Interpretation of spectro-polarimetry of comet 17P/Holmes during outburst in 2007

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Spectro-polarimetry of comet 17P/Holmes carried out a day after its outburst in October 24, 2007 shows a strong dependence of negative polarization on wavelength λ: while λ increases from 0.5 to 0.9 μm the polarization falls from –0.6% to almost 0. Ten days after the outburst, polarization was found to be approximately -1% for all λ. We found such behavior to be consistent with highly absorbing (e.g., m=1.5+0.1i) agglomerated debris particles that obey a power-law size distribution and have a small-size limit near 0.6 μm.

INTRODUCTION

The outburst of comet 17P/Holmes occurred on October 24, 2007 and, within two days, the apparent total brightness of the comet increased by 630,000 [1]. In this manuscript we present and interpret spectro-polarimetric observations carried out by the "Kanata" group of Hiroshima University. Using the 1.5 m Kanata telescope and spectro-polarimeter operating at a wavelength range of 0.5–0.9 μm [2], comet 17P/Holmes was observed on October 25 (15:15 UT), October 27 (16:24 UT), and November 3 (15:17 UT), during which the phase angle α went from 16.6° on October 25, to 16.1° on October 27, and 14.3° on November 3.

The average linear polarization was measured using a slit with angular length of 17.3 and width of 3.4 arcsecs, corresponding to a projected area of 20500×4000 km^2. The slit was centered on the photometric nucleus of the comet (i.e., the brightest point of halo) and oriented along a north-south direction. Taking into account that even for the earliest observation on October 25, the diameter of the dust halo exceeded 90 arcsecs [3], one can conclude that the measured polarization results primarily from the inner part of the coma.

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Fig. 1 shows spectral profiles of linear polarization of comet 17P/Holmes. At all wavelengths and dates, the degree of linear polarization P is negative. Note that the negative linear polarization at small phase angles is widely observed for comets (e.g., [4]). Interestingly, during the earliest observation, the negative polarization reveals a dependence on wavelength λ: an increase of wavelength from 0.5 to 0.9 μm results in a decrease of the amplitude of negative polarization from 0.6% to almost zero. On October 27, the dependence of polarization on wavelength is weaker than that on October 25. And on November 3, the amplitude of the negative polarization is almost independent of wavelength as polarization P remains approximately -1% throughout the wavelength range. As for dust color, it was red in appearance on October 25 and became redder in later observations. Note, that these findings are qualitatively consistent with other spectro-polarimetric observations of comet 17P/Holmes [5,[6]; whereas, the diversities between them could be explained by different observation conditions.

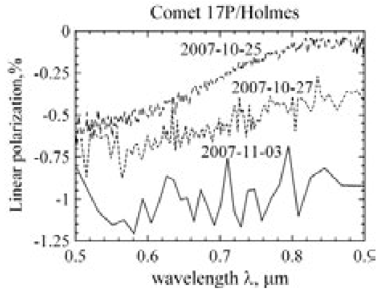

Figure 1. Degree of linear polarization as a function of wavelength for comet 17P/Holmes.

INTERPRETATION OF SPECTRO-POLARIMETRY OF COMET 17P/HOLMES

We model the cometary particles as agglomerated debris [7] and use the discrete dipole approximation (DDA) to calculate their scattering. The particles are non-extremely porous and consist of small irregular constituents. Both features can be seen in images of cometary dust collected in the stratosphere (e.g., [8]). We examine homogeneous agglomerated debris with many different refractive indices m chosen to represent likely cometary materials: water ice, Mg-rich silicates, and organic. We characterize the particles in terms of the size parameter $x = 2\pi r/\lambda$, where r is the radius of the circumscribing sphere for an agglomerated debris particle.

One possible explanation of the spectral behavior of linear polarization of comet 17P/Holmes on October 25 can be ascertained from Fig. 2. We see that the evolution of P_{min} with x is qualitatively the same despite the significant difference between the amplitudes of negative polarization produced by highly and weakly absorbing particles. Our results can be summarized as follows. Negative polarization does not exist for small x (< 4–6). The negative polarization appears at $x \sim 5$ and grows rapidly. The amplitude of the negative polarization reaches its maximum at $x \sim 8$–10, and then slowly decreases toward zero. For convenience, we denote the size parameter at which the negative polarization appears as x_{app}; whereas, the size parameter of the maximal amplitude of negative polarization we designate as

x_{max}. In the case of highly absorbing particles, we can observe a disappearance of negative polarization at $x \sim 30$.

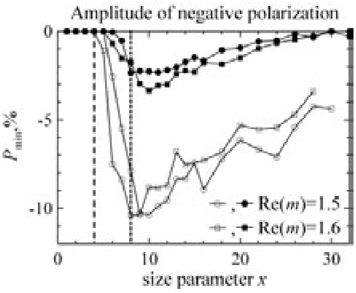

Figure 2. Dependence of amplitude of the negative polarization P_{min} on size parameter x. Open symbols show Im(m) = 0.02; whereas, closed symbols show Im(m) = 0.1.

In our simulations, the ratio of x_{max} to x_{app} remains approximately 2, i.e., $x_{max} = 2\ x_{app}$. This relationship holds for Re(m) = 1.5 – 1.6, with slight deviation for Re(m) = 1.313 and Re(m) = 1.7. The relationship is almost independent of Im(m) in the range of values 0–0.1. Therefore, a particle can produce a significant negative polarization at short wavelengths, while at longer wavelengths, it may produce no negative polarization at all. For instance, in Fig. 2, one can see that all particles with $x = 8$ produce noticeable negative polarization; whereas, at $x = 4$, none of the particles do. Note that the dramatic change in polarization on October 25 occurs within the range of λ from 0.5 to 0.9 μm. This may suggest that there is an abundance of particles having a corresponding size $r \approx 0.6$ μm; such particles have $x \approx 4$ at λ = 0.9 μm and $x \approx 8$ at λ = 0.5 μm. Furthermore, because cometary particles follow a power-law size distribution (e.g., [9]), the abundance of particles with $r \approx 0.6$ μm can be obtained only if the distribution of particles has a bottom limit around 0.6 μm. Therefore, one can conclude that, in the inner part of the dust halo of comet 17P/Holmes, particles smaller than 0.6 μm do not appear in considerable concentrations on October 25, 2007.

So far, we have only considered particles with a fixed size. To simulate light scattering in the dust halo of comet 17P/Holmes, we consider a cloud of independently scattering agglomerated debris particles that follow the size distribution r^{a} ($1.5 < a < 3.5$ [9]). Fig. 3 shows the degree of linear polarization at small phase angles corresponding to $m = 1.5 + 0.1i$ for this distribution. The left panel corresponds to a power-law index $a = 3.5$ and the right panel to $a = 1.5$. In each panel, the solid line shows the case of incident light at λ = 0.9 μm; whereas, the dotted line shows the case for an incident wavelength λ = 0.45 μm.

As one can see in Fig. 3, a size distribution characterized by power index $a = 3.5$, with a lower size limit of 0.6 μm, provides a significantly more prominent negative polarization branch at λ = 0.45 μm than at λ = 0.9 μm; whereas, with $a = 1.5$, the negative polarization shows little wavelength dependence. We would like to stress that this wavelength dependence appears for all refractive indices considered in this study, with the primary differences in the refractive index being reflected in the magnitude of the negative polarization. For instance, in the case of weakly absorbing particles, the total amplitude of negative polarization is approximately 6–7%, which is significantly larger than the observed values. Such weakly absorbing particles are blue in appearance, which is contrary to observations.

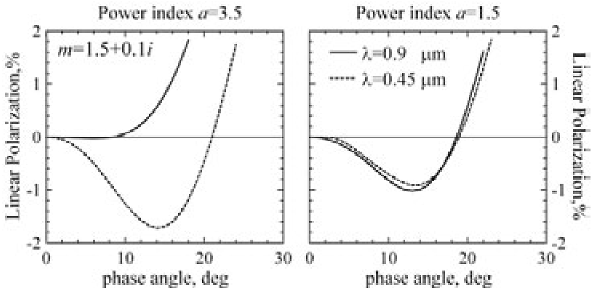

Figure 3. Dependence of the linear polarization degree on the phase angle for agglomerated debris particles averaged over size at two different wavelengths of the incident light.

Highly absorbing particles, however, are red in appearance for all considered Re(*m*) and *a*. Moreover, at Re(*m*) = 1.5–1.6, these particles produce a negative polarization branch whose amplitude is comparable to that observed for comet 17P/Holmes. The evolution in spectral behavior of linear polarization observed for comet 17P/Holmes between October 25 and November 3 can be attributed to a change in the power index *a* from 3.5 to 1.5. Such an alteration of power index is consistent with a decrease of the relative contribution of smaller particles with time.

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