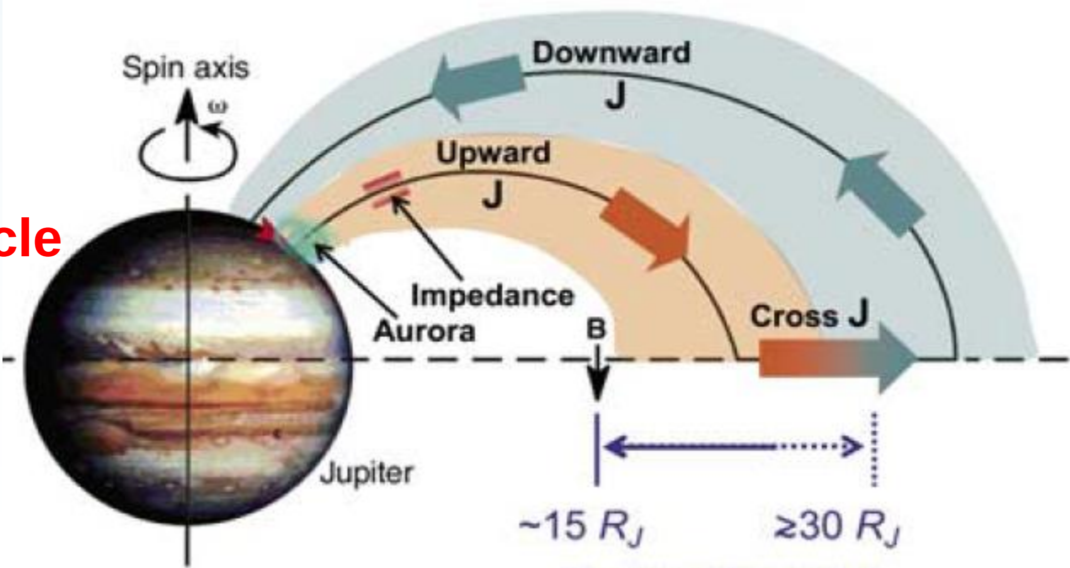
Left upper: Gladstone et al. (2002)
Left lower and right: Dunn et al. Nature Astro (2017)

What processes lead to X-ray aurorae?

Charged particles need to be accelerated to produce the X-rays

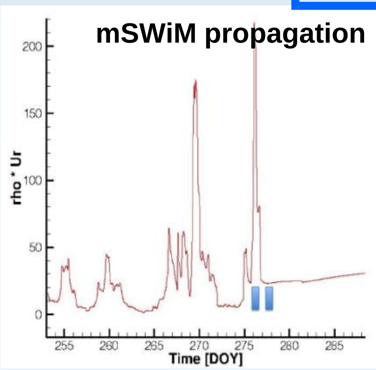
- Downward currents and huge potential drops at the pole [Cravens+ 2003; Clark+ 2017; Paranicas+ 2018]
- Pulsed dayside reconnection [Bunce+ 2004]
- Kelvin Helmholtz instabilities and field line resonances [Kimura+ 2016; Dunn+ 2016; 2017]
- Alfven Waves between plasma sheet and poles [Manners+. prep]
- Reconnection in the outer magnetosphere [Guo+ 2018]

Characterisation of in situ particle populations and magnetic field necessary for a comprehensive understanding



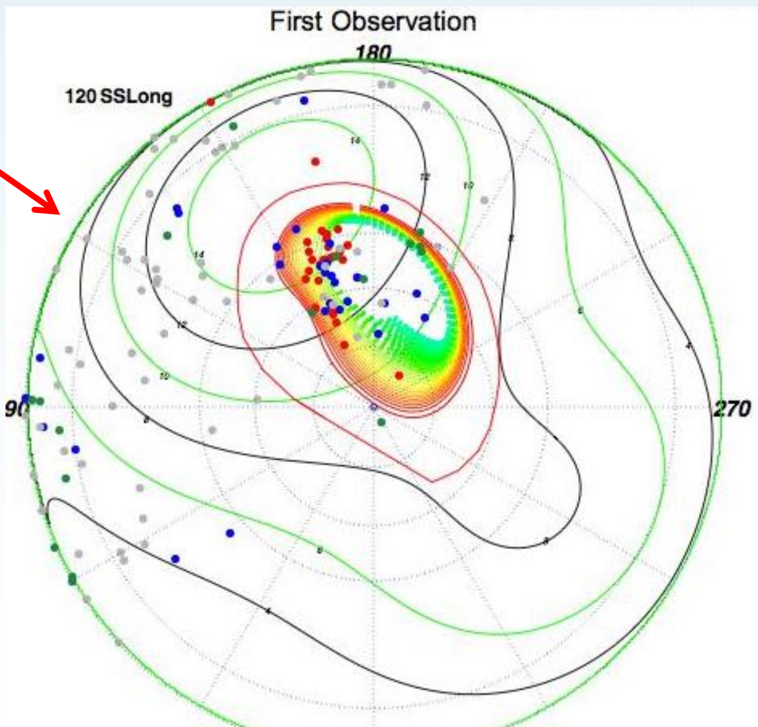
Mauk & Saur 2007

Jupiter – *Chandra* TOO Oct. 2011

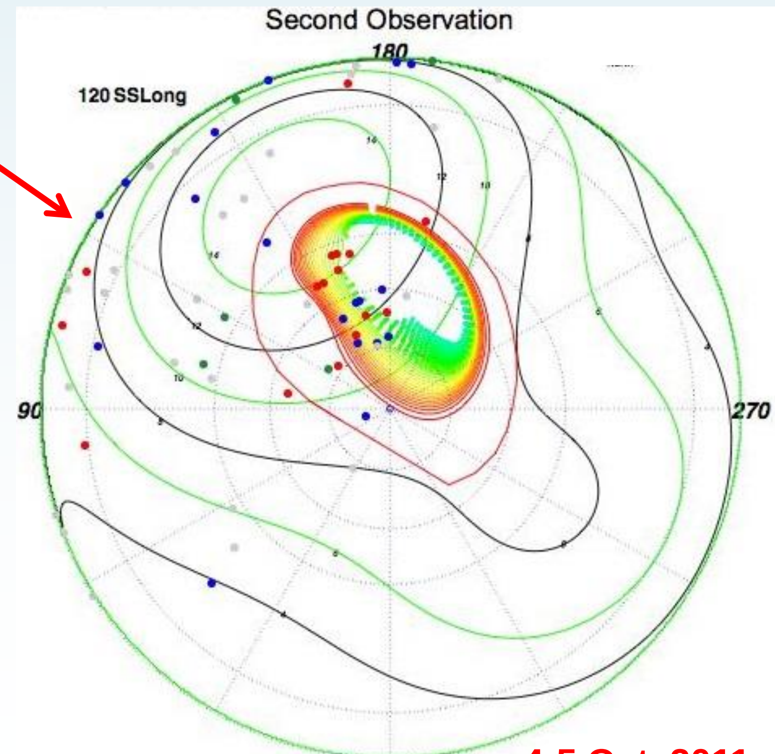


Chandra ACIS polar projections in System III:

Red	0.2 – 0.5 keV	(C/S)
Blue	0.5 – 0.8 keV	(O)
Grey	0.8 – 1.5 keV	(solar)
Green	> 1.5 keV	(bremss.)



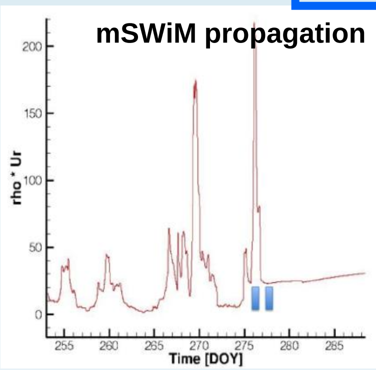
2-3 Oct. 2011



4-5 Oct. 2011

Dunn+ 2016

Jupiter – *Chandra* TOO Oct. 2011



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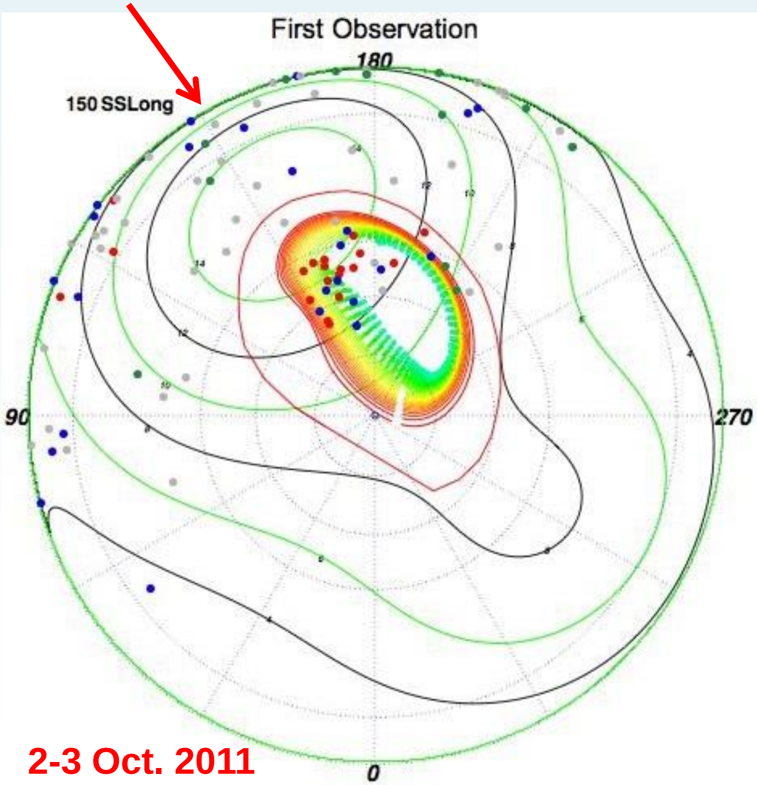

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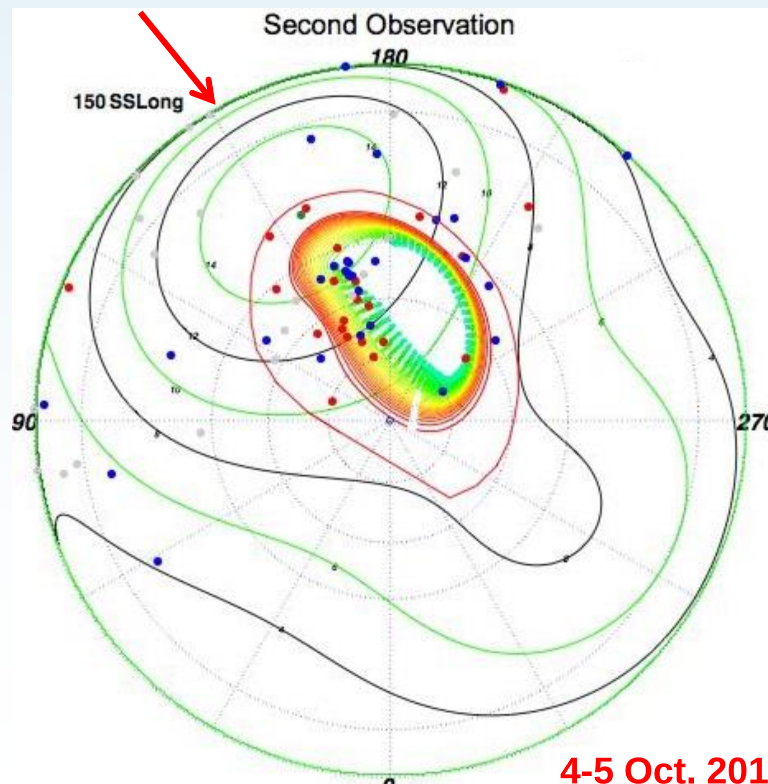

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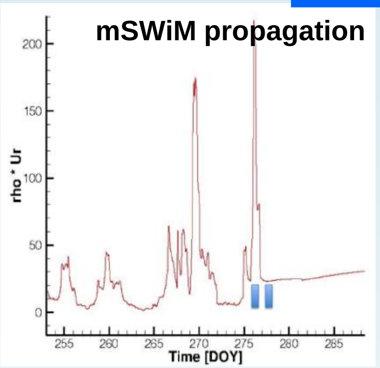

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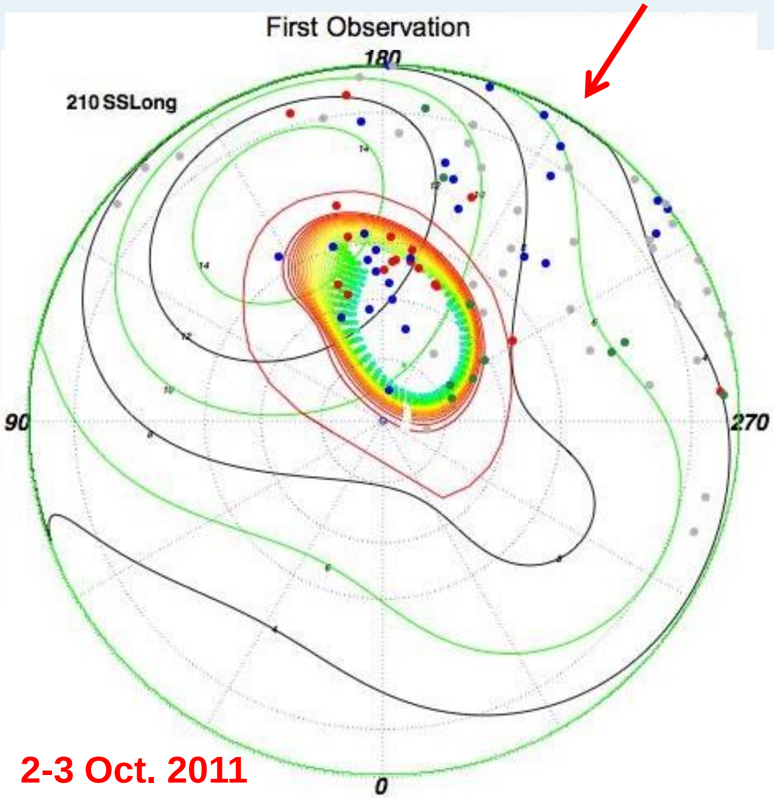

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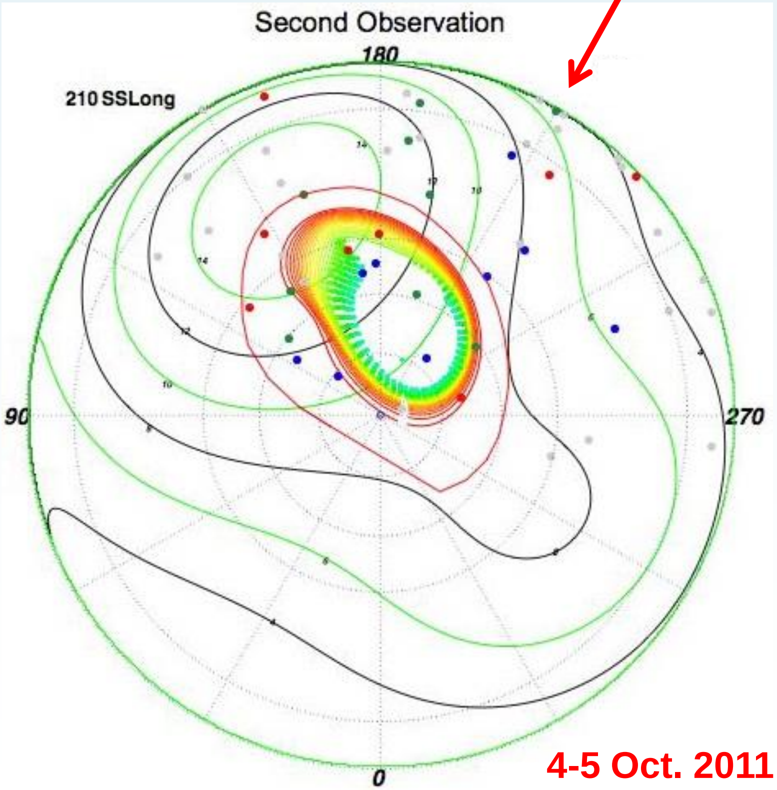
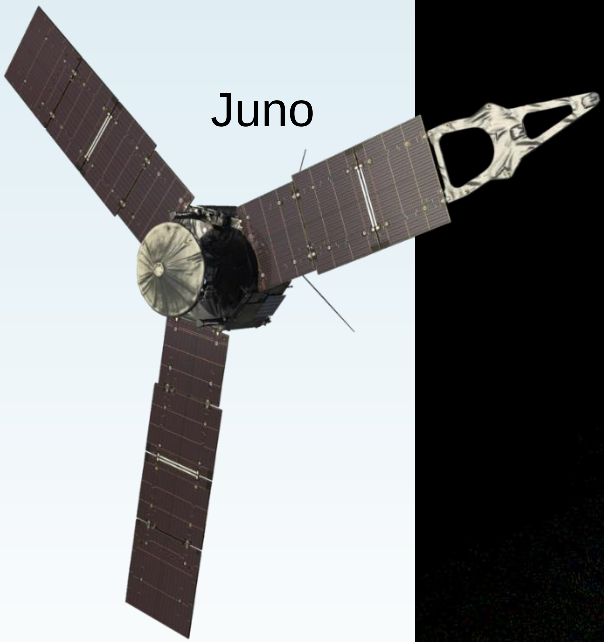


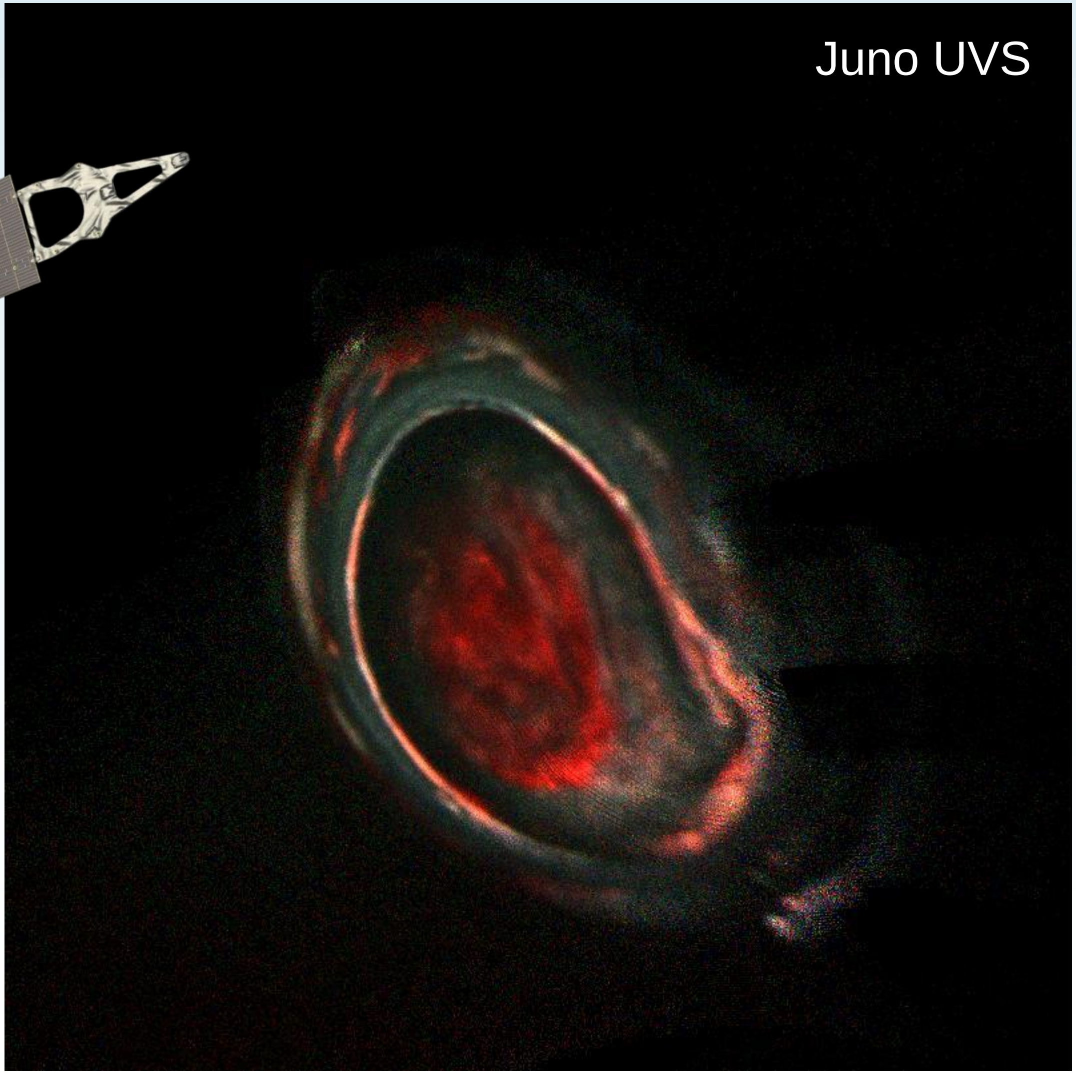
4-5 Oct. 2011

Dunn+ 2016

Juno UVS at PJ6, May 2017

Credit: NASA

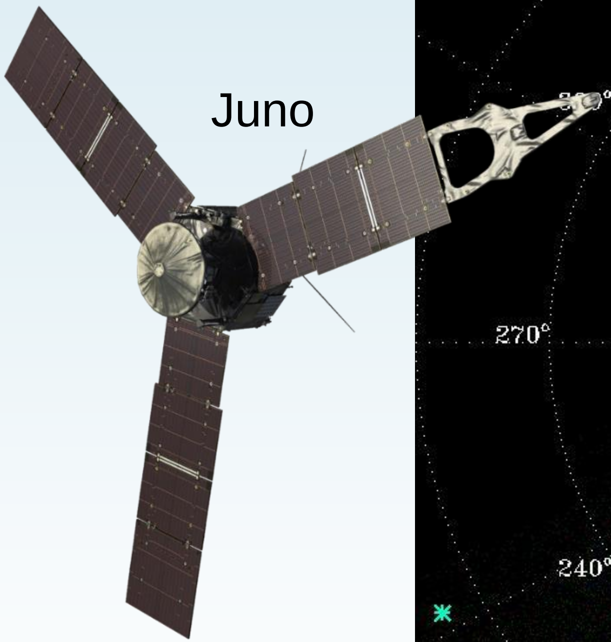


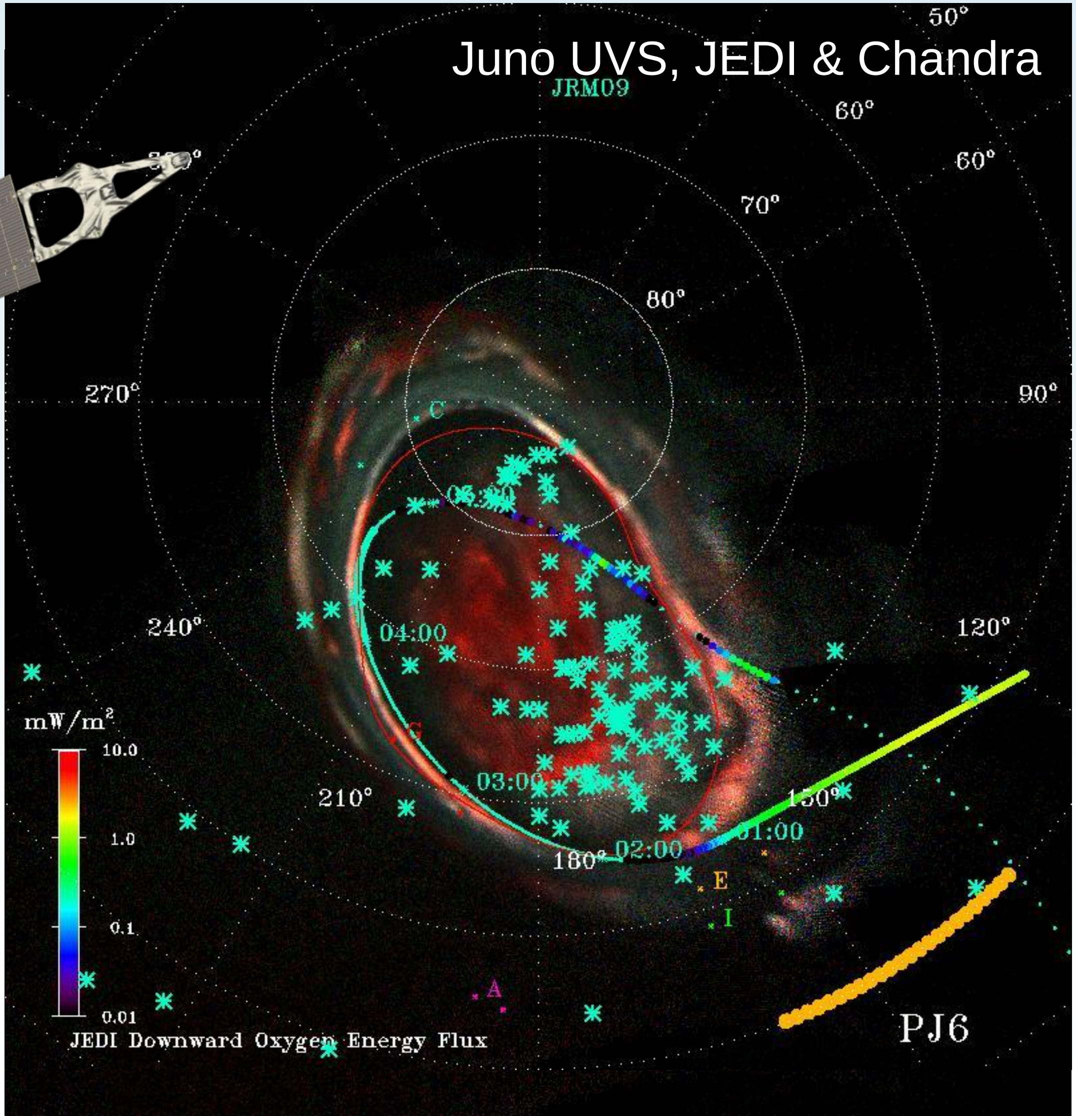


UVS – Gladstone

Juno UVS & JEDI, and *Chandra* at PJ6, May 2017

Credit: NASA





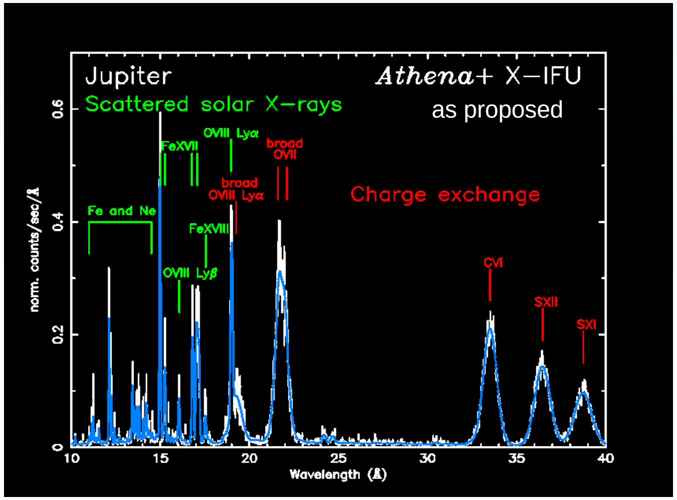
UVS &
Chandra – Gladstone
JEDI – Rymer

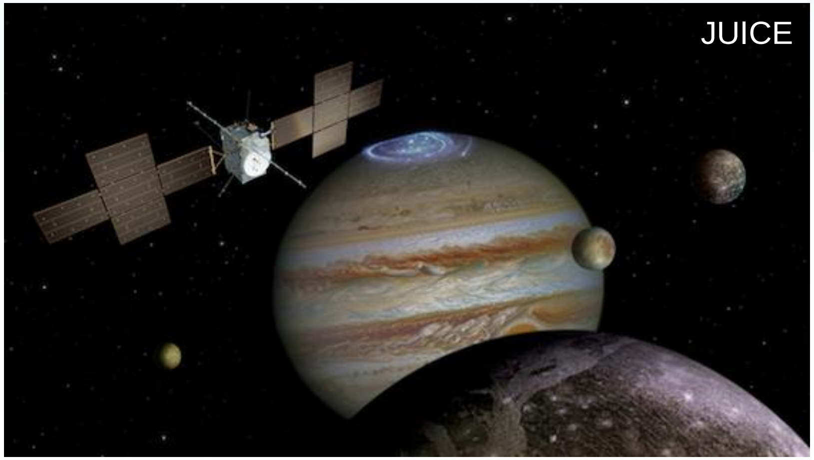
Multi-wavelength and in situ observing

Multi-wavelength observations (X-rays, UV, visible, IR, radio) offer clues

In situ measurements of particle populations, magnetic field conditions and accelerations which lead to the X-ray emissions, simultaneous with remote multi-wavelength observing are **invaluable** to establish the physics underlying the processes

ATHENA in combination with **JUICE** (launch 2022, at Jupiter 2029) would provide a major step up on what Chandra and XMM-Newton can do now in association with Juno





Credit: ESA

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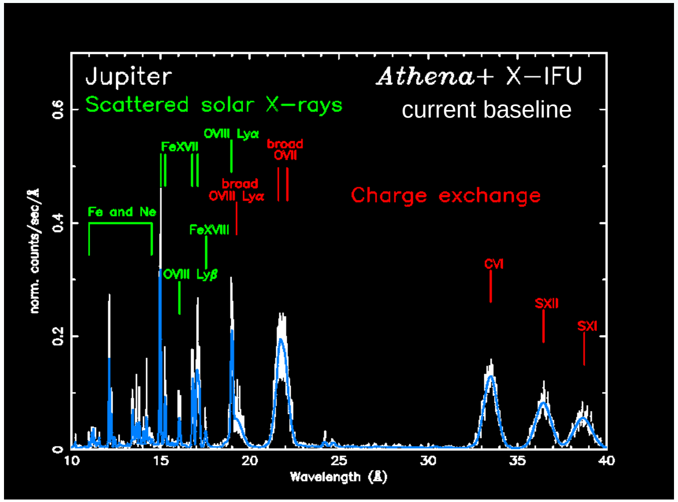
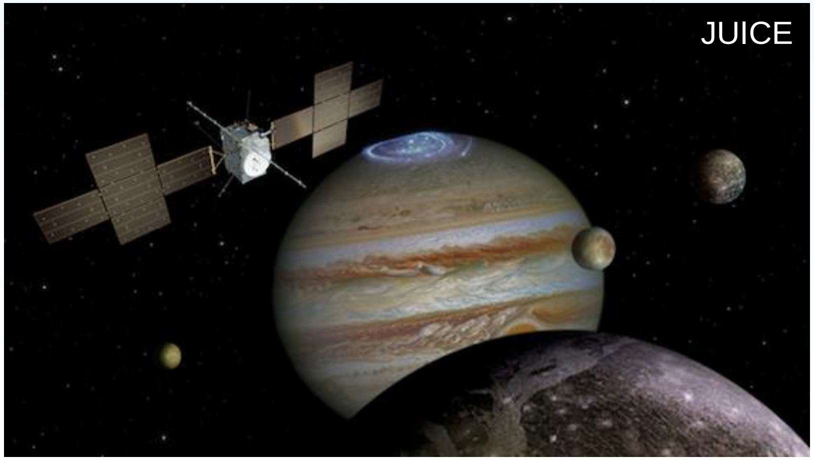


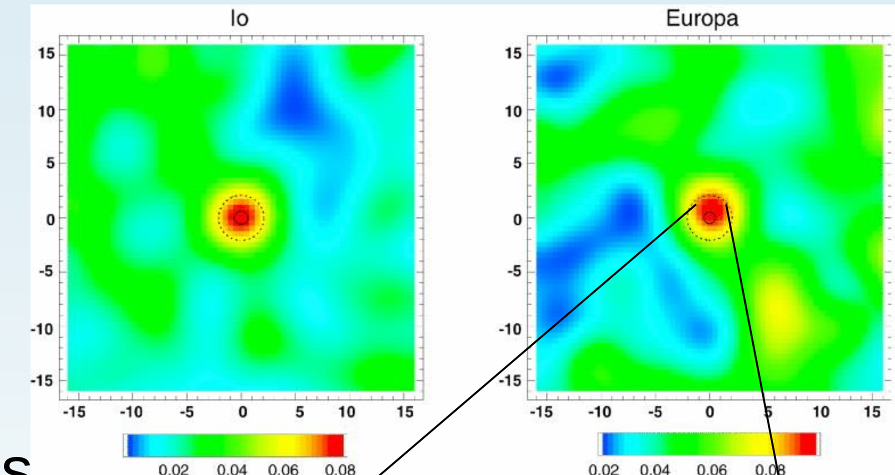


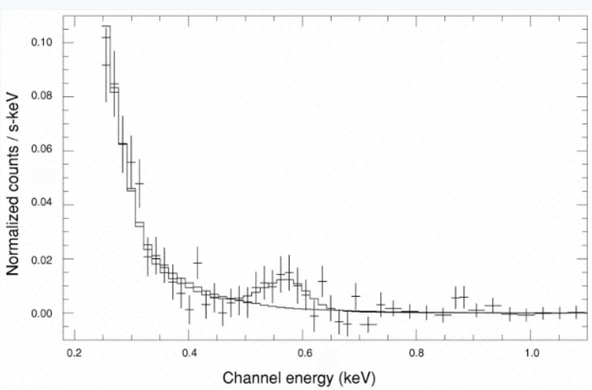
Credit: ESA

X-rays from the Galilean satellites and the IPT

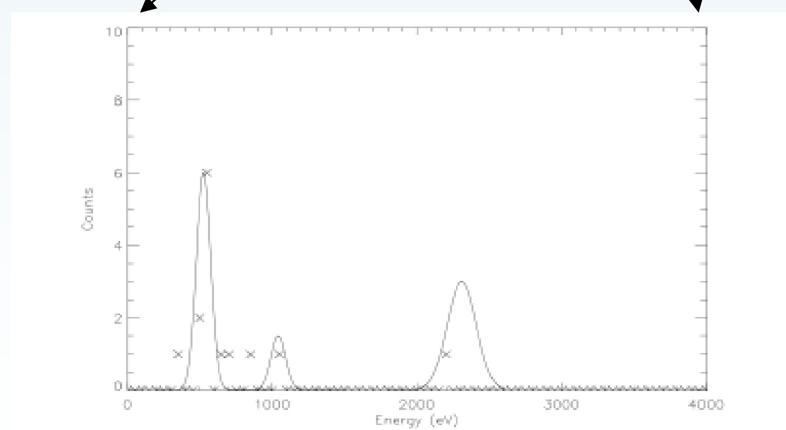
Io and Europa X-rays (*Chandra* ACIS) from energetic H, O and S ion impacts → fluorescence

Non-thermal electron bremsstr. + OVII em. from Io Plasma Torus





Elsner et al. 2002

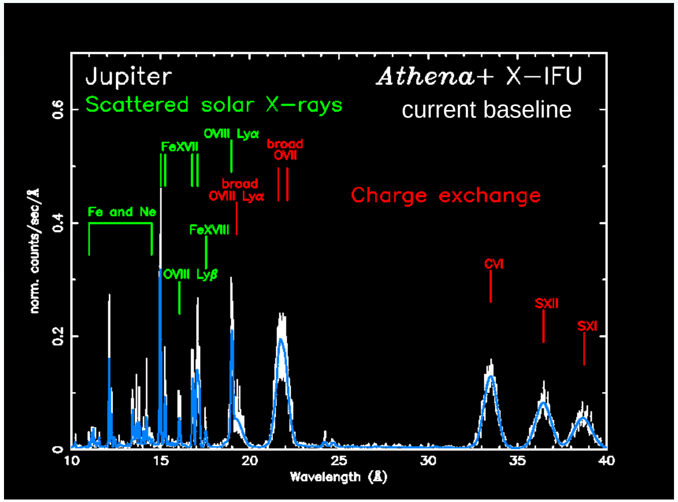


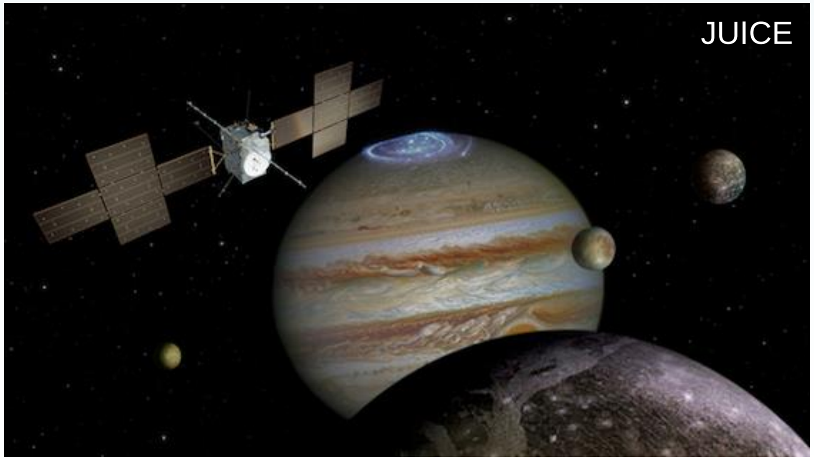
Nulsen et al. in prep.

Multi-wavelength and in situ observing

JUICE will carry an optical camera, visible-IR (clouds) and UV imaging spectrometer, sub-mm wave instrument, Ganymede laser altimeter, radar (icy moons), magnetometer, particle environment package, radio & plasma wave study, gravity experiments

Ultimately the time has come to have **X-ray telescopes on-board planetary missions**, such as that considered for Uranus and Neptune, to provide necessary sensitivity and spatial/energy resolution and establish X-rays on a par with other wavebands!





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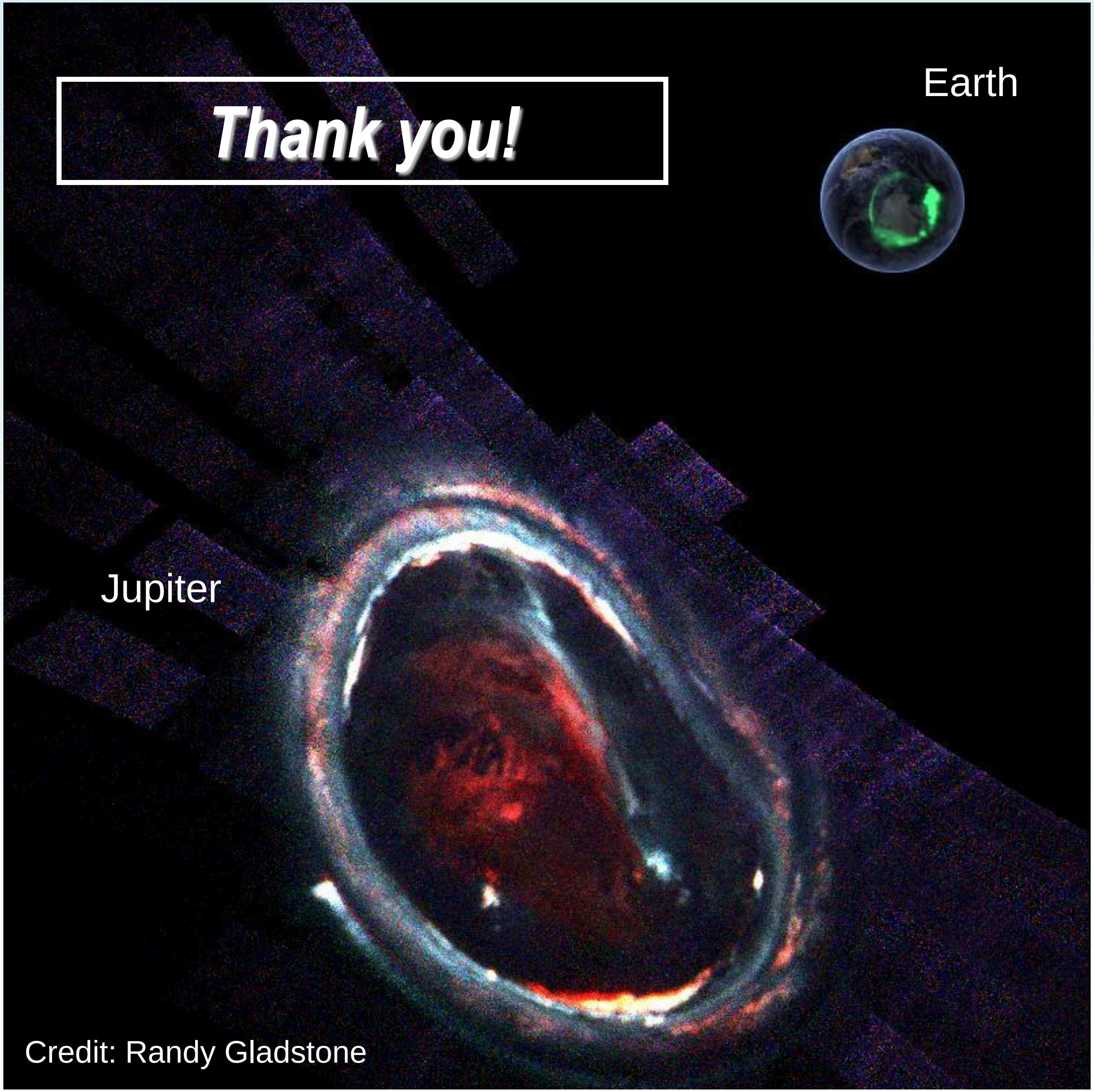
Thank you!
Earth
Jupiter
Credit: Randy Gladstone