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A STAR-POINTING UV-VISIBLE SPECTROMETER FOR REMOTE-SENSING OF THE STRATOSPHERE.

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We have constructed a novel instrument for ground-based remote sensing, by mounting a UV-visible spectrometer on a telescope and observing the absorption by atmospheric constituents of light from stars. Potentially, the instrument can observe stratospheric O_3, NO_3, NO_2 and OClO. It is particularly useful for polar measurements in winter beacuse it observes at night. By using an array detector, spectral noise from atmospheric flicker is avoided. By using a 2D array, light from the sky adjacent to the star is measured simultaneously, as shown in Fig. 1, and subtracted. This is important at twilight, at the poles during aurora, or in hazy conditions near city lights. By using a cooled detector designed for the highest quality astronomical imaging, dark current is small enough that shot noise on the photon flux at the detector dominates. Within 3 months of construction, this new instrument was deployed outside, in the Arctic, in winter.

The 300 mm diameter telescope, designed for amateur astronomy, uses an equatorial German mount with a very rigid support tube so that observations are possible in winds of 5 knots. A dome to cover the telescope would be too cumbersome, instead we use a smaller weatherproof structure with leaves which hinge down. This is convenient during operation and minimises wind resistance when closed during storms, important because of our inability to secure the structure to a platform in the field.

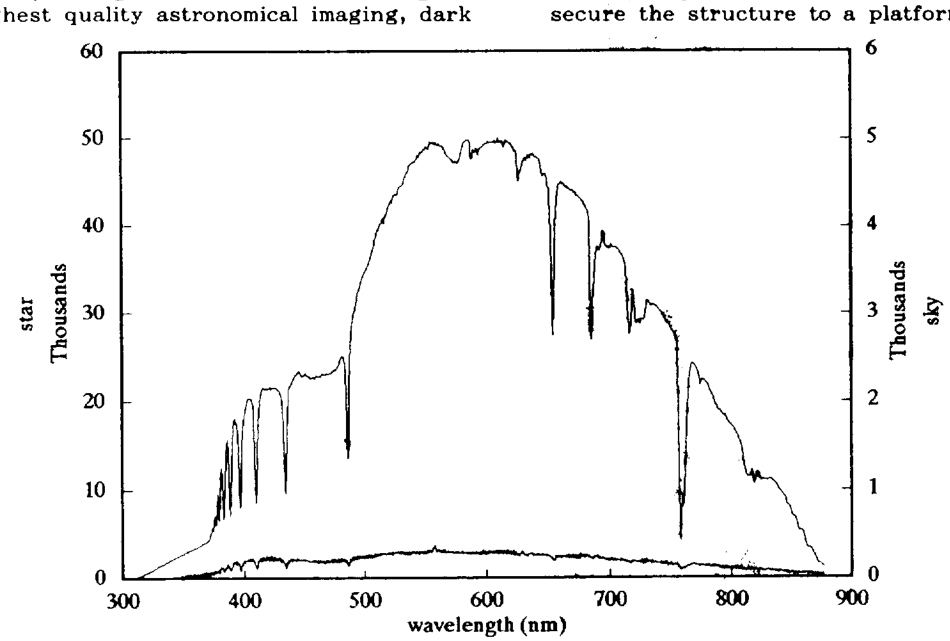

Fig. 1. By using a 2-D detector array, the sky spectrum (lower trace, x10) and star spectrum (upper trace) can be obtained simultaneously and the sky spectrum subtracted from the star spectrum. This is important for polar measurements because of the auroral peaks in the sky spectrum near 560 nm and 630 nm. Units in these and other figures are the sum of digitiser counts in all pixels across the detector, perpendicular to the wavelength axis, in 120 s exposure (in our system, 1 count = 34 electrons).

On the telescope, the eyepiece has been replaced by an optics plate containing the spectrometer and other components, shown in Figure 2. Despite the support tube for the Cassegrain secondary being made of fibre-glass and ambient temperatures which vary from +15°C to -20°C, external refocussing of the optics plate on its slides is unnecessary. A beam-splitter diverts 2% of the light to a commercial TV camera, whose accompanying tracking software feeds error signals to the telescope's motor controller. This allows accurate tracking with poor polar alignment in difficult field conditions, and restores the star's image on to the spectrometer slit if strong winds displace the telescope. Clutches between the drive gears and the axes allow an operator to orient the telescope rapidly towards the desired star. Orientation is completed by observing the star through a spotter telescope and moving the telescope motors by means of a hand controller whose switches parallel the relays in the TV camera's control box. This places the image of the star within the 0.5° field of view of the TV camera, whose software then acquires the star.

The spectrometer slit is of width 50 μm, large enough to pass most of the light despite optical aberrations. The relay optics to the TV camera images 2 pixels on to the width of the slit. In an earlier design which imaged 1.5 pixels on to the slit width, the image of a star at the slit hunted by more than the slit width, causing significant loss of signal. The spectrometer is of modest dispersion (200 grooves/mm) so that all the spectrum can be observed simultaneously. The image at the slit contains the blur circle of the star at its center, typically of diameter 120 μm, and light from the sky on either side. The imaging spectrometer has an inherent blur circle of about 80 μm, which limits its resolution to about 1.5 nm. The image at the detector (1152 x 298 pixels, each 22 μm square) contains the spectrum of the star in a stripe of width about 150 μm (7 pixels) and the spectrum of the sky on either side.

Because of our differential analysis procedure, smooth variations in responsivity along the detector are not important, by contrast to variations between adjacent pixels. By illuminating the slit with a tungsten lamp, we measured the interpixel variability to be about 2% peak-to-peak, significant because absorption by constituents can be less than 1%. Figure 3 shows the improvement in quality of a spectrum after division by the interpixel variability, which was stable to within 1 part in 10^4.

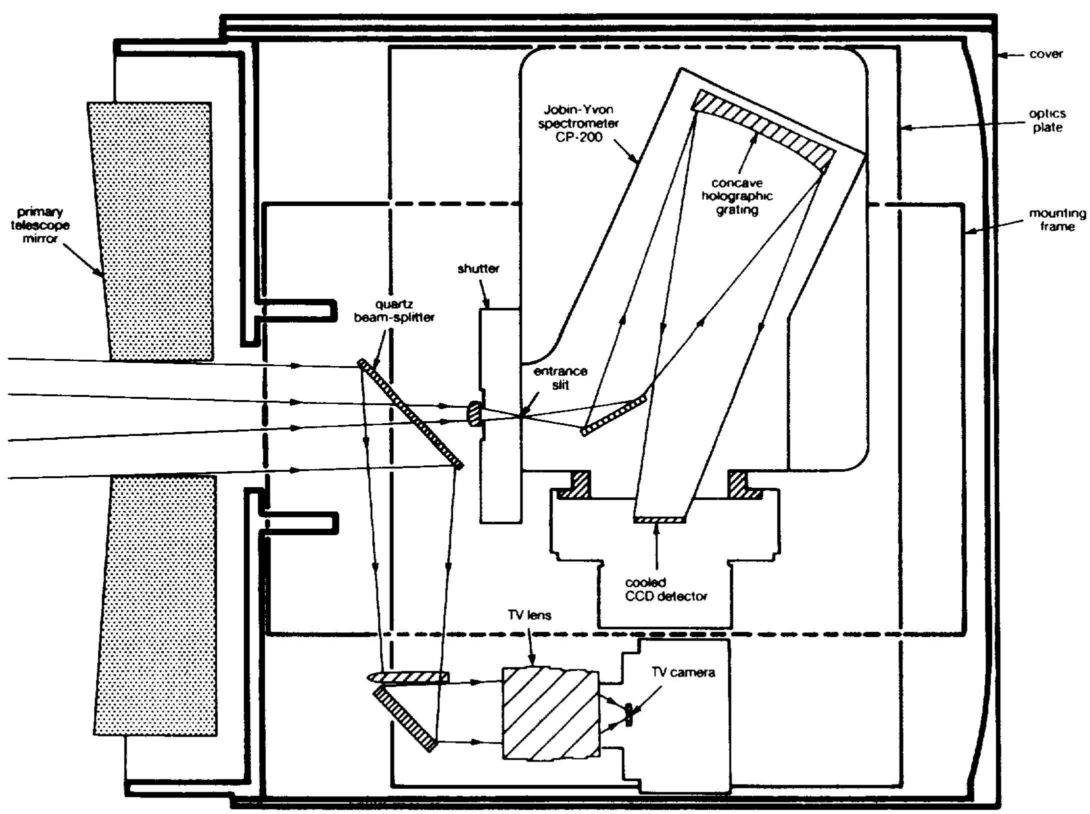

Fig. 2. The optics plate and its location on the telescope, where an eyepiece would otherwise be. A UV achromatic lens focusses light from the telescope (f/18.3) on to the slit of the small imaging spectrometer (f/2.9), which displays its flat-field image on a cooled 2-D detector array.

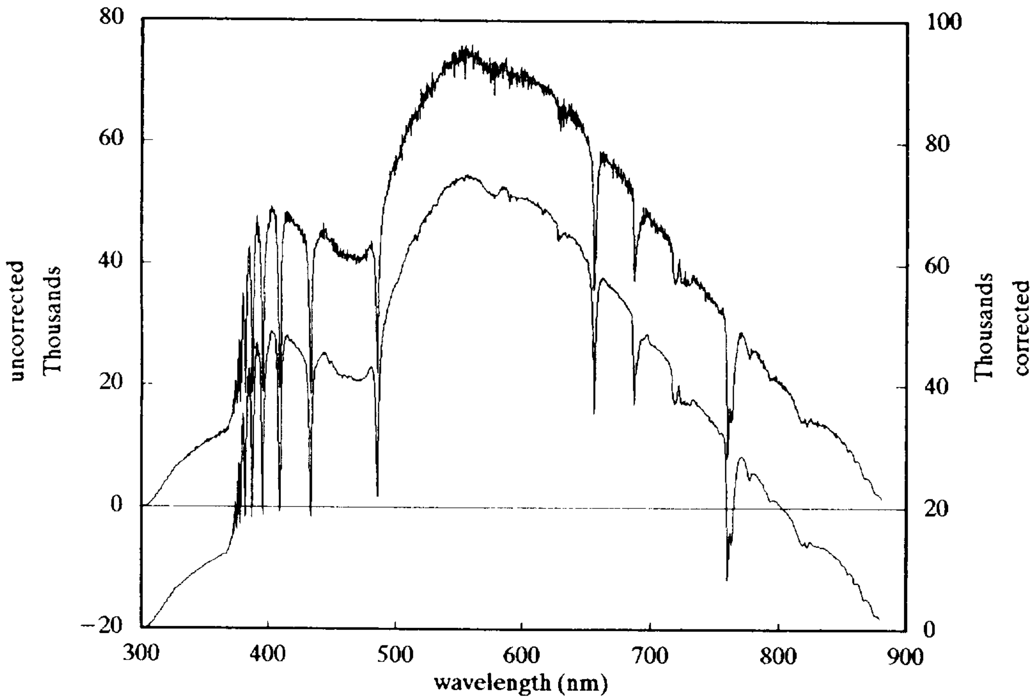

Fig. 3. A raw spectrum of Vega after 30 minutes' integration (upper trace), and after dividing by interpixel variability (lower trace). The variability was measured with a tungsten lamp, which has an inherently smooth spectral emission. The high quality of the lower spectrum is clear.

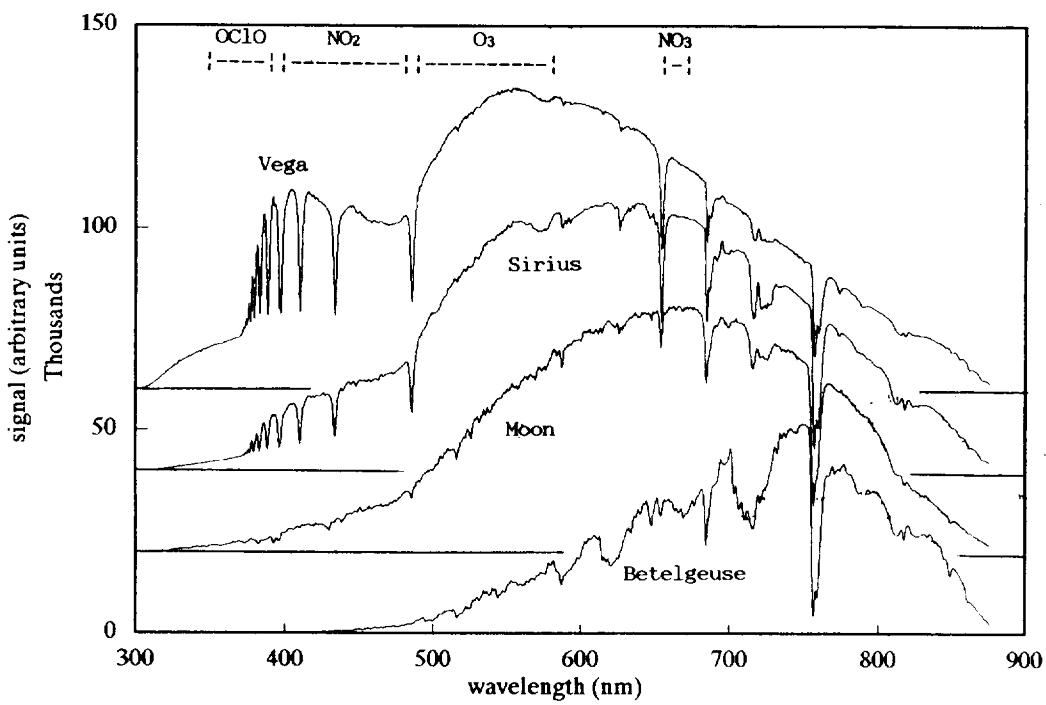

Fig. 4. Relative spectra of brighter objects. The hotter blue stars (Sirius, Vega) give more signal at the wavelengths of OClO and NO_2 absorption, and the strong Balmer-line absorptions in their atmospheres (380 to 480 nm) are excellent for wavelength calibration but can upset retrievals of NO_2.

Although the TV camera could track and the spectrometer could acquire spectra from stars of magnitude M3, useful signals are only obtained from stars brighter than M1 - Sirius, Vega, Rigel, Cappella. When visible, the moon and Jupiter give the most signal, although the moon is not brighter in the ratio of its magnitude because its image overfills the slit. Figure 4 shows some typical spectra.

As part of the European Arctic Stratospheric Ozone Experiment (Nov 1991 to March 1992), the telescope was located on a pier at the lake at the Swedish Royal Academy's station at Abisko (69°N). The site was especially useful for observations of stars for atmospheric measurements because the sky across the lake could be viewed to within 3° of the horizon from ground level. Despite unusual cloudiness at Abisko in 1991/92, many spectra of Vega (see Figure 5), the moon and Jupiter were acquired. Unfortunately, Sirius is not observable at this latitude. Spectra from the daylit zenith sky, via a glass window and an aluminium reflector, were also collected routinely. Analysis and results are described in a companion paper (Fish et al., these Proceedings).

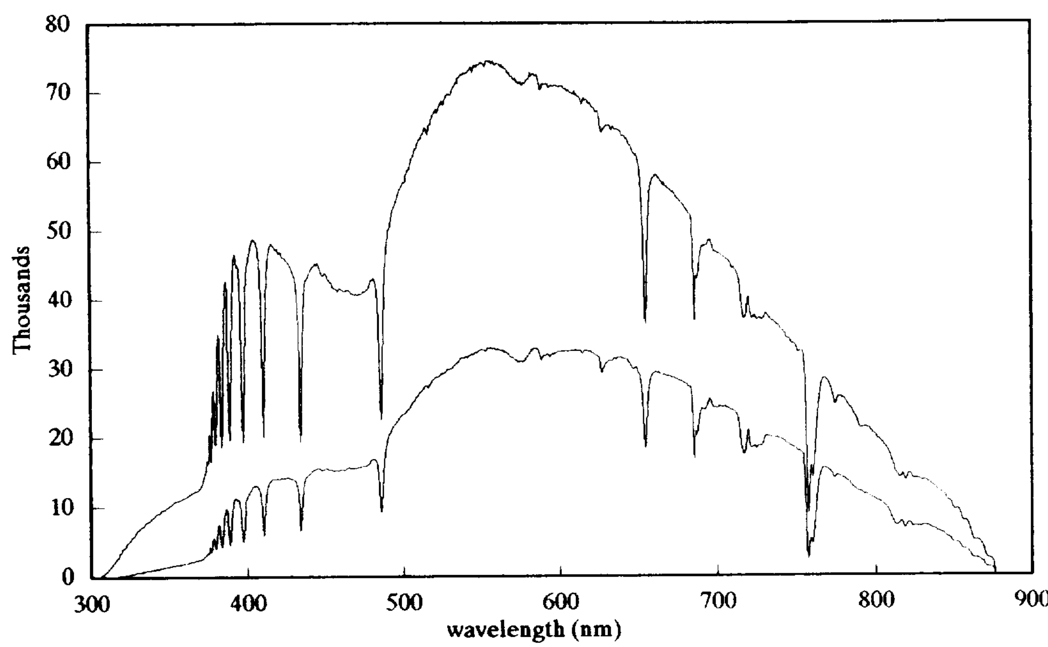

Fig. 5. Spectra of Vega measured during the night of 1 to 2 March 1992 at Abisko, at elevations of 50° (upper trace) and 17.2° (lower trace), with integration times of about 2 hours each. Spectral analysis for constituent amounts is performed with the ratio of a pair of spectra such as these.

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