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EXISTENCE OF NANOPARTICLE DUST GRAINS IN THE INNER SOLAR CORONA?

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ABSTRACT

Motivated by the recent paper by Habbal et al., we have made spectroscopic observations in the wavelength range of 1072.8–1079.0 nm of the solar corona above the coronal hole region on several days using a coronagraph. We made raster scans above the coronal hole region as well as other coronal regions for comparison. The exposure time of 200 s at a single location permitted us to detect signals of the order of 10^{-7} of the solar disk brightness. We did not find any indication of emission around 1074.7 nm due to fluorescence from silicon nanoparticle dust grains in the coronal hole region in the inner corona proposed by Habbal et al. This may be due to the absence of silicon nanoparticle dust grains in the coronal hole region or to our detection limit.

Subject headings: interplanetary medium — line: identification — Sun: corona — Sun: infrared

1. INTRODUCTION

A number of experiments have been conducted during total solar eclipses to detect interplanetary dust near the Sun and a dust ring around the Sun (Rao et al. 1981; Hodapp et al. 1992; Lamy et al. 1992; Ohgaito et al. 2002; and others) and have yielded contradictory results. Kuhn et al. (1996, 1999) made spectroscopic observations in the infrared part of the solar spectrum to detect coronal emission lines. From the polarimetric observations of the [Fe XIII] emission line at 1074.7 nm made during the total solar eclipse of 2001 June 21, Habbal et al. (2003) found tangentially polarized emission in the radial extension of the low-temperature and low-density coronal holes as opposed to a predominantly radial polarization in the rest of the solar corona. They argued that the observed emission and the tangentially directed polarization in the coronal holes were due to an emission band around 1074.7 nm and attributed it to the fluorescence from silicon nanoparticle dust grains in the inner corona. Habbal et al. (2003) found the "emission band" after subtracting two filter images centered at 1074.7 and 1072.8 nm. If the emission really exists, a hump at around 1074.7 nm could be confirmed with a spectroscopic observation covering 1072.8–1074.7 nm, as we have attempted here.

We have made spectroscopic observations in 1074.7 and 1079.8 nm emission lines to study the density structure in the steady coronal loops (Singh et al. 2002). Encouraged by the recent paper by Habbal et al. (2003), we used the same setup of the CCD camera to make new spectroscopic observations in the coronal hole region and other coronal regions for comparison, with longer exposure time compared to Singh et al. (2002). Here we report our findings and discuss the results.

2. OBSERVATIONS AND DATA ANALYSIS

We have made spectroscopic observations of coronal hole regions in the wavelength range of 1072.8–1079.0 nm using the 25 cm aperture coronagraph of Norikura Observatory. The optics of the coronagraph forms the image of the Sun and the corona with an image scale of 25″ mm^{-1}. The spectrograph of 7 m focal length yields a dispersion of 0.261 nm mm^{-1} at the second order around 1075 nm. The CCD camera of 1024 × 1024 pixel format with a pixel size of 24 × 24 μm from Photometrics has an efficiency of about 10% in the wavelength range of our interest. The chip size of the CCD camera permitted us to record the spectrum over 6.1 nm around 1075 nm. Because of our interest in the 1073 nm wavelength, we did not record the [Fe XIII] emission line at 1079.8 nm. Data were read by a 14 bit analog-to-digital converter operating at a speed of 200 kHz.

We have made raster scans of a coronal region overlying the coronal hole at the north pole in the period of 2003 September 9–17 whenever the sky permitted. We also observed a coronal region above the coronal hole at the south pole on 2003 September 22 as guided by the EUV Imaging Telescope (EIT) images obtained from *SOHO*. We also made raster scans of other coronal regions for comparison purposes. The slit width of 200 μm equivalent to 5″ on the Sun, with an exposure time of 200 s, yielded a signal of about 10,000 counts close to the limb, about 60% of the saturation limit of the CCD camera.

Immediately after the raster scan, we obtained the spectrum of the center of the solar disk by introducing a neutral density filter in front of the spectrograph slit with exposure times ranging from 200 to 300 ms. The transmission of the neutral density filter around 1075 nm is 3.532%, as measured using a scanning spectrophotometer (UV-3100PC of the Shimazu Corporation) available at the National Astronomical Observatory, Tokyo, Japan. We also obtained three spectra at the disk center using a wide slit of 10 mm and averaged these spectra to generate a spectrum for flat-field corrections. Two dark spectra with exposure times equal to that of the coronal spectrum and disk spectrum were obtained after every raster scan. The binned pixel size of 24 × 48 μm provided a spatial resolution of 2″ and a spectral resolution of 0.0125 nm. The high spatial and spectral resolution was chosen to give longer exposure time without reaching the saturation limit of the CCD camera.

After the observation, we averaged the spectra along the slit and dispersion to enhance the signal-to-noise ratio. The step size of the raster scans was chosen between 5″ and 30″, depending on the coronal region. The details of observations made on various days are given in Table 1. The observed signal

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TABLE 1
Details of Coronal Observations

Date	Coronal Region	Slit Width (μm)	Exposure Time (s)	Step Size (arcsec)	Observed Area (arcsec)
2003 Sep 09 ……	North pole	200	140	20	500 × 480
2003 Sep 15 ……	North pole	160	200	20	500 × 480
	East limb	160	20	5	500 × 245
2003 Sep 16 ……	North pole	160	200	25	500 × 500
	South pole	160	50	5	500 × 100
2003 Sep 17 ……	North pole	160	150	30	500 × 450
	West limb	160	20	10	500 × 300
2003 Sep 22 ……	South pole	200	200	30	500 × 480

was corrected for the dark signal by subtracting the dark frame from the observed spectrum. The flat-field correction was done by dividing the observed spectrum by the flat-field spectrum, and the photospheric scattered light component was removed from the coronal spectrum using the solar disk spectrum. Then, to enhance the probability of detection of the emission, we analyzed the data by combining the data of 10, 25, 50, and 100 pixels in spatial resolution and 4, 8, and 16 pixels in spectral resolution. All chosen sets of data have produced similar results, with random noise decreasing with the increase in the number of pixels used for the averaging.

To compute the intensity of the emission line, we measured the intensity of the nearby continuum at the center of the solar disk obtained with a neutral density filter of known transmission, with the same experimental setup. The observed count at the disk center in the continuum was 7267 ± 32 with an exposure time of 200 ms. The intensity of the emission line was determined from the peak of the Gaussian fit to the emission-line profile obtained after the flat-field correction and subtraction of the scattered light component. Then the intensity of the line is given by n/N, where n and N are the numbers of counts per second for the coronal line and the solar disk continuum, respectively.

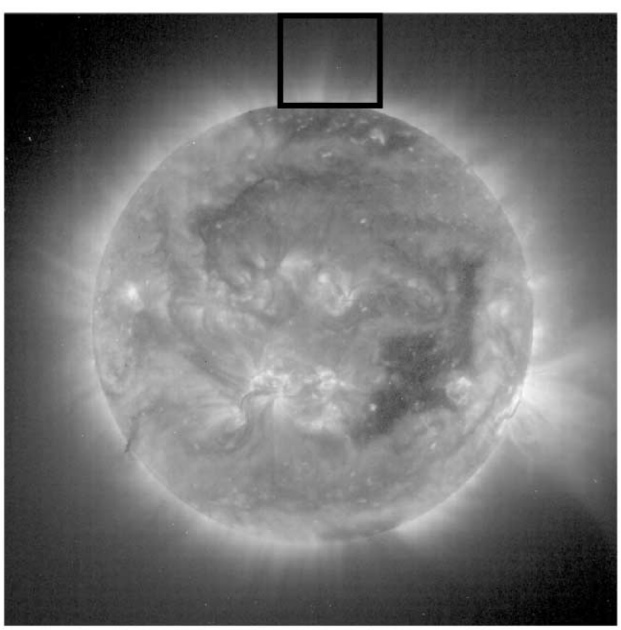

Fig. 1.—Image of the solar corona at the 195 Å [Fe xii] line obtained by EIT on board *SOHO* on 2003 September 10. The box marked at the north pole indicates the coronal region observed lying above a coronal hole.

3. RESULTS AND DISCUSSION

Figure 1 shows the image of the solar corona obtained on 2003 September 10 at 195 Å ([Fe xii] line) from EIT on board *SOHO*, which indicates the existence of a coronal hole at the north polar region. This coronal hole was visible throughout the period of observations. Similarly, a coronal hole was seen on the south pole on 2003 September 22.

Figure 2 shows the solar disk spectrum in the wavelength range of 1073–1079 nm. In addition to a number of absorption lines, a small-amplitude wavelike pattern is also seen in the spectrum. This pattern is due to very faint interference fringes caused by the infrared filter RM-90 and is common in both the disk and the observed coronal spectra. This pattern disappears from the coronal spectra after the subtraction of the scattered light component is done using this disk spectrum. The figure shows the observed counts per second as a function of wavelength. The count around 1076.5 nm was divided by the transmission of the neutral density filter to compute the value of N (counts per second) at the disk center.

Six panels in the first and second rows of Figure 3 show the intensity in units of 10^{-6} of the central solar disk brightness as a function of wavelength at various heights from the east limb for the wavelength range of 1073–1079 nm with an exposure time of 20 s. The height of observations is indicated at the top of each spectrum. All the spectra are shown in the same scale for easy comparison. A dark-subtracted and flat-fielded spectrum (before scattered light correction) at a height of 50″ above the limb in the top left panel of the first row shows that the scattered light component was 30×10^{-6} of the solar disk brightness. The spectral profile in the middle panel of the first row obtained at

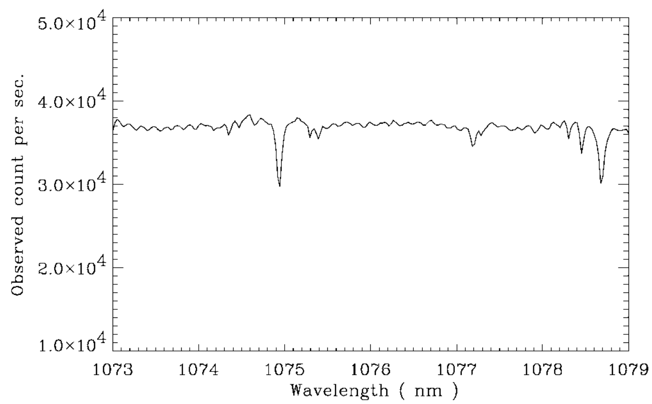

Fig. 2.—Profiles of the 1073–1079 nm spectra of the center of the solar disk. Prominent absorption lines at 1074.9 nm and at other wavelengths are seen. In addition, a small-amplitude wavelike pattern visible in the spectrum is due to interference fringes caused by the infrared filter.

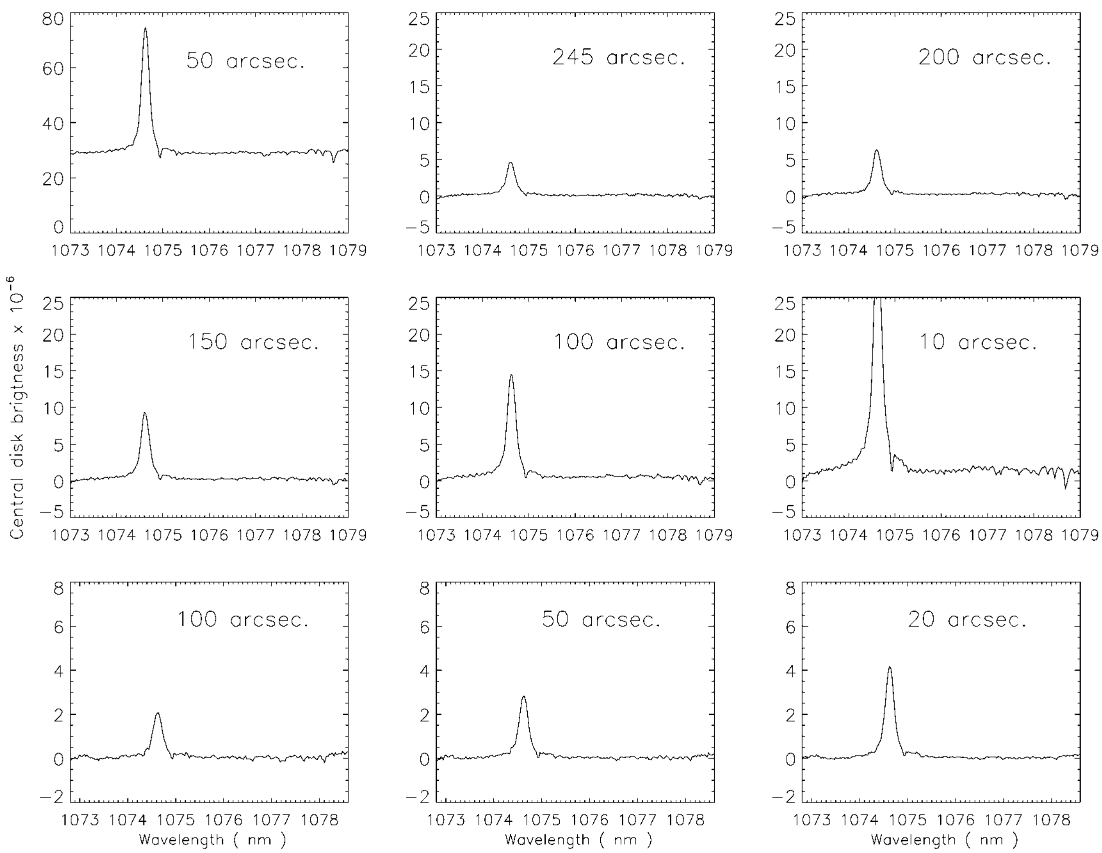

FIG. 3.—Profiles of the 1073–1079 nm spectra of the coronal region above the east limb obtained on 2003 September 15 at various heights. The bottom three panels show profiles of the 1073–1079 nm spectra of the coronal region above the south limb obtained on 2003 September 16 at various heights. The height above the limb, where the spectral profile was obtained, is indicated at the top of each spectral profile. All the profiles show emission at 1074.7 nm due to the [Fe XIII] line, and some of these show small dips at 1074.9 nm and at other wavelengths because of remnants of signal due to the absorption lines of the solar disk. The left panel in the first row shows a dark-subtracted and flat-fielded spectrum (before scattered light correction) at a height of 50″ above the limb. Other panels show the spectra after the scattered light correction.

245″ above the limb clearly shows the 1074.7 nm emission line due to [Fe XIII]. The spectral profiles also show small narrow dips at 1074.9 nm and some other wavelengths because of remnants of absorption lines of the solar disk. The intensity of the emission line at 245″ above the limb was found to be 5×10^{-6} of the solar disk brightness, and the noise in the continuum of the spectrum is less than 1×10^{-6}.

The bottom three panels of Figure 3 show the spectral profiles at different heights above the limb on the south pole region on 2003 September 16 when there was no coronal hole at the south pole. These were obtained to compare the spectra with those of the coronal hole. The bottom left spectral profile, obtained at 100″ above the limb with pixel-averaging of 20″ along the slit and a spectral resolution of 0.025 nm, clearly shows the emission peak at 1074.7 nm due to the [Fe XIII] line. The figure shows that the intensity of this emission is 2×10^{-6} of the solar disk, and the noise in the spectral profile is 5×10^{-7}. These numbers are for observations made with an exposure time of 50 s. The noise in the spectral profile is expected to be less by a factor of 2 for observations made with an exposure time of 200 s.

Figure 4 shows the plots of spectra in the wavelength range of 1073–1079 nm in the coronal region above the coronal hole at the north pole obtained on 2003 September 15 with an exposure time of 200 s. The position of the spectrograph slit above the north pole is indicated for each of the spectral profiles. The bottom right spectrum at 20″ above the limb does not show any emission at 1074.7 nm due to [Fe XIII], indicating low temperature in the coronal hole region. The spectra at higher altitudes (the highest being 480″ above the limb) also do not show any emission in the observed wavelength range. (The drop in the intensity at 1073 nm is due to the edge problem in our CCD camera and is not real. This happens occasionally, when we make observations in the infrared wavelengths and the signal is weak. Some effect is visible even after the flat-field correction.) The figure shows that the spectral profiles at higher altitudes above the limb (440″ and 480″) are almost flat with small variations of the order of 1×10^{-7}, but a broad dip around 1076 nm is seen in the profiles obtained at lower heights. This may be due to a small error in the flat-field correction, as the scattered light component at lower heights is larger. This may not be due to the emission around 1074.7 nm because the intensity levels around 1074 and 1077 nm are almost the same. The maximum amplitude of variation over the whole spectral coverage is 3×10^{-7} of the solar disk brightness. Therefore, we may say that the detection limit with the 200 s exposure in our setup is 3×10^{-7} of the solar disk brightness. The region above the south polar coronal hole observed on 2003 September 22 also did not show any emission in this wavelength range at all heights up to 480″ above the limb.

Habbal et al. (2003) have argued the existence of an emission band around 1074.7 nm in the coronal hole regions from the

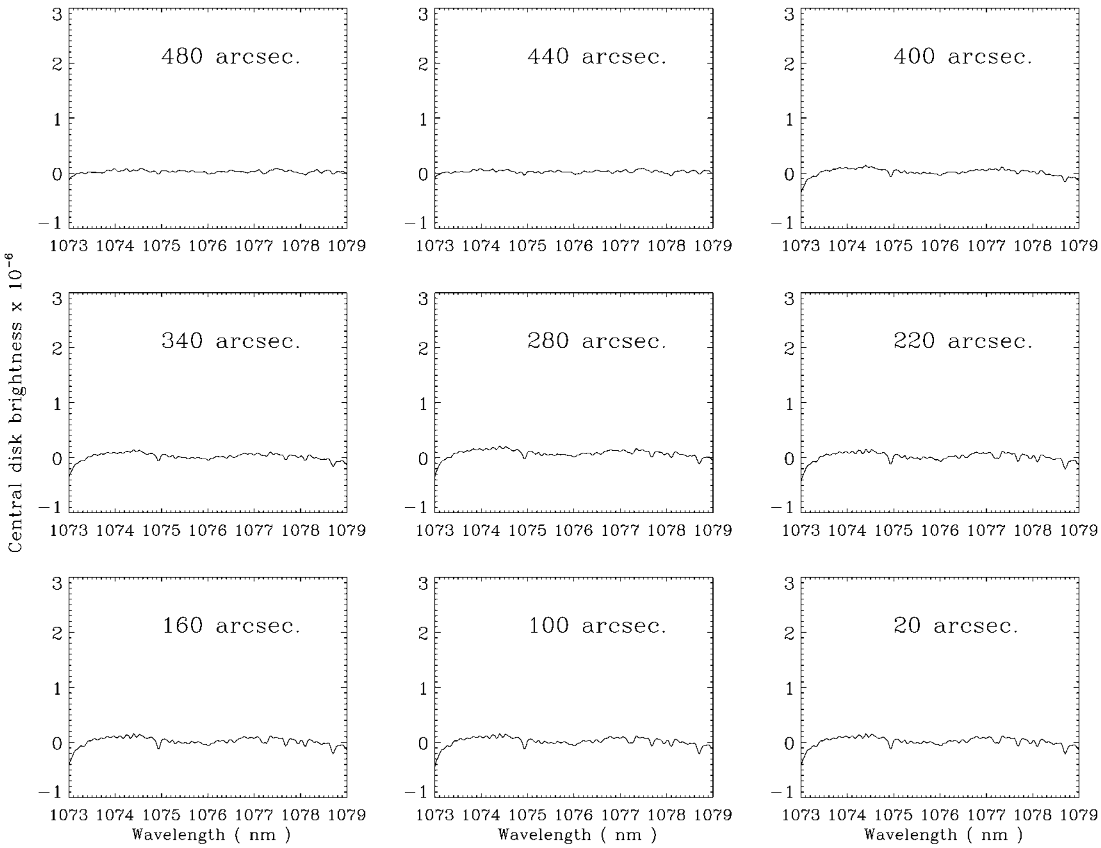

FIG. 4.—Profiles of the 1073–1079 nm spectra of the coronal region above the north polar coronal hole obtained on 2003 September 15 at various heights. The height above the limb, where the spectral profile was obtained, is indicated at the top of each spectral profile.

observed tangential direction of the polarization, but our observations indicate that possible emission around 1074.7 nm due to fluorescence from silicon nanoparticle dust grains in the inner corona is very weak, below the level of 10^{-7} of the solar disk brightness, if it exists. We believe that sufficient intensity of the emission is required to make useful polarization measurements. There is a probability that very low intensities observed in the coronal hole regions may cause systematic uncertainty in the determination of polarization direction. More spectroscopic observations with a detection limit well below 10^{-7} of the solar disk brightness are needed to verify the detection of the proposed emission from silicon nanoparticle dust grains in the inner corona.

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