The Cambridge OH Suppression Instrument (COHSI): Status After First Commissioning Run

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ABSTRACT

COHSI (the Cambridge OH Suppression Instrument) was successfully commissioned at the United Kingdom Infrared Telescope on Mauna Kea during a seven night observing run (19,20 & 25-29 March 1998) which coincided with this conference. Here we briefly describe the instrument and give a preliminary report on its performance at this time. The suppression optics and masks worked extremely well and the instrument background was found to be very low.

Keywords: OH suppression, near-infrared, spectrograph, photo-etching, optical fibers

1. INTRODUCTION

The sensitivity of any ground based near infrared spectrograph is limited by the background from the instrument itself, the telescope and dome, and the Earth's atmosphere. In the 1.0-1.8μm region, this background is dominated (95-98%) by emission from the OH (hydroxyl) molecule, formed at an altitude of ~90km.[1,2,3] The OH emission strength varies on both short and long time scales, and at resolutions R<2000, where these lines are significantly blended together, they become a significant drawback for medium and low resolution spectroscopy at these wavelengths.

At the United Kingdom InfraRed Telescope (UKIRT) on Mauna Kea, the sky brightness is 15.5 and 13.9 mag/arcsec^2 for the J (1.0-1.35μm) and H (1.43-1.80μm) atmospheric windows, respectively. In comparison, the interline sky background has been measured by Maihara, *et al*[1] to be about 18-19 mag/arcsec^2. By removing these skylines, the remaining background is much lower, which will result in surveys with greatly improved sensitivity. In addition, removal of the OH skylines greatly reduces the systematic errors in sky-subtraction caused by the variability of the OH emission and leaves a smoother background spectrum, giving redshift surveys a more even sampling in redshift space.

COHSI was designed to optically filter out the ~200 OH airglow lines which dominate the 1.0-1.8μm night sky spectrum. In this respect, it is similar to OHS for the University of Hawaii 2.2m and the OHS for SUBARU.[4,5] However, unlike these other instruments, COHSI is fiber-fed and offers both integral field and multi-object spectroscopy modes. The March 1998 commissioning run we are reporting on here featured only the integral field mode. The multi-object mode will be tested for the first time later in the year. The main scientific goal of COHSI is to carry out redshift surveys of very faint (J~21 and H~20) galaxies with redshifts in the range $1 < z < 2$.

2. COHSI INSTRUMENT DESCRIPTION

A full description of COHSI has been given by Piché, *et al* 1997. [6] Briefly, COHSI consists of: 1) the focal plane unit (FPU); 2) the suppressor module; 3) the cryogenic spectrograph; and 4) the optical fiber assembly which interconnects the first three parts. The FPU is mounted on the telescope while the suppressor and cryogenic spectrograph sit on the

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observing floor. The fiber assembly is effectively two separate fiber feeds which are physically joined together inside the suppressor.

Light from the telescope, collected by fibers, is first dispersed inside the suppressor with a spectral resolution of R~5000-7000. At these resolutions the OH skylines are well separated and are filtered out via reflective masks mirrors. The "OH clean" light is next completely undispersed and fed into the output fiber bundle. The output fibers channel the light into a liquid nitrogen cooled spectrograph, where the light is finally redispersed (R~500) with grisms onto two 256×256 pixel HgCdTe PICNIC arrays, one covering the J (1.0-1.35μm) band and the other covering the H (1.43-1.80μm) band. COHSI's integral field mode consists of 100 fibers. The multi-object mode will have 60 fibers. Details of the COHSI integral field unit are given in Kenworthy, *et al* 1997.[7]

Figures 1, 2, 3 & 4 illustrate various aspects of COHSI on its first commissioning at UKIRT.

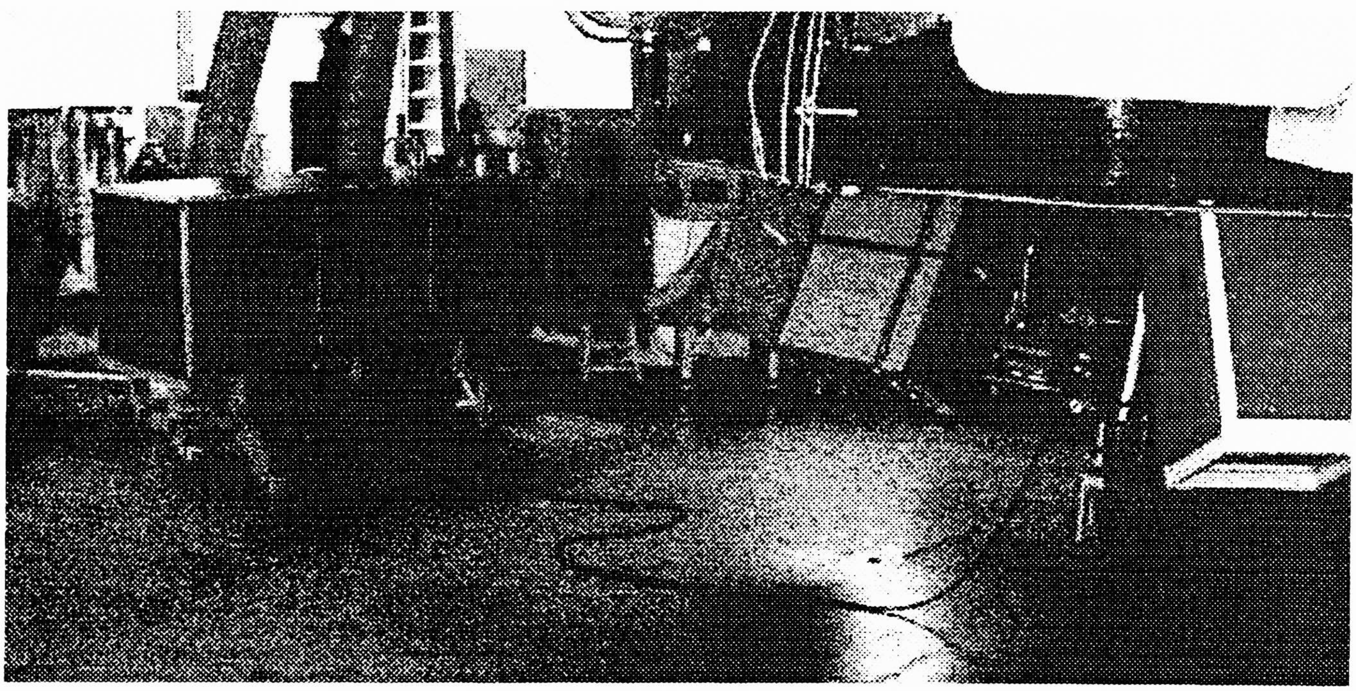
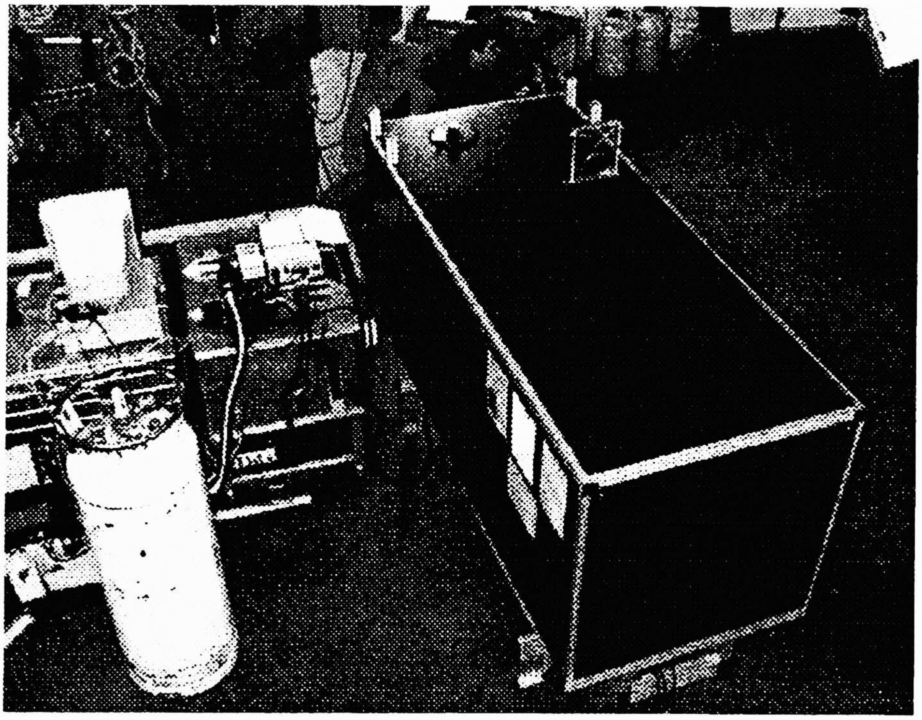


Figure 1 shows COHSI in its operating position on the UKIRT observing floor. The suppressor is the large black box on the left. The large structure to the upper right of the picture is the back end of UKIRT. The cryogenic spectrograph is behind the suppressor and cannot be seen in this view. The optical fibers can be seen as a black line trailing across the floor connecting UKIRT to the suppressor. When the telescope moves the suppressor remains stationary. The fibers are long enough and sufficiently well protected to allow the telescope its full operational range of movement.



The aerial view in **Figure 2** shows the suppressor and the cryogenic spectrograph, the latter being the gray box just to the left of center. The optical fibers which carry the OH filtered light from the suppressor to the spectrograph can been seen connecting the two. The large cylinder in the fore-ground on the left contains liquid nitrogen for cooling the spectrograph. Because of the lower boiling point of liquid nitrogen at Mauna Kea, the PICNIC detectors are operated at ~76K.

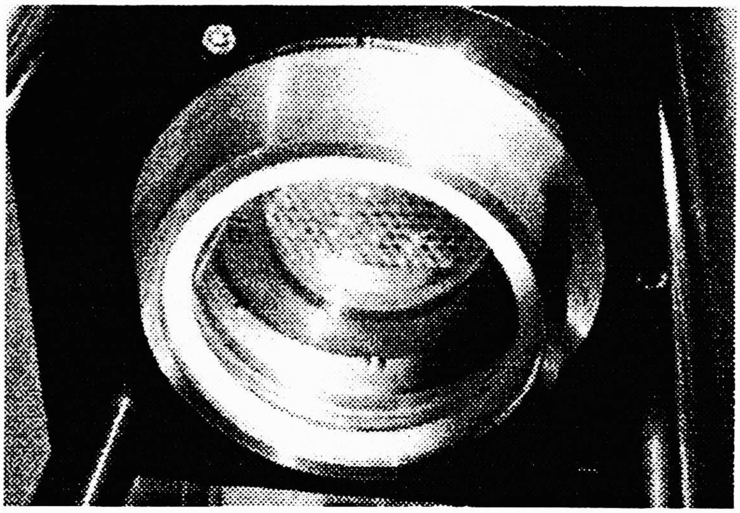


Figure 3 shows a close-up of the integral field unit mounted on the telescope. There are 100 lenses in the lens array and each one feeds an optical fiber of 110μm core diameter. The large lens in front of the array is the fore-optics field lens. A magnifying lens ahead of the field lens (not shown in the figure) is used to convert the scale at the Cassegrain focus to that required at the lens array. A field of view of 10×4 arcsec with ~0.6arcsec per fiber was used throughout the commissioning run.

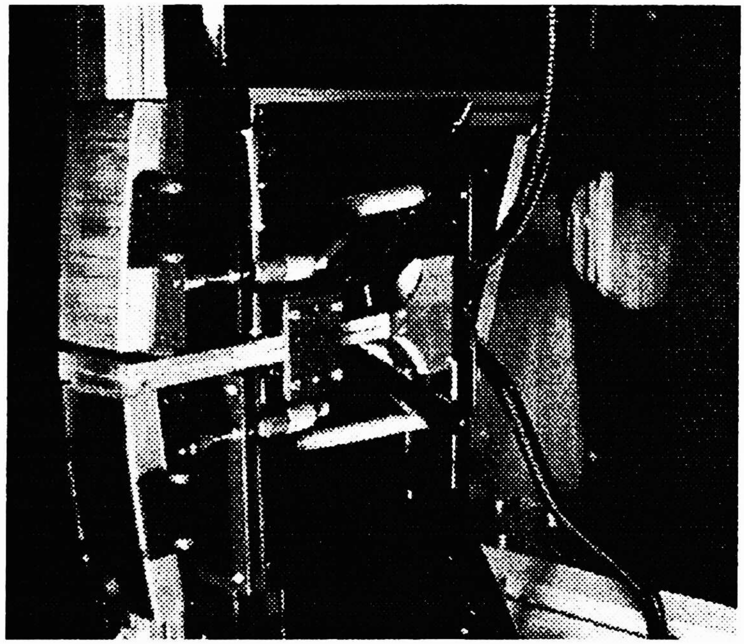


Figure 4 shows the focal plane area of the Schmidt optics of the suppressor. The mask mirrors can be seen on the extreme left hand side (H on top and J below). The conduit with the fibers from the telescope enters at the top of the picture and the output fibers go out the bottom of the picture. The ends of the fibers, which launch the light into the suppressor and then collect it on the way out, form a double fiber slit in between the two mask mirrors, falling on the atmospheric water band at 1.4μm. The OH features on the masks can be seen as horizontal lines and make the masks resemble a bar code. One of the two circular apertures in the aspheric plate which feed the light to the diffraction gratings can be seen on the right of the picture.

3. MASK MAKING TECHNOLOGY

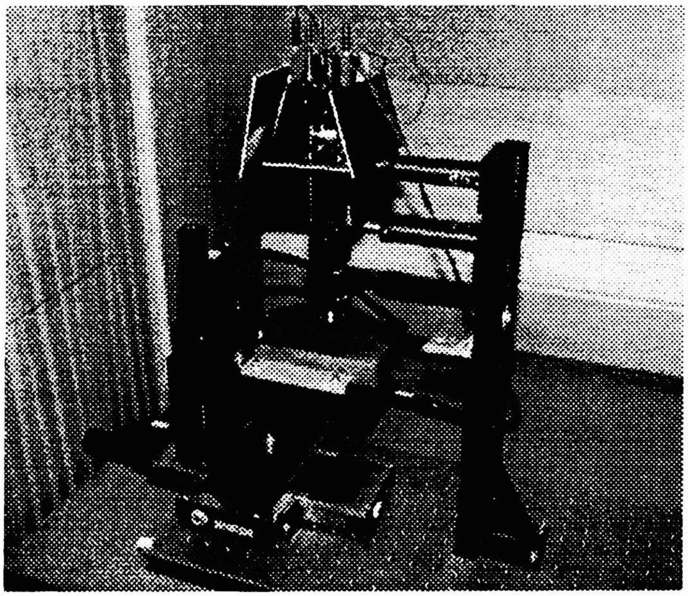
The greatest technological challenge in the COHSI instrument design is the manufacture of the suppression masks which demands a very high contrast pattern of high positional accuracy (<20 microns) over a curved surface. For our desired suppression, we required the parts of the mask mirrors corresponding to the OH skylines to be <0.5% reflective whilst the rest of the surface needs to ~98% reflective over the entire 1.0-1.8μm region. In our labs in Cambridge we developed a mask making technique based on photo-chemical etching.

Our convex spherical mask mirrors (radius of curvature is 834mm) are made of Zerodur. After the Zerodur substrates have been cut and polished the next stage of manufacture is to lay down three coatings on the curved surface: the first is an anti-reflection coating (<0.5% reflective over the J&H bandpass); the second is a reflective gold coating; and the third is a layer of photo-resist which can selectively be removed by exposure to blue-UV light.

We use a ZEMAX computer model to generate the coordinates of 193 skyline positions (98 in J and 95 in H) mapped across the entire curved mask plane. The computer model uses the as-built values for the suppressor where possible but because these are not known with enough precision the model is fine-tuned to give the exact dispersion which we measured very precisely in the lab (~35μm/Å). This provides XYZ coordinates which accurately represent the distortions (slit curvature in particular) at the mask and the shape of the mask surface. These coordinates are fed into a computer-controlled XYZ stage which literally draws our mask lines with an intense point light source onto the mirror surfaces, keeping them in focus in three dimensions (see Figures 5a & 5b).

We next develop the photo-resist, i.e. we remove the photo-resist that has been exposed to the light. After baking the masks to toughen the remaining photo-resist and make it non-responsive to light, we have industry place them in a chemical bath to etch away the gold on the mask no longer protected by the photo-resist (i.e. the mask lines). This reveals the anti-reflection coating beneath. The end result is ~100 narrow lines per mask, anti-reflection coated, separated by gold coated areas. The transitions from gold to AR coating are very sharp (<2 microns). Further details of this technique will be given in Ennico, 1998.[8]

The COHSI masks used in the UKIRT March 1998 commissioning run have mask features 250μm wide, made deliberately wider than the measured spectral spot sizes at the masks (~180μm) to catch the OH. About 17% of the spectral surface on each mask is "black."



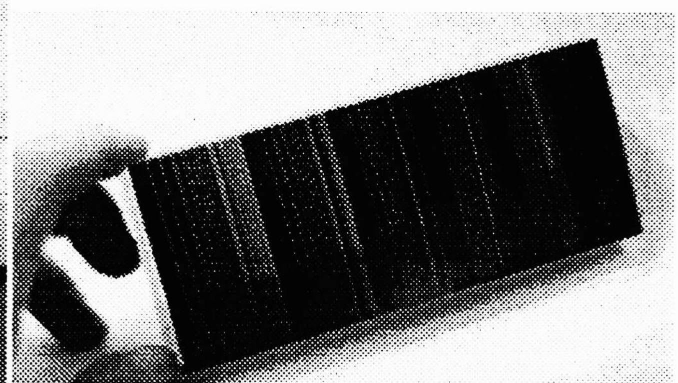


Figure 5a (left) illustrates how we expose the photo-resist on the COHSI OH suppression masks in our labs. A blue-intensive light is used to "draw" the mask lines on the photo-resist layer on the top of the mask mirror surface. The positions and focus of the mask lines are controlled by the motions of a XYZ stage operated by a lab computer. This procedure is performed in a darkroom.

Figure 5b (right) shows a completed, etched COHSI J band mask mirror. When illuminated from the back, the mask lines can be seen in transmission while the reflective gold areas appear dark. The photo also illustrates the structure of a high resolution OH sky spectrum, consisting of bands, blends and individual lines. The wavelength range for this mask runs from 1.35μm-1.0μm, from left to right in photo.

4. SUPPRESSING THE OH AIRGLOW AND MINIMIZING THE BACKGROUND LIGHT

Being able to selectively reject the wavelengths of the OH spectrum whilst cleanly letting through all other wavelengths is the most challenging aspect of COHSI. During the commissioning run we successfully demonstrated that COHSI was able to do this very well. Figure 6 shows a stack of two dimensional spectra that we obtained when we scanned the OH spectrum across the masks. The top spectrum is deliberately misaligned and the alignment is improved until the OH is well suppressed. The scan continued and the suppression was lost again for the lower spectra.

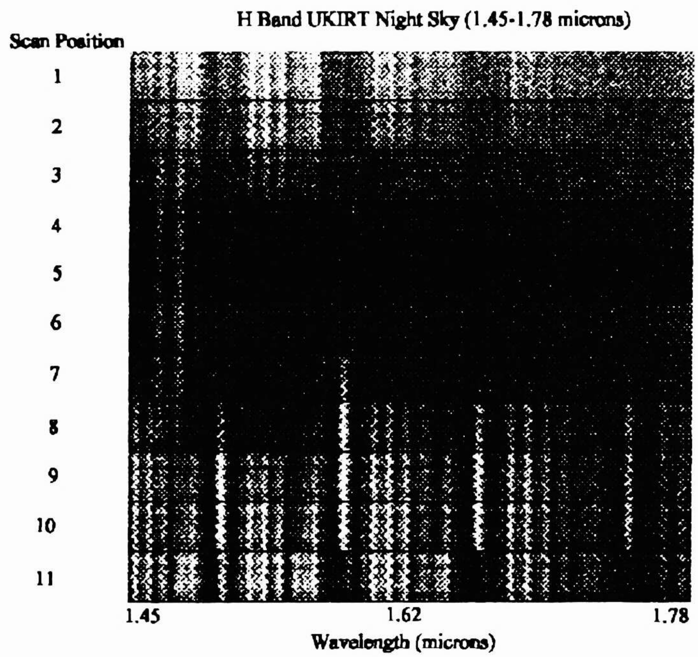


Figure 6 depicts scanning of the H band OH sky. We can deliberately misalign the wavelength calibration to allow the OH lines to come through. This figure illustrates 11 scan positions. The top scan (scan position 1) is misaligned and as we scan down the picture, the alignment of the OH with the mask lines improves until we have correct alignment (scan positions 4 & 5). The scanning then continues towards the bottom and the masks become progressively more misaligned. Each scan position represents a motion of $45\mu m$ at the mask mirror surface. Two H band skylines at the short wavelength end appear not to be suppressed at the best suppression position. They have yet to be identified and their positions will be noted and added to the COHSI masks.

When the glow from the OH in the Earth's atmosphere is filtered out, the remaining background light from the sky is extremely faint.[1] It is therefore vital that COHSI does not introduce any contaminating background light which would compromise the faint limit for the galaxies we intend to observe. During the observing run we achieved an instrumental background of 0.2 electrons/s/pixel for wavelengths shorter than $1.6\mu m$ which is almost entirely dominated by the detector dark current. This is 2.5× lower than we originally expected at the outset of the project and this will help enormously once we start to do major surveys in the near future because, once the OH is suppressed, the most dominant background source is the dark current.

5. ACKNOWLEDGEMENTS

The COHSI project was initially supported by PPARC grant GR/J79300 and then later by generous contributions from Dr. A.K. Velan and the Dr. Raymond & Beverly Sackler Foundation. K.A. Ennico acknowledges support by an AAUW Educational Foundation dissertation fellowship.

Finally, we thank the UKIRT support staff for their excellent assistance particularly during the March commissioning run.

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