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Isolating the 130.4 nm and 135.6 nm emissions in Ganymede's aurora using broadband optics

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Abstract

We discuss a technique for isolating the two main Far Ultraviolet emission lines in Ganymede's aurora by adding flight proven transmission filters to a broadband, wide-field imager design. We find that the ratio of OI emissions at 135.6 nm and 130.4 nm can be recovered if the transmission of the filters and other optical elements are well known. This ratio allows constraints to be placed on the relative abundances of O atoms and O_2 molecules within Ganymede's atmosphere, leading to more accurate models of atmospheric composition.

1. Introduction

The Jupiter system Ultraviolet Dynamics Experiment (JUDE) is a wide-field Far Ultraviolet (FUV) imager to be proposed for ESA's JUICE mission to Jupiter. By obtaining large-scale images at high spatial and temporal resolution, the instrument will increase our understanding of emissions within Jupiter's aurora and in the airglow and aurora of its moons. JUICE will spend a significant proportion of its mission in orbit around Ganymede, and the imager can provide an enhanced understanding of this unique moon.

1.1. Ganymede's FUV aurora

Ganymede is the only moon in our solar system known to possess an intrinsic magnetosphere. HST observations have shown FUV emission lines from atomic oxygen at 130.4 nm and 135.6 nm, mainly concentrated in two bright regions corresponding open/closed field line boundaries, implying that the emissions are auroral in nature [4],[1]. The ratio of intensities of these two emission lines allows the relative abundances of O and O_2 in the atmosphere to be inferred: in a pure atomic oxygen atmosphere, a ratio of less than 1.2:1 is expected [1]; measurements of this ratio from HST/STIS observations of Ganymede have given values of between 1.2 ± 0.2 and 3.2 ± 1.6 [1], therefore implying that the atmosphere is dominated by O_2. Large-scale images of the emission regions, combined with information about spatial and temporal variations in the OI FUV emission ratio, would allow models of Ganymede's atmospheric composition and auroral production mechanisms to be refined.

1.2. JUDE optical concept

JUDE's optics consist of nickel-plated aluminium mirrors, onto which multilayer reflective coatings are deposited, giving a bandpass of ~120–150 nm. Placing two or more normal-incidence transmission filters immediately in front of the focal plane detector allows multiple bandpasses to be defined within this range. For the purpose of the calculations outlined below, two filters were chosen, with peak transmissions at 122 nm and 147 nm. Although these normal-incidence filters are broadband devices with overlapping bandpasses, the resulting instrument throughput in the 122 nm channel is higher for the 130.4 nm line OI line, while the 147 nm channel is biased towards detection of the 135.6 nm OI line. Hence line ratios can be recovered from observations made with the instrument.

2. Emission ratio calculations

We assume no significant FUV emission from Ganymede's atmosphere other than the two O I lines, based on the low background seen in HST/GHRS observation of Ganymede [4]. The flux through each of the two transmission filters is then given by

$$F_{total(a)} = t_{130.4(a)}C_{130.4} + t_{135.6(a)}C_{135.6}, \quad (1)$$

$$F_{total(b)} = t_{130.4(b)}C_{130.4} + t_{135.6(b)}C_{135.6}, \quad (2)$$

where t is the transmission of the filter at the specified wavelength, and (a) and (b) represent the 122 nm and 147 nm filters respectively. The C terms refer to the flux after reflection by the coated optics but *before* the signal passes through the filters, and the F terms represent the total flux after reflection followed by transmission through filter a or b. These equations can be solved to give the flux after reflection by the optics at the two wavelengths of interest:

$$C_{130.4} = \frac{F_{total(b)} - \frac{t_{135.6(b)} F_{total(a)}}{t_{135.6(a)}}}{t_{130.4(b)} - \frac{t_{135.6(b)} t_{130.4(a)}}{t_{135.6(a)}}}, \quad (3)$$

$$C_{135.6} = \frac{F_{total(a)} - t_{130.4(a)} C_{130.4}}{t_{135.6(a)}}, \quad (4)$$

The raw count rates in the O I emission lines can then be recovered by dividing $C_{130.4,135.6}$ by the effective area of the instrument at the relevant wavelength.

2.1 Atmospheric model

The reliability of the emission ratio calculations can be tested using spectra obtained from HST/STIS observations of Ganymede [1]. The emissions seen in these spectra are broadened as a result of the STIS response to an extended source, so we have deconvolved this response from the data to provide a spectrum more representative of the raw Ganymede emissions. The OI emissions are multiplets, and in the approximation that Ganymede's atmosphere is optically thin, the intensities of the multiplet component lines are in the ratio of their transition properties [3]. The widths of the emission lines were estimated assuming two possible atmospheric conditions: firstly with the O atoms responsible for the emissions in thermodynamic equilibrium (so that the line widths were estimated from the thermal energy of the atoms); and secondly with the line widths based on the kinetic energy of O atoms which are not in thermodynamic equilibrium. In either case the line width is small (much less than 1 Å).

The model spectra were multiplied by the transmission curves of the JUDE filters and coatings (Figure 1). The measured 135.6 nm : 130.4 nm ratio for each spectrum was then compared to the ratio estimated using Equations 3 and 4.

3. Results

The results of the initial ratio calculations were in good agreement with the "true" values in the input model; the recovered line ratio, obtained using Equations 3 and 4, was accurate to within 1% of the value in the input spectrum. The calculations were repeated with Poisson noise added to each spectrum at a signal:noise ratio of 2:1. This is higher than the expected noise level at Ganymede based on previous observations and represents a worst-case scenario. With noise, the accuracy of the ratio calculation varied considerably between the modelled spectra, from ∼2% to ∼17%. For comparison, previous estimates of this emission ratio at Ganymede have been quoted with uncertainties of between 13% and 50% [1].

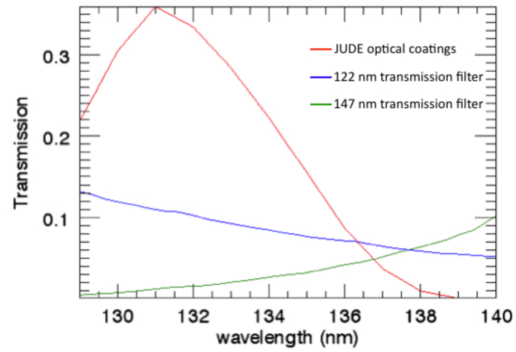

Figure 1: Transmission curves for optical coatings (red line [2]), 122 nm filter (blue line [5]) and 147 nm filter (green line [5]) in the wavelength region 130–140 nm.

4. Summary and Conclusions

The ratio of the intensities of OI emissions in Ganymede's aurora at 130.4 nm and 135.6 nm, in combination with wide-field images of the auroral distribution, will help to characterise Ganymede's atmosphere and aurora further. We have shown that this ratio can be measured to a higher precision than previously possible using a wide field imager equipped with two commercially available FUV transmission filters.

References

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