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The Cassini Campaign observations of the Jupiter aurora by the Ultraviolet Imaging Spectrograph and the Space Telescope Imaging Spectrograph

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Abstract

We have analyzed the Cassini Ultraviolet Imaging Spectrometer (UVIS) observations of the Jupiter aurora with an auroral atmosphere two-stream electron transport code. The observations of Jupiter by UVIS took place during the Cassini Campaign. The Cassini Campaign included support spectral and imaging observations by the Hubble Space Telescope (HST) Space Telescope Imaging Spectrograph (STIS). A major result for the UVIS observations was the identification of a large color variation between the far ultraviolet (FUV: 1100–1700 Å) and extreme ultraviolet (EUV: 800–1100 Å) spectral regions. This change probably occurs because of a large variation in the ratio of the soft electron flux (10–3000 eV) responsible for the EUV aurora to the hard electron flux (∼15–22 keV) responsible for the FUV aurora. On the basis of this result a new color ratio for integrated intensities for EUV and FUV was defined ($4\pi I_{1550\text{–}1620\ \text{Å}}/4\pi I_{1030\text{–}1150\ \text{Å}}$) which varied by approximately a factor of 6. The FUV color ratio ($4\pi I_{1550\text{–}1620\ \text{Å}}/4\pi I_{1230\text{–}1300\ \text{Å}}$) was more stable with a variation of less than 50% for the observations studied. The medium resolution (0.9 Å FWHM, G140M grating) FUV observations (1295–1345 Å and 1495–1540 Å) by STIS on 13 January 2001, on the other hand, were analyzed by a spectral modeling technique using a recently developed high-spectral resolution model for the electron-excited H_2 rotational lines. The STIS FUV data were analyzed with a model that considered the Lyman band spectrum ($\mathrm{B}\ {}^1\Sigma_u^+ \rightarrow \mathrm{X}\ {}^1\Sigma_g^+$) as composed of an allowed direct excitation component ($\mathrm{X}\ {}^1\Sigma_g^+ \rightarrow \mathrm{B}\ {}^1\Sigma_u^+$) and an optically forbidden component ($\mathrm{X}\ {}^1\Sigma_g^+ \rightarrow \mathrm{EF}, \mathrm{GK}, \mathrm{H\bar{H}}, \ldots\ {}^1\Sigma_g^+$ followed by the cascade transition ${}^1\Sigma_g^+ \rightarrow \mathrm{B}\ {}^1\Sigma_u^+$). The medium-resolution spectral regions for the Jupiter aurora were carefully chosen to emphasize the cascade component. The ratio of the two components is a direct measurement of the mean secondary electron energy of the aurora. The mean secondary electron energy of the aurora varies between 50 and 200 eV for the polar cap, limb and auroral oval observations. We examine a long time base of Galileo Ultraviolet Spectrometer color ratios from the standard mission (1996–1998) and compare them to Cassini UVIS, HST, and International Ultraviolet Explorer (IUE) observations.

Keywords: Spectroscopy; Jupiter magnetosphere; Jupiter atmosphere; Ultraviolet observations

1. Introduction

Jupiter's UV aurora has the strongest optical signature of the electromagnetic interaction between the magnetosphere and the ionosphere. After the Sun, the jovian aurora is the

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most intense source of UV radiation in the Solar System. Jupiter's aurora deposits far more energy into its upper atmosphere than occurs elsewhere in the Solar System. Its ultimate power source is the rotational energy of Jupiter and plasma processes in the near co-rotating middle magnetosphere. From the time of Voyager in 1979 (Broadfoot et al., 1981) to the present observations by HST STIS and Cassini UVIS in the new millennium (Dols et al., 2000; Ajello et al., 1998, 2001), estimates of deposited power have remained the same for two solar cycles at a level of $\sim 10^{13}$ W (requiring an energy input of ~ 10 erg/cm^2/s). Moreover, this enormous power input into the auroral zone presumably controls thermosphere global dynamics (Emerich et al., 1996) and atmospheric chemistry (Perry et al., 1999; Wong et al., 2000). The high spatial resolution capability (~ 200 km) of STIS with the two-dimensional multi-anode array MAMA detectors provides FUV images that resolve the polar cap and main auroral oval (Gustin et al., 2002; Grodent et al., 2003a, 2003b).

The modeling of the dynamical magnetosphere–ionosphere coupling causing the jovian aurora has been aptly described by Hill (2001), Bunce and Cowley (2001), and Cowley and Bunce (2001). These authors suggest that the auroral oval indicates the presence of a global-scale Birkeland current system that maps to $\sim 30\ R_{\mathrm{j}}$. This current system passes planetary angular momentum to the outward moving plasma sheet maintaining the middle magnetosphere in near co-rotation (Hill, 2001). In the region of upward currents (downward electrons), field-aligned potentials accelerate electrons to auroral energies (10–100 keV) (Mauk et al., 2003).

The flyby of the Cassini spacecraft past the jovian planetary system allowed a long observation period (approximately October 1, 2000 to March 22, 2001) dubbed the Cassini Campaign (CC). The remote sensing instruments taking part in the CC auroral observations were UVIS, STIS, Far Ultraviolet Spectrometer Explorer (FUSE), Chandra and Infrared Telescope Facility (IRTF). In this paper, along with the companion paper by Pryor et al. (2005), we describe the CC auroral observations by UVIS. Herein we model the closest approach aurora spectra that were obtained in the period from December 29, 2000 (DOY 364) to January 2, 2001 (DOY 2) with the spacecraft distance changing from 138 to 142 R_{j}. The UVIS instrument provided complete H_2 Rydberg band spectra coverage from 800 to 1700 Å at both 2.4 and 4.8 Å FWHM. The UVIS is the second Jupiter-observing instrument to achieve this spectral resolution over the full spectral range of Rydberg bands after the Hopkins Ultraviolet Spectrograph (HUT), which measured a single spectrum of the jovian aurora in November 1995 at 3.0 Å FWHM. The UVIS data archive is much more extensive consisting of tens of spectra of the aurora. The temporal variations of the complete UV spectrum during the flyby are particularly striking. The variation is interpreted in terms of temporal variations of the ratio of the soft electron component that excites the EUV (Ajello et al., 2001) to the hard electron flux that excites the FUV (Ajello et al., 1998). Additionally, we study spatially resolved medium resolution spectra (0.9 Å FWHM with the G140M grating) from STIS obtained during the CC on January 13, 2001. A recently developed high-resolution code (Liu et al., 2002) for modeling the intensity of the H_2 rotational lines from the STIS spectra allows a different approach to the modeling of the Lyman band spectrum by providing very accurate computations of the separate contributions to the spectra from direct excitation and cascading. The contribution of cascade to the measured outgoing portion of the FUV spectrum is predominantly excited by low-energy secondary electrons (Ajello et al., 1998). The cascade cross-section from the EF, GK, and $\mathrm{H\bar{H}}$ states of H_2 is optically forbidden with a cross-section that is sharply peaked at low electron energy (~ 20 eV) (Liu et al., 2003). STIS also acquired complete FUV spectra with the G140L grating; one of these observations on December 28 occurred close in time to the December 29 closest approach UVIS measurement. The spectra from the two spacecraft are analyzed independently, since each spacecraft observed different aurora.

2. The observations

The observations for the Jupiter aurora by UVIS during the CC began in October 2000. There were approximately 100 h of viewing the aurora and about 100 observations of various kinds (torus, satellite and Jupiter disk) by the time the CC ended on March 22, 2001. Some Jupiter system observations of the disk had the slit-oriented parallel to the jovian equator to simultaneously measure and spatially resolve the aurora and torus emissions during far encounter. Later observations had the slit oriented perpendicular to the jovian equator, an effective way to simultaneously observe the north and south aurora on separate spatial pixels of the imaging detector. To achieve observations that separately resolve the north and south auroral regions required a narrow time window around closest approach of the Cassini flyby. The UVIS could achieve a minimum of eight-pixel spatial resolution of the Jupiter disk for the period of ±15 days around closest approach. Closest approach occurred on December 30, 2000 with a disk diameter of 14 mrad.

The characteristics of the UVIS instrument have been discussed in detail in a recent paper (Esposito et al., 2004). In brief, the instrument consists of separate telescopes for the EUV (563–1182 Å) and FUV (1115–1913 Å) channels, respectively, with an option of one of three separate entrance slits for each instrument: low resolution (75, 100 µm [FUV, EUV] slit widths), high resolution (150, 200 µm [FUV, EUV] slit widths) and occultation slit (800, 800 µm [FUV, EUV] slit widths). Each configuration determines the field-of-view (FOV) in the plane of dispersion. The UVIS field-of-view is 1 mrad (206 arcsec) × 59 mrad for the EUV high-resolution channel and 0.75 × 60 mrad for the FUV high-resolution channel in the directions of the slit width