Synergistic observations of the giant planets with HST and JWST: Jupiter's auroral emissions

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37 HST programs, giant planets aurora

- GTO-1269 (FOC) in 1991 C0
- ...
- GO-14634 (STIS) Juno era 2016-2018
**First** published image of Jupiter’s FUV Ly-\(\alpha\) aurora

FOC (DD time)

Dols et al., 1992

F. Paresce
STAR Institute

star.ulg.ac.be

More than 100 researchers

- Planetology
- Stellar Physics
- Extragalactic Astrophysics & Astro-particles
- Instrumentation

Trappist-1
HST - FOC
Development of the photon counting detector and space qualification of the FOC instrument
Instrumentation

Centre Spatial de Liège

JWST - MIRI

Contribution to the Input Optics and Calibration Unit (IOC), the Instrument Control Electronics (ICE) and various optics for MIRIM
Solar System Planets

Jupiter’s aurora

OK HST
OK JWST

« JWST will be able to observe the outer planets without saturating in at least some modes. »
Auroral process applies to all magnetized bodies surrounded by plasma.

- Brown dwarf aurora (Hallinan et al., 2015)
- Ganymede aurora (Saur et al., 2015)

Maxwell-Faraday induction law:
\[ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \]

Ampere law:
\[ \nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} \]

Current system
Nichols, 2011
Jupiter (North) FUV aurora
HST STIS TTAG F25SRF2 MIRFUV
GO-14634

H$_2$ / H / He / CH$_4$

Total emitted UV Power $\sim 1$ TW
$\sim 200$km/pix 30sec
Saturn (South) FUV aurora
HST STIS Accum 25MAMA MIRCUV GO-10083
540 sec ~500km/pix 0.1 TW

Clarke et al., 2005
Uranus (?) FUV aurora
HST STIS Accum F25MAMA MIRCUV
GO-12601

29 Nov. 2011

1000 sec
~1000km/pix
0.001 TW

Lamy et al., 2012
NASA Juno mission 53.5d orbit PJ03
Magnetic coordinates (tilted)
**Jupiter** (North) FUV aurora
HST STIS TTAG F25SRF2 MIRFUV
GO-14634

151 HST orbits
Coordinated with Juno
Magnetic Anomaly near the surface of Jupiter

Grodent et al., 2008
Multiple satellite footprints

(a) Bonfond et al., 2016

BONFOND: IO FOOTPRINT 3-D EXTENT

Figure 8. Example of Io footprint as seen from above (a) without and (b) with motion compensation.

(c) Comparison of the apparent width of the auroral curtain with (solid line) and without (dashed line) motion compensation.

Bonfond et al., 2016

\[ D_{\text{TEB}} = \max \]
\[ D_{\text{RAW}} = \max \]

\[ D_{\text{RAW}} = \min \]

\[ D_{\text{TEB}} = 0 \]

Figure 1: Scheme of the Alfvén wing reflection pattern and Trans-hemispheric Electron Beams (TEB, shown in red) when Io is in its northern-most (top), central (middle) or southern-most position relative to the plasma torus (shown in yellow). The Main Alfvén Wing (MAW) is shown in blue and the reflected one is shown in blue. On the top panel, in the North, the distance between the MAW spot and the TEB spot (\(D_{\text{TEB}}\)) is maximal as well as the distance between the MAW spot and the RAW spot (\(D_{\text{RAW}}\)). Note that in a linear case, \(\max D_{\text{RAW}} \sim 2 \max D_{\text{TEB}}\). In the South, \(D_{\text{TEB}}\) is also maximal, but the TEB spot is now upstream of the MAW spot. \(D_{\text{RAW}}\) reaches its minimum. When Io is in the center of the torus (middle panel) the situation in the two hemispheres is symmetric, and the TEB spots are merged with the RAW spots.

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Multiple satellite footprints

Bonfond et al., 2016

\[ D_{\text{TEB}} = \max \]
\[ D_{\text{RAW}} = \max \]

\[ D_{\text{RAW}} = \min \]

\[ D_{\text{TEB}} = 0 \]

Bonfond et al., 2016
Spectral auroral scan (unsupported mode)
HST STIS FUV MAMA G140L slit 52x0.5 1425A

EUV - FUV aurora

\[ \text{H}_2 + e \rightarrow \text{H}_2^* + e \rightarrow \text{H}_2 + h\nu \]

\[ \text{H}_2 + e \rightarrow \text{H} + \text{H}^* + e \rightarrow 2\text{H} + h\nu \]

Grodent et al., 2001
IR aurora

\[ \text{H}_2 + e \rightarrow \text{H}_2^+ + 2e \]
\[ \text{H}_2^+ + \text{H}_2 \rightarrow \text{H}_3^{+*} + \text{H} \]
\[ \text{H}_3^{+*} \rightarrow \text{H}_3^+ + h\nu \]
\[ \tau \sim 1000 \text{ sec} \]
\[ \text{H}_3^+ + \text{CH}_4 \rightarrow \text{CH}_5^+ + \text{H}_2 \]
\[ \text{H}_3^+ + e \rightarrow \text{H}_2 + \text{H} \]
\[ \text{H}_3^{+*} + \text{H}_2 \rightarrow \text{H}_3^+ + \text{H}_2^* \]
\[ \text{H}_2^* \rightarrow \text{H}_2 + h\nu \]

\( \text{H}_2 \) quadrupolar

Grodent et al., 2001
Jupiter IR aurora
ESO VLT CRIRES (AO, 8m)
Spectral scan (similar to UV)
pixel scale $\sim0.1''$ (0.2'', STISx8)
L-band 3-4 $\mu$m

Stallard et al., 2016

long-slit 10 sec for 15 min
Jupiter IR aurora

NASA IRTF NSFCam (3m)
120 sec Images

Pixel scale ~0.15” (0.2” STISx8)
narrow band 3.45 μm

<table>
<thead>
<tr>
<th>29jun95</th>
<th>08jul96</th>
<th>07aug97</th>
<th>27jul98</th>
<th>23sep99</th>
<th>11oct99</th>
<th>19dec00</th>
<th>CML</th>
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Stallard et al., 2016
Subaru Telescope
0.2” resolution with AO.
10 x 2 sec exposures.

Unpublished material, courtesy Hadjime KITA, Haruna WATANABE (Tohoku Univ.)

8.2 m. National Astronomical Observatory of Japan, Mauna Kea

Spatial resolution appears to be limited by $\text{H}_3^+$ lifetime (several minutes)
Juno - Jupiter flyby

(next PJ05 on March, 27)

JIRAM high-res images of the IR aurora
Figure 47 gives an example of the spectrometer coverage on the northern aurora during orbit 10. The period of observation extends from 18 hours and 6 hours from perijove. The dwell time calculation considers the motion of the spacecraft with respect to the Jupiter 1-bar surface and the planet's rotation. The horizontal line in the diagram represents the position of the spectrometer slit on the imager. The slit is combined covering the period of observation between 18 hours and 6 hours from perijove. Figure 50 shows the positioning of the spectrometer slit on the imager. The slit is pointed in adjacent positions during the acquisition sequence to give full coverage of the auroral main oval of 30 N. In this case the spectrometer slit is pointed on the main hot spot latitude bands during orbit 3. In this case the spectrometer entrance slit—overlays 256 pixels on one of the 128 lines of the M-band side of the imager.

For trajectories, the instrument will have the most favorable view of the planet. Consequently, the JIRAM optical axis will be contained in the orbital plane of the spacecraft from the planet. The change of the pixel resolution during one of the MWR orbits is shown in Fig. 48. The horizontal line in the diagram shows the minimum and the maximum integration times that JIRAM will use. The pixel down to almost 1 km per pixel at closest approach.

During each orbit, the quality of the measurements can be reduced by the presence of environmental radiation which will oblige JIRAM to be within the data volume budget. An important parameter to take into account in planning the observations is the dwell time, which is the ratio between the instantaneous average size of the ground footprint and the ground speed vector, which links the spatial resolution to the integration time. The dwell time can start 18 hours before perijove time. The spatial resolution varies significantly with time during planetary observation.

The distance from the planet 1-bar atmospheric level will vary rapidly as a function of the distance from the planet. The spacecraft speed will be high and the spatial resolution at the planet will be very high fluxes. Electrons with energies higher than 10 MeV are expected to have fluxes of environmental radiation (energetic electrons and protons) present in Jupiter's magnetosphere. The spatial resolution and it is applicable when the spatial resolution can be sacrificed for a better signal-to-noise ratio. Spectrometer, an averaging of 4 or 16 contiguous slit pixels can be activated to diminish the noise due to thermal reasons. The efficacy of the routine depends on the quality of the input data. The routine is lossless and, then, has a limited efficiency due to the fact that the full information contained in the spectral data has to be maintained. In the presence of a high noise due to thermal reasons the routine does not converge to a solution. However, the compression of the data will be applied only in specific cases.
With appropriate IR instrument, it is possible to achieve the same image quality as that offered by HST-STIS in the UV.

However, UV and IR do not show exactly the same features (ionospheric convection motion, Joule heating, atmospheric Temperature, …).

⇒ Use JWST!

Possible to use JWST for Jupiter’s aurora? Yes, NIRCam (NIRSpec) is perfectly suited
Near-infrared spectra of the four giant planets compared to the saturation limits of NIRCam filters, assuming 640×640 pixel sub-array imaging.

Norwood et al., 2015
Possible configuration for observing Jupiter using the 640x640 sub-arrays on NIRCam

Norwood et al., 2015
Near-infrared spectra of the four giant planets compared to saturation limits of the NIRSpec IFU (black) and slit (red). Maximum spectral resolution mode (R=2700). Gray regions = 30% uncertainty in the saturation values.

Norwood et al., 2015
Thank You!