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A New Spectrograph Platform for Auroral Studies in Svalbard

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Abstract.

A versatile spectrograph platform has been installed by University College London at the Adventdalen Observatory in Svalbard. The platform was primarily built to support the Southampton University study of proton aurora and small-scale auroral features. It has successfully recorded the spectral profile of the Doppler broadened H-beta emission line (486.1 nm) and observed the predicted red shifted component due to proton back-scatter. The platform consists of a HiTIES (High Throughput Imaging Echelle Spectrograph) manufactured by Boston University together with two photon-counting photometers built by UCL and a narrow-field intensified video camera. All instruments are co-aligned and centered on the magnetic zenith. This combination of instruments can discriminate between spatial and temporal variations of small-scale features and thus complements measurements by narrow beam radar, which is unable to do this. The system can be controlled remotely over the Internet.

1 Introduction

The UCL Svalbard Spectrograph Platform was built to study auroral features with high time and spatial resolution and is intended to complement observations made by the Eiscat Svalbard Radar (ESR). The original motivation for the project was the Southampton University study of proton precipitation described elsewhere in these proceedings (Lanchester, 2001). The platform currently consists of four co-aligned instruments: The HiTIES imaging spectrograph, two narrow-band photometers and a narrow-field intensified video camera. Special consideration has been given to operation of the platform over the Internet and many functions can be remotely controlled and observed.

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2 The HiTIES Spectrograph

The imaging spectrograph itself was designed and built by the Center for Space Physics, Boston University (Baumgardner, 1993). It is based on their innovative HiTIES (High Throughput Imaging Echelle Spectrograph) design. The optical configuration is shown in Figure 1. The image of a slit corresponding to a ten degree arc in the sky is dispersed by an echelle grating. However, instead of the cross-dispersion element traditionally used to separate successive orders of diffraction, an innovative filter mosaic is used to select the spectral regions of interest. The mosaic is positioned at an intermediate image plane and consists of strips of narrow-bandwidth interference filter - the strips being set at right angles to the dispersion axis. Each strip is chosen to select a specific spectral region and is positioned over the image of that region at the chosen order. Because the filters have a very narrow pass band (5nm) they completely exclude the spectra from other orders which are co-located. Careful selection of the orders and fine tuning of the grating angle enable up to five regions of interest to be accommodated on the image in this way.

The re-imaging optics relay the spectra to a camera. The one supplied with the spectrograph was manufactured by PixelVision and is an ultra low noise CCD camera, equipped with thermoelectric coolers to reduce its operating temperature to around 220 degrees Kelvin. The resolution of the CCD is 1100 x 1050 elements, but neighbouring pixels may be added together, or 'binned', to provide extra sensitivity at the expense of spatial or spectral resolution. The spectral resolution for unbinned images is in the region of 0.1nm. For auroral observations the typical exposure time required is from 10 to 60 seconds.

2.1 Design of the filter mosaic

The filter mosaic measures 50mm square. The strips of interference filter extend the full length of the image axis and are positioned adjacent to one another, each coinciding with

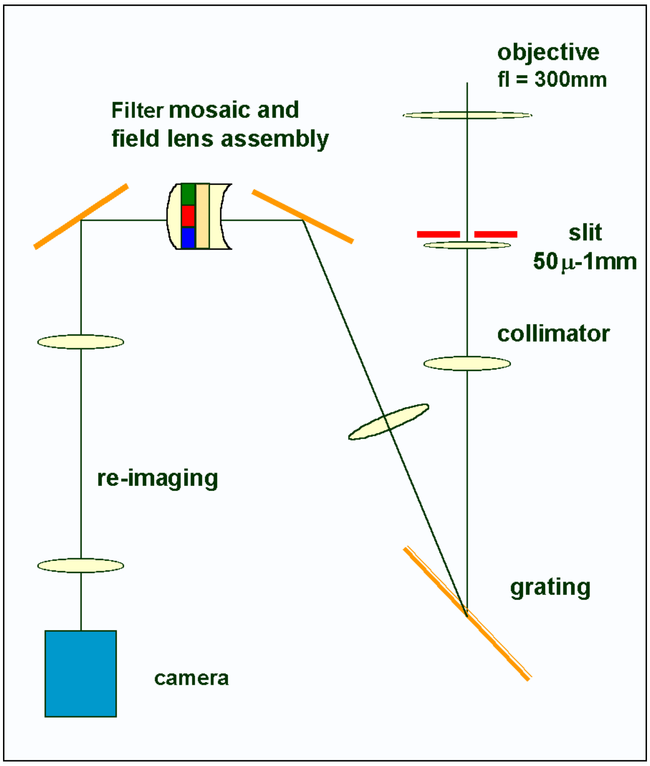

Fig. 1. The optical configuration of the spectrograph

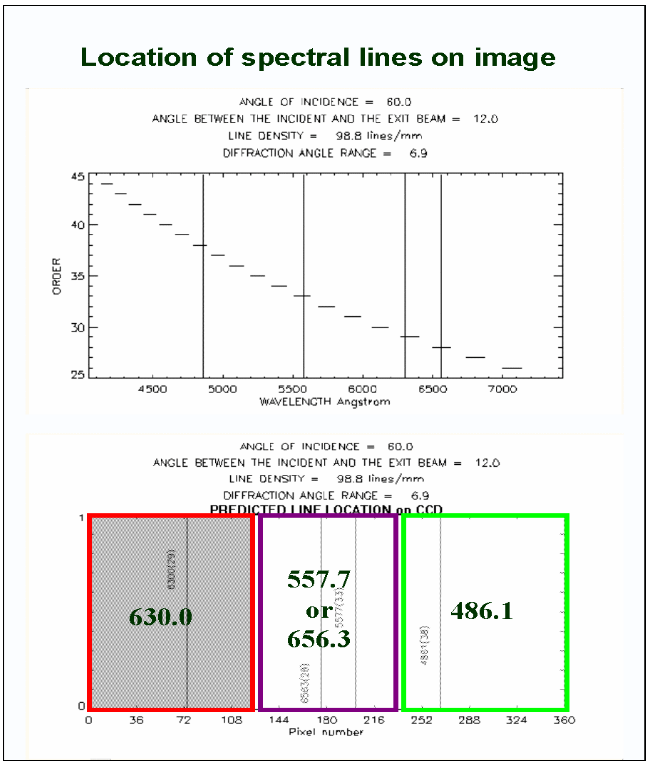

Fig. 2. Design of the filter mosaic.

the slit image of a spectral feature of interest. The mosaic is held in a removable cassette which slides out of the main spectrograph housing. The cassette also carries the necessary field lenses which are mounted either side of the filter. Pre-assembled filter mosaics can thus be exchanged easily according to the requirements of different observing schedules. A program written in IDL is used to determine the position of each spectral region of interest. The display from the program is shown in figure 2. The top half of the display plots the order of diffraction against wavelength. The width of each step of the 'staircase' indicates the range of wavelengths for that order which are imaged on the area occupied by the filter mosaic. Four spectral emission lines of interest are marked. The bottom half of the display shows how the lines appear on the mosaic itself. The 486.1nm Hβ emission cuts through the right side of the step corresponding to order 38 and so is located towards the right of the image. Similarly, the 630nm oxygen line is on the left of order 29. The 577.7nm and 656.3nm emissions are both imaged near the centres of their respective orders, so for this particular arrangement only one of them may be chosen. In this instance, therefore, a mosaic of three filter strips can be constructed. The angle of the grating can be adjusted with a micrometer screw thread to enable regions of interest to be shifted along the image and from one order to the next.

Fig. 3. The solar eclipse observation.

3 The Narrow-band Photometers

The purpose of the photometers is to provide high time resolution measurements of the intensities of the Hβ and ionised molecular nitrogen emissions and to facilitate calibration of the spectrograph sensitivity. They were designed and manufactured at UCL. The operating software drives high speed counting circuits and provides a real time display and data recording on a Pentium computer. The time resolution is adjustable down to 0.1 seconds and the calculated sensitivity is 20 counts per second per Rayleigh. Each photometer is equipped with a 2 inch diameter, 1nm bandwidth interference filter. The field of view of one degree full angle was chosen to be comparable with that of the Svalbard EISCAT Radar at auroral heights and is co-aligned with the centre of the slit of the spectrograph. The detectors used are Hamamatsu photomultipliers, equipped with low noise (<20 counts per second) bi-alkali photocathodes specially designed for photon counting applications.

4 The Narrow Field Video Camera

This is a commercially available video CCD camera provided by Photonic Science Ltd., which is equipped with a state of the art XD4 (enhanced super-S25) image intensifier manufactured by DEP. It is equipped with an f1.2, 50mm focal length lens to give a field of view 16 degrees by 12 degrees. A long-pass filter is used to eliminate the long-lived emissions at wavelengths shorter than 645nm. The video is recorded on a time lapse SVHS recorder and a video feed is provided to a frame grabber installed on the photometer computer so that the image may be viewed over the Internet.

5 First results

The spectrograph was delivered to University College in May 1999. In order to evaluate the instrument thoroughly prior to installing it at its final destination in the Arctic, it was decided to take advantage of an exciting opportunity for first light - the total solar eclipse, visible in the UK on August 11th. The three hydrogen Balmer lines, alpha, beta and gamma (656.3nm, 486.1nm and 434.0nm), normally visible in sunlight as absorbtion lines, are present in the corona as emission lines and, therefore, should be visible as such during totality. In order to adapt the instrument for solar observation it was necessary to modify the instrument platform to mount the spectrograph rotated by 90 degrees so that the slit was horizontally aligned. The instrument was transported to Helston, Cornwall, UK, where it is shown on its mount in figure 3. It was fitted with an attenuating solar filter which was removed during totality. A three section filter mosaic was constructed for the three hydrogen lines. In spite of the disastrous weather, the clouds parted for a brief instant, during which the three emission lines were clearly observed. The raw images obtained shortly before and during totality are shown in figure 4. The additional structure visible in the solar spectrum provides an accurate method of calibrating the spectral axis of the instrument. Figure 5 shows a histogram plot of the absorbtion features (integrated along the spatial axis). The spectrograph clearly demonstrated its ability to measure three features from quite different parts of the visible spectrum simultaneously at high resolution.

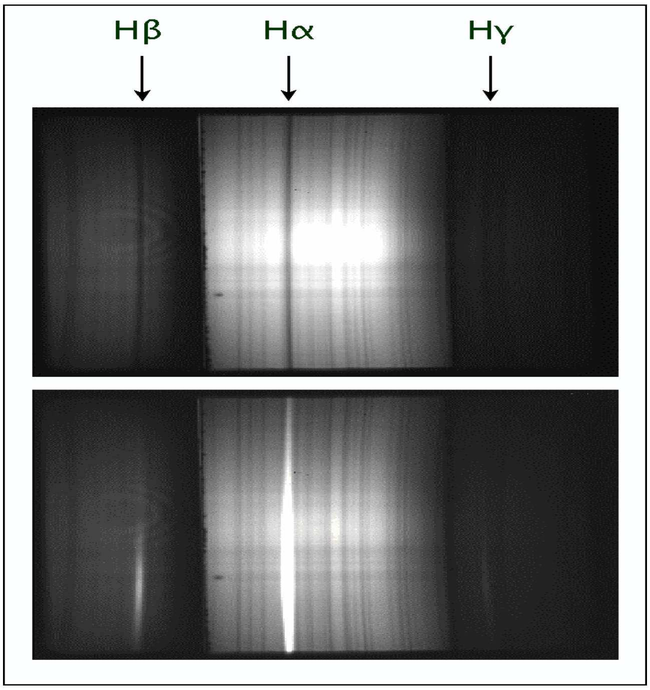

Fig. 4. The spectrograph images before and during totality

On its return to UCL, the platform was equipped with its two photometers and intensified video camera. The spectrograph was fitted with a filter mosaic to observe Hβ and the molecular nitrogen emissions (N_2^+) at 465.2 and 470.9nm. One photometer was assigned to Hβ and the other was shared between the two nitrogen lines, selected by manually changing the filter. The platform was installed at the Adventdalen Observatory near Longyearbyen, Svalbard in November 1999. The instruments were carefully co-aligned by observing Po-

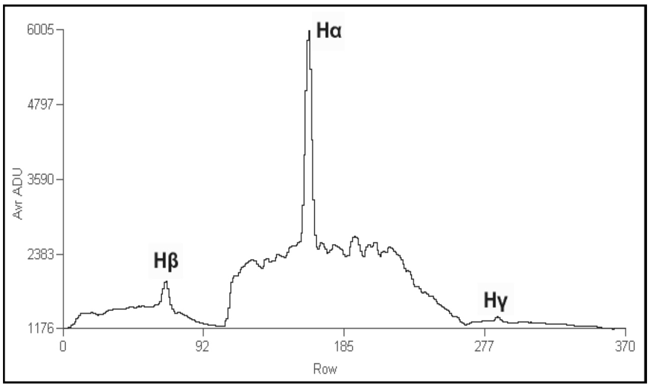

Fig. 5. Histogram plot of the solar spectrum during totality

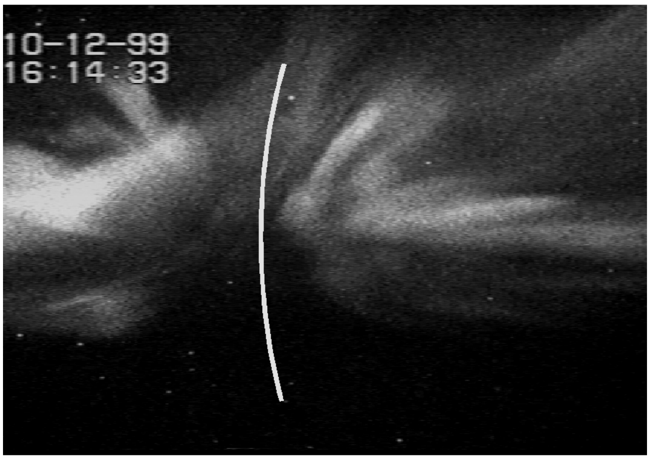

Fig. 6. The narrow field camera.

laris before directing the platform towards the magnetic zenith. Correct alignment was confirmed by observing the images from the video camera of the aurora radiating from the zenith, shown in Figure 6. Superimposed is the approximate field of view of the spectrograph slit. The slit is curved to compensate for the curvature introduced by the grating, so that the image of the slit on the filter mosaic is a straight line.

Unfortunately there followed a protracted period of problems with the PixelVision camera. Whilst this was undergoing repairs, an intensified CCD camera was temporarily fitted to the spectrograph and successfully recorded the strong proton aurora of 26th November 2000. Figure 7 shows the Hβ spectrum recorded over a 3nm bandwidth during a three hour period. Again, the spectrum is co-added along the spatial axis to improve the signal-to-noise ratio. This event and the detailed data analysis is described fully elsewhere in these proceedings (Lanchester, 2001). The Doppler broadened Hβ signature was clearly seen by the spectrograph and was both blue and red shifted as predicted. The event was easily detected by the photometers. Figure 8 compares the signal obtained during this event with a typical electron aurora recorded the previous night.

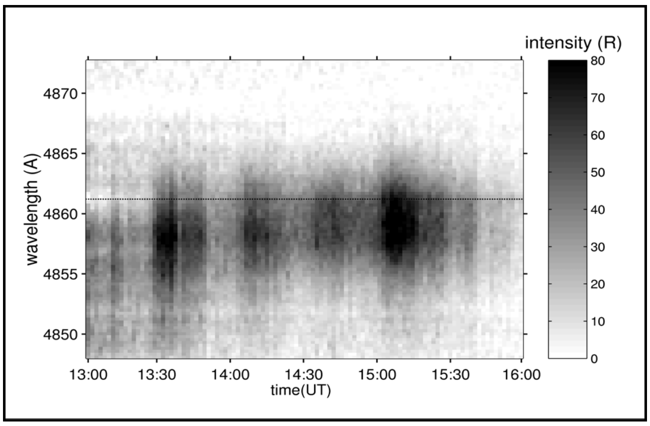

Fig. 7. The proton aurora event of 26th November 2000.

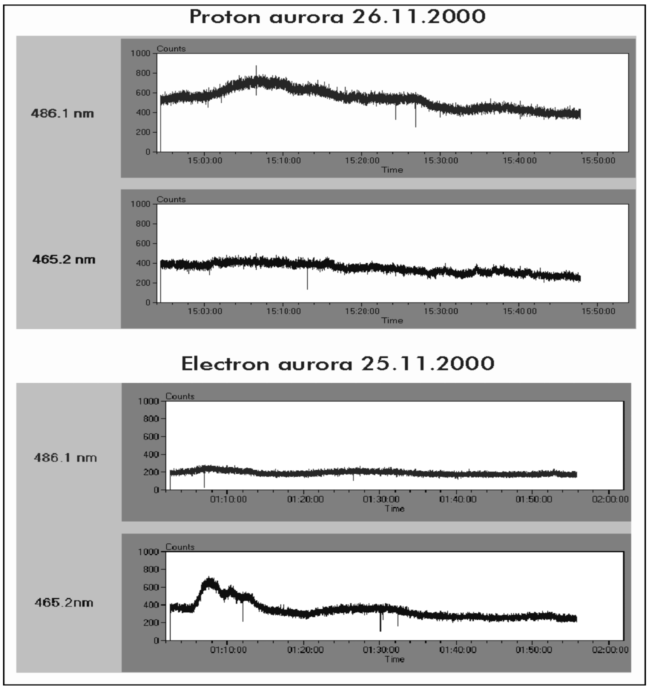

Fig. 8. Photometer recordings of proton and electron aurora.

6 Future work

In spite of the problems incurred by the unreliability of the PixelVision camera, the platform has successfully demonstrated its ability to realise its design criteria. We shall be operating it during the coming season in conjunction with our observing programme at ESR. Currently we are testing a photon-counting detector developed at UCL for astronomical work (Fordham, 1991). This is an intensified CCD with pulse centroiding, which will provide high resolution with a much more favourable signal-to-noise ratio. It is not subject to the readout noise associated with bare CCDs, the only significant source of noise being that incurred by the photon statistics (Poisson noise). It is anticipated that this improvement will enable detailed structure in the spatial direction to be observed more easily. A further proposed improvement is an off-band photometer channel for subtraction from the Hβ channel to remove background contamination caused by electron-induced emissions.

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