Molecular Hydrogen Lines Observed with SUMER in the Spectrum of a Sunspot

Udo Schühle[1], Charles M. Brown[2], Werner Curdt[1], Uri Feldman[2]

[1] Max-Planck-Institut für Aeronomie, D-37191 Katlenburg-Lindau, Germany
phone: -49-5556-979-458, e-mail: schuehle@linmpi.mpg.de
[2] Naval Research Laboratory, Washington, DC 20375, USA

Abstract

We present spectra in which emission lines of molecular hydrogen have been found in the SUMER spectral range. Lines have been found solely over sunspot regions at wavelengths above 100nm. Mostly the emission of the molecular hydrogen band system is too weak to be observed among the spectra of hotter plasmas. Most lines had been observed previously with HRTS and identified by Bartoe et al. (1979). Only fluorescence lines, excited by coincidence with emission of other solar lines, have been found strong enough. One series of fluorescence lines is particularly strong. The relative intensities of these lines could be determined and compared with their transition probabilities. They are in good agreement.

1. Introduction

The excitation and emission of molecular hydrogen lines is of considerable interest for diagnostics of cool plasmas due to the hydrogen molecule's rich spectrum. Since in the quiet Sun temperature is sufficiently high to dissociate most of the hydrogen molecules, the lines of molecular hydrogen are comparatively faint. We therefore tried to identify such lines by their relative enhancement inside sunspots compared to quiet Sun locations.

Lines of the hydrogen molecule have been observed previously with the High Resolution Telescope Spectrometer (HRTS) with enhanced intensity over sunspot regions. Lines of the Lyman bands and one fluorescence series of the Werner bands have been identified by Bartoe at al. (1979).

In the Lyman bands, lines are expected to be strong in the 130nm to 150nm range, but the identification in this range is not always unambiguous because of the many lines of neutral atomic species abundant in this range of the solar spectrum. The strongest lines observed in HRTS spectra are from the fluorescence series which was identified by Bartoe et al. as a Q3 series excited by the O VI 103.2nm line in the (v'=1,v"=1) band of the C-X electronic system. Only two members of this series could be observed by HRTS in the wavelength range above 117.5nm, and their branching ratio was reported to be not in accordance with the well known transition probabilities. With the SUMER instrument shorter wavelengths are accessible, and more lines of this series can be observed and their relative intensities be measured.

2. Data acquisition and analysis

We analyse SUMER "reference spectra" acquired by an observing sequence specially designed for this purpose. On March 18, 1999, a single sunspot was close to the central meridian which was chosen as the target. Its position on the solar disk was determined from the white light intensity image of the Michelson Doppler Interferometer (MDI) onboard SOHO. The SUMER telescope was pointed such that the slit of the spectrometer crossed the sunspot, and the target was followed using the solar rotation compensation steps of the telescope. The position of the slit relative to the sunspot was verified regularly during the measurements using the image of the Rear-Slit-Camera at 630nm. A SUMER „reference spectrum" was acquired. The small size of the sunspot umbra of about 20 arc-seconds allowed only 20 pixels to be sampled along the slit direction (north-south), which limits the signal-to-noise ratio. We have attempted to compensate for this by taking an average of three exposures of 90 seconds at each wavelength position. We applied the flat-field and geometric distortion correction to achieve a precise wavelength calibration of the images.

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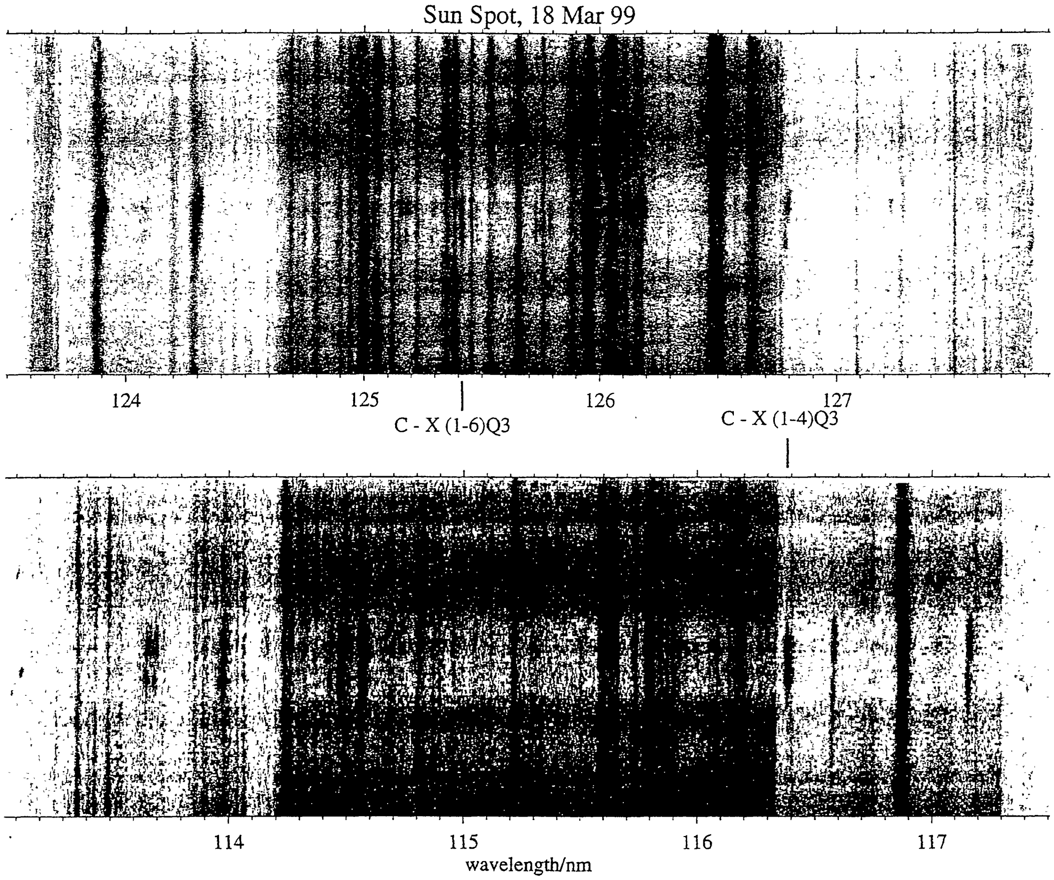

Figure 1: Two images of the reference spectrum used to identify molecular hydrogen lines. Note, the sunspot is located at the centre of the slit. Strong H_2 lines are identified at 125.41 nm and 116.39 nm.

3. Results

Figure 1 shows a sample spectrum, displayed as an „absorption spectrum". The sunspot is located at the centre of the 120" long slit, which coincides with the area of reduced intensity of the continuum. Lines of molecular hydrogen can be uniquely identified in these images as sharp lines with no large Doppler shifts appearing only inside the area of the sunspot. All other lines have considerable intensity outside the spot area or show large Doppler shifts and widths. Figure 2 shows the profile of one of the strong lines along the length of the slit. We see that the molecular hydrogen emission can be some hundred times enhanced in the sunspot over the normal quiet Sun.

The lines found were then identified with the line list of Sandlin et al. (1986) and Bartoe et al. (1979). Other lines of the Lyman bands have been searched for with help of the list of lines and molecular constants given by Herzberg and Howe (1959). The search for the strongest emission bands of the Lyman system around 140nm led to the conclusion that the emission is comparatively weak, and a full molecular band could not be identified. The dense solar spectrum in this range precludes that many lines can be observed unblended.

Few lines, however, are identified unambiguously by their unique appearance described above. They appear as P-R-doublets and are therefore fluorescence series excited by coincidence with one or more of the strong atomic emissions. However, most of these series of fluorescence lines are also fairly weak. Only one strong series is prominent among these lines, the Q3 series of the (v'=1,v") bands of the C-X electronic system. In Figure 2 we show the intensity profile along the slit of one example of these lines, the (1,4) Q3 line, which is the strongest of this series. In fact, within the sunspot area these lines appear among the strongest lines of all. Evidently, molecular hydrogen is extremely abundant above the sunspot, but the emission is in general effectively quenched.

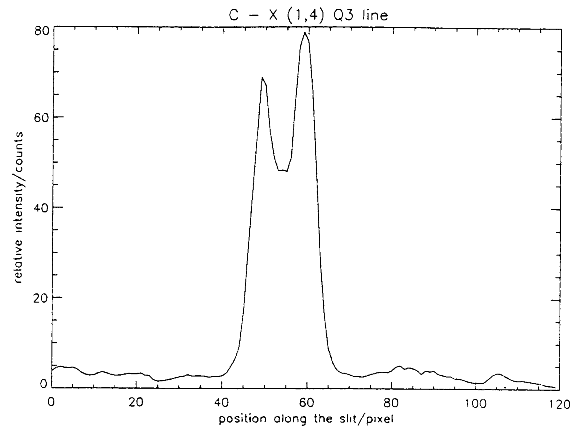

Figure 2: Intensity profile along the slit of the molecular hydrogen C-X (1,4) Q3 line

Eight lines of this series could be observed, corresponding to v‘‘=0 to v‘‘=7. All wavelengths predicted by Bartoe et al. (1979) agree well with our measurements. Five of these lines are unblended. The (1,0) line is blended by the N III 98.97nm line, the (1,1) line by the O VI 103.2nm line, and the (1,7) line is blended by the Si III 129.9nm line. In general, each blend contributes to the fluorescence excitation, the O VI 103.2nm excitation probably being the strongest.

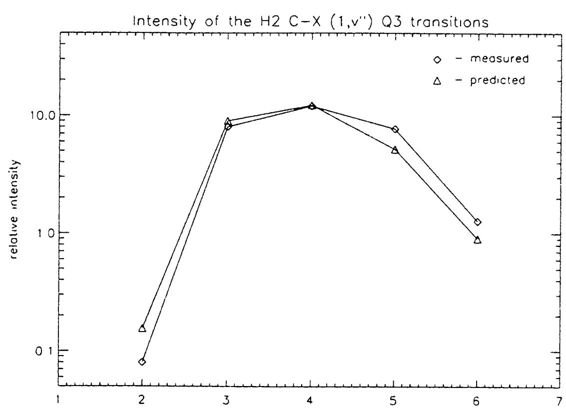

Figure 3: Intensities of the H_2 C-X (1,v‘‘) Q3 lines compared with the theoretical transition probabilities for v‘‘=2 to v‘‘=6.

The unblended lines can be used to measure their intensities and branching ratios, which can be compared to the theoretical branching ratios strictly given by the Franck-Condon-Factors at the J=3 level. A deviation from the predicted branching ratios could be a hint to line-of-sight opacity at the particular wavelength. In Figure 3 we show the relative intensities measured of the v‘‘=2 to v‘‘=6 lines and the transition probabilities from Allison and Dalgarno (1970). We see that the measured intensities are in agreement with the prediction.

4. Conclusions

Emission of molecular hydrogen in the SUMER spectra has been found by a special observation of a sunspot. The emission lines found are strongly enhanced at the location of the umbra and could practically not be observed outside the sunspot area. The search for progressions of molecular bands was elusive. Only lines produced by fluorescence excitation could be observed. One strong series of fluorescence could be used to measure their branching ratios and, in contrast to a previous observation by Bartoe et al.. good agreement with the theoretical values has been found.

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5. References

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