

## Infrared Spectroscopic Observations of Neutral Helium During the 1994 Eclipse

I. Mann

*Max-Planck-Institut für Aeronomie, Postfach 20, D-37189  
Katlenburg-Lindau, Germany*

J. R. Kuhn and M. J. Penn

*National Solar Observatory, P. O. Box 62, Sunspot, NM 88349, USA*

**Abstract.** We present the detection of a neutral helium line in observations of the solar corona obtained during the 1994 eclipse, and show that a coronal excitation process is unlikely to cause such a significant HeI emission that extends out to a distance of 3 solar radii ( $R_{\odot}$ ) from the center of the sun. Besides the scattered light of a solar prominence, as well as components of geocoronal helium, the observed emission line may come from the neutral helium components in the interplanetary medium. Recombination of ions on interplanetary dust particles may play a role for the formation of the neutral helium.

### 1. Observation

The spectrograph observations were taken during the 1994 November 3 eclipse from the Chilean altaplana. The experiment consisted of a 15 cm reflecting telescope and a small Ebert-Fastie spectrograph with an infrared grating blazed for wavelengths near  $1 \mu\text{m}$  to first order. A liquid nitrogen cooled HgCdTe NICMOSIII array (256x256 pixels) was used as the detector. Most of the observing time was devoted to a single pointing with the slit extending over the east limb of the moon. The slit length was 1.9 solar radii ( $R_{\odot}$ ) projected onto the plane of the sky and its orientation was fixed in the E-W direction. Each spectral region was observed as the average of two 1 sec integrations, and successive spectra overlapped in wavelength so that each wavelength was independently observed at least twice. We obtained a spectrum from the single pointing over a wavelength range of  $1.0 \mu\text{m}$  to  $1.5 \mu\text{m}$  with a noise level of about  $5 \cdot 10^{-8} B_{\odot}$ .

Our measurements reveal diffuse emission from HeI in the infrared 1083 nm line beyond projected distances of  $2 R_{\odot}$  from suncenter, which, given coronal temperatures of over  $10^6$  K is surprising. The line is observed with a maximum intensity of at least (a few detector elements were saturated)  $3 \cdot 10^{-6} B_{\odot}$  at  $1.1 R_{\odot}$  and with decreasing intensity to about  $1 \cdot 10^{-7}$  at  $3 R_{\odot}$ . Although the absolute wavelength of the line is only determined with an accuracy of about 0.3 nm, the HeI lineprofile shows clear evidence of two Doppler shifted components. The relative shift between these components can be measured to about 0.1 pixels or 3 km/s. A component near the lunar limb (presumably HeI emis-

sion from a prominence) is bright and is blue shifted with respect to a “diffuse” component (visible to nearly  $3 R_{\odot}$ ) by approximately 20 km/s or about one pixel. This shift is much larger than characteristic photospheric velocities (a few km/s) and also much greater than the separation between the unresolved components of the HeI emission (about 0.01 nm). The two-component He emission is observed consistently in both spectra, which were obtained with different grating positions. Furthermore the FeXIII emission lines, which are well measured in the data frames which also record the HeI emission line (see Figure 1), show a constant, single velocity component across the full slit position. There is evidence that the red component is visible against the lunar limb, which suggests that it is either a foreground (geocoronal) source or is due to terrestrially scattered light from a diffuse interplanetary source. Further analysis (see Kuhn et al. 1996) will better constrain the absolute wavelength scale and light scattering properties of the terrestrial atmosphere. Regardless of such further analysis we are faced with the dilemma of two components to the HeI emission – the unexpected second component being redshifted by about 20 km with respect to the prominence emission. As a result of climatic conditions, we were unable to achieve a description of the F-coronal continuum brightness from dust particles.

## 2. Discussion

### 2.1. Coronal Sources of Helium

The emission mechanism for the 1083 nm line is complex, involving radiative and collisional excitation of the triplet levels in HeI but we can estimate a linestrength by scaling the chromospheric emission by the ratio of the expected neutral He density between the chromosphere and the corona. Following Arnaud and Rosenflug (1985) we expect the neutral helium to total helium number ratio to be approximately  $10^{-9}$  at a temperature of  $10^6$  K. With a chromospheric HeI emission brightness of  $0.3 B_{\odot}$  (Avrett et al. 1994) at a mean density of  $10^{11} \text{ cm}^{-3}$  we could expect the coronal HeI brightness to be of order  $10^{-12} B_{\odot}$  at  $R = 2 R_{\odot}$  which is many orders of magnitude fainter than the observed 1083 nm brightness.

Strong emission of neutral hydrogen in the Lyman  $\alpha$  profile (121.6 nm) was explained by resonance scattering of chromospheric Lyman  $\alpha$  from the residual neutral hydrogen in the corona and by the electron impact excitation of the coronal neutral hydrogen (Gabriel 1971). This raises the question of whether a similar process (instead of a component of cool gas) can produce the observed HeI emission at 1083 nm. Scaling the intensities with an average ratio of helium to hydrogen  $n_{\text{He}}/n_{\text{H}} = 10\%$  in the corona (see for instance Hansteen et al. 1994) and the relative contributions of neutrals, which amount to  $n_{\text{HeI}}/n_{\text{He}} = 1.86 \cdot 10^{-8}$  and  $n_{\text{HI}}/n_{\text{H}} = 6.45 \cdot 10^{-7}$  for  $T = 0.5 \cdot 10^6$  K (from Arnaud and Rothenflug 1985) the expected line intensity for a similar process in the case of the Helium would amount to less than 1% of the observed Hydrogen Lyman  $\alpha$  brightness. Furthermore, the observed Helium line is a transition from the  $1s2p \ 3P$  level to the metastable  $1s2s \ 3S$  level in the triplet system. Photoexcitation of the  $1s2p \ 3P$  level from the ground state stems from 59.14 nm radiation. Whereas the Lyman  $\alpha$  is the brightest chromospheric emission line in the XUV, the emission in the range of Helium lines is more than  $10^{-3}$  fainter, and thus cannot cause a

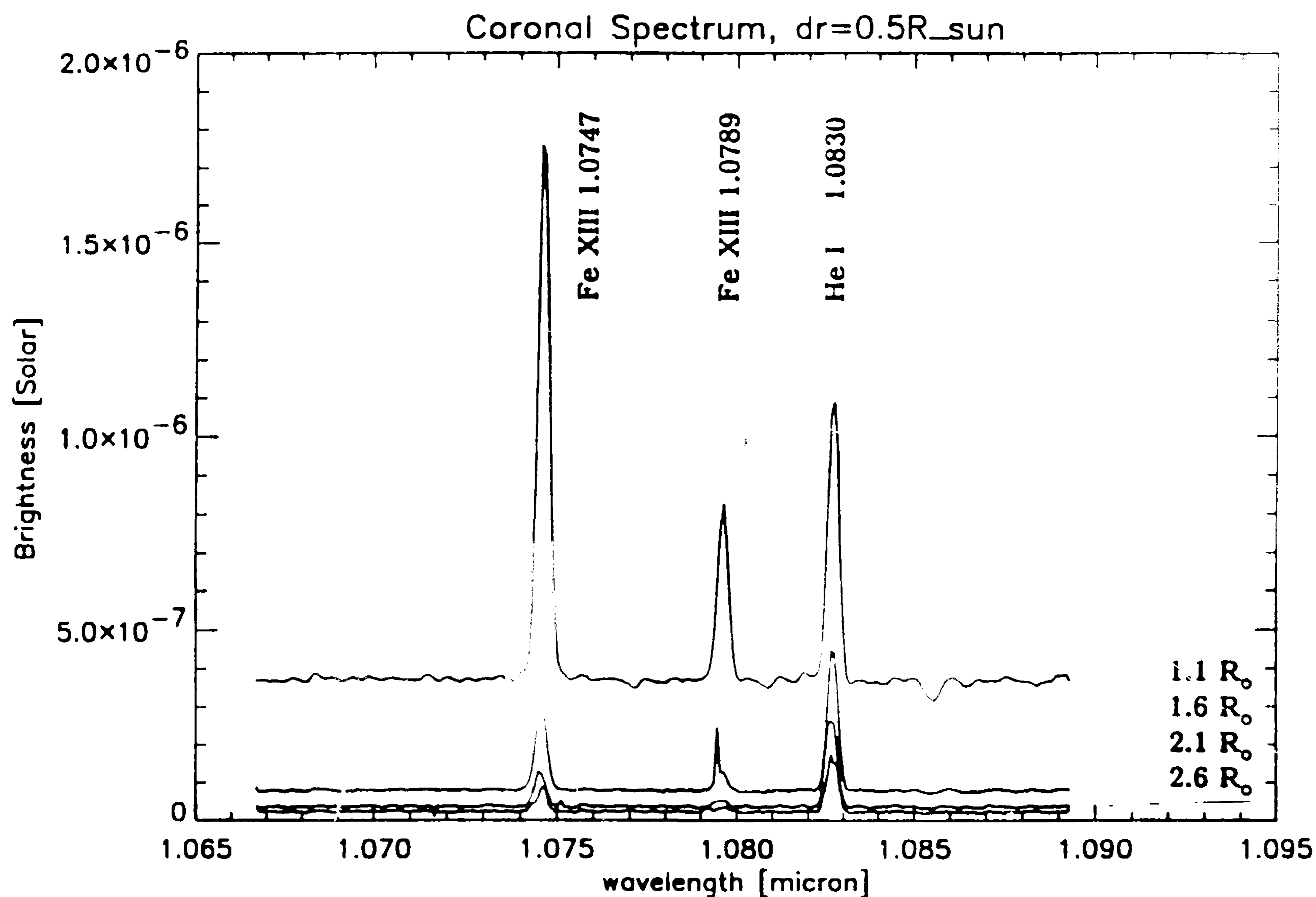


Figure 1. Observed coronal spectrum at a distance of  $1.1 R_{\odot}$ ,  $1.6 R_{\odot}$ ,  $2.1 R_{\odot}$ ,  $2.6 R_{\odot}$  from the center of the sun. The brightness is given in mean solar disk brightness at the same wavelengths.

sufficient population of the  $1s2p$  level in the triplet system. This brings the line intensity of the He I line, produced by photoexcitation from chromospheric light to less than  $3 \cdot 10^{-8} B_{\odot}$ .

## 2.2. Interplanetary and Interstellar Sources

If we compare the observed column emission of  $10^{-7} B_{\odot}$  to the chromospheric column emission of  $0.3 B_{\odot}$  assuming a scale height of 200 km for the chromosphere and a scale height of  $2 R_{\odot}$  for the corona the derived neutral density in the corona amounts to about  $1 \text{ cm}^{-3}$ . So the density from the line emission is at least two orders of magnitude higher than the density of the typical corona (see, cf. Allen 1983). But the observed emission is the integrated signal along the line of sight and hence may partly be from regions further away from the sun. Components of geocoronal emission are also expected, but will not show a Doppler shift.

A faint glow of He I radiation in the 58.4 nm resonance line due to the focusing of the interstellar neutral gas that approaches the sun as discussed by Holzer and Axford (1971) is nowadays well detected by satellite experiments. However, photoionization reduces the amount of neutral helium already at 0.5 AU. Besides the UV resonance line, we can expect the He I 1083 line to be prominent, since it gives the decay to the metastable level in the triplet system. This component may give an emission signal along the line of sight.

Moreover, some theories suggest that recombination of ions on the surface of interplanetary dust particles may be important. A model calculation (Fahr et al. 1981) predicts neutral helium densities produced by dust particles up to  $10^{-3} \text{ cm}^{-3}$  at  $5 R_{\odot}$ . Assuming a more recent estimate the dust distribution extends to less than  $3 R_{\odot}$  from the Sun, giving a geometric cross section between 4 and  $6 \cdot 10^{-20} \text{ cm}^{-1}$  (Mann and MacQueen 1993) in the innermost corona. Assuming such a component of dust particles at  $3 R_{\odot}$  the influence on recombination of helium ions may yield a neutral helium density of  $0.01 \text{ cm}^{-3}$  at about  $3 R_{\odot}$ .

### 2.3. Conclusion

We have shown, that we can exclude the possibility that coronal excitation processes cause the HeI emission at 1083 nm, as seen in the data. So we conclude, that the observations may include different components: interplanetary neutral helium emission in the solar vicinity, interstellar neutral emission along the line of sight and a component of the geocoronal emission.

The analysis of the present data is limited by atmospheric scattered light. Nevertheless it is evident that the infrared He emission line is likely to be a very useful probe of cool interplanetary material. Future observations, under low scattered-light conditions, will simplify the interpretation of moderate resolution spectroscopic data like those described here. Improved signal-to-noise and even moderate enhancement of the spectral resolution should allow a straightforward spectral decomposition of the He I emission into indentifiable components at a surface brightness level near  $10^{-7}$ . More spectroscopic data from the eclipse may provide a useful model of the IR atmospheric scattering function and hence enable additional constraints on the nature of this diffuse HeI component.

**Acknowledgments.** This work is based on measurements with the Sac Peak infrared spectrograph. Jim Mason, Robert MacGraw, and Larry Wilkins from the National Solar Observatory, Sac Peak were an important part of the eclipse expedition and made this work possible. The Research was supported by the National Science Foundation. I.M. thanks the members of the eclipse expedition for the opportunity to join the observations.

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