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# Polarimetry and Photometry of Comet C/1996 B2 Hyakutake

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**Polarimetric and photometric observations of Comet C/1996 B2 Hyakutake were carried out at the 70-cm telescope of Kharkov State University Observatory from March 25 to April 7, 1996. The goal of the observations was to determine the polarization maximum of the cometary continuum. We have found that the maximal degrees of polarization in the blue (4845 Å) and red (6840 Å) continuum domains are 24.0% and 26.1%, respectively, and lie at a phase angle close to 94°, slightly dependent on wavelength. According to the gas-to-dust ratio and color, Comet Hyakutake belongs to the group of dusty comets such as West 1976 VI, P/Churyumov–Gerasimenko 1982 VIII, P/Kopff 1983 XIII, P/Hartley–IRAS 1984 III, P/Giacombini–Zinner 1985 XIII, P/Halley 1986 III, Bradfield 1987 XXIX, Liller 1988 V, Levy 1990 XX, and P/Faye 1991 XXI. The polarization data for comet Hyakutake are in good agreement with the data for these comets in the 37°–73° overlap region of phase angles. Consequently, the maximum of Hyakutake's polarization may be taken as the maximum of polarization at least of this group of dusty comets. The fluxes for the $C_2$ and $C_3$ emission bands and dust continuum and the corresponding production rates for Comet Hyakutake are given.** © 1998 Academic Press

*Key Words:* **Comets; Hyakutake; Polarimetry; Photometry**

## 1. INTRODUCTION

This investigation continues the study of the polarization phase dependence of the cometary continuum initiated by Kiselev and Chernova (1978, 1981) and Chernova *et al.* (1993). Narrow-band observations of comets at phase angles larger than 90° are still not numerous. The goal of these observations is the determination of the polarization maximum of the cometary continuum. They are extremely important for the construction of the whole synthetic polarization phase dependence of the cometary continuum and the development of an adequate theory of scattering. On the other hand, a search for similarities and differences in polarization of dust among comets is also very important for the taxonomy of comets. Many authors (Chernova *et al.* 1993; Hadamcik *et al.* 1996; Levasseur-Regourd *et al.* 1996) pay close attention to these problems.

## 2. OBSERVATIONS AND DATA REDUCTION

Comet C/1996 B2 Hyakutake was observed with the 70-cm reflector with a Cassegrain configuration (f/16) at the Chuguev Observation Station of Kharkov State University from March 25 to April 7, 1996. This station is located about 70- km to the southeast of Kharkov at 156 m altitude. The observations were made with a set of narrow-band comet filters. The ultraviolet, blue, and red continuum filters centered at 3650 (UC), 4845 (BC), and 6840 Å (RC) and the molecular band filters for $C_3$ at 4060 and $C_2$ at 5140 Å were used. The diaphragm was 88 arcsec. The comet was placed visually near the center of the diaphragm. Due to the high velocity of the comet the single integration time was chosen in the range from 3 to 10 sec. This allowed the brightest part of the coma to be kept near the center of the diaphragm during the integration. The night sky measurements were conducted at the 2° position from the coma in the anti-tail direction.

A photometer–polarimeter and a polarimetric observation technique similar to the apparatus and technique which were developed at the Sanglok Observatory, Tadjikistan (Kayumov *et al.* 1989), were used. A photon counting detector was controlled by the PC 386 computer which was also used for the preliminary calculation of the polarization parameters. The instrumental polarization was obtained from observations of nonpolarized standard stars and was subtracted from the data set.

Only two nights were reasonably suited for photometric observations which were made in the polarimetric mode. This permitted us to obtain the photometric and polarimetric data simultaneously. The extinction coefficients were determined in each night using Bouguer's method. The extinction and standard stars were taken from the list of Osborn *et al.* (1990). The reduction of photometric observations was carried out by the method described by A'Hearn (1991). We used the new expression (A'Hearn *et al.* 1995) for correction of the $C_2$ emission in the blue continuum. For the determination of molecular column densities, we used the fluorescence efficiencies $g(C_3) = 10^{-12}$ erg mol$^{-1}$ and $g(C_2) = 4.4 \times 10^{-13}$ erg mol$^{-1}$ given



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**TABLE I**
**Observational Data and Production Rates for Comet Hyakutake 1996 B2**

| Date, UT (1996) | log $\rho$ (km) | $r$ (AU) | $\Delta$ (AU) | $\alpha$ (°) | log($F_\lambda$) (erg cm$^{-2}$ s$^{-1}$) C$_2$ | C$_3$ | log $Q$ (s$^{-1}$) C$_2$ | C$_3$ | $W_{4845}$ (Å) |
|---|---|---|---|---|---|---|---|---|---|
| Mar 25.959 | 3.521 | 1.028 | 0.104 | 70.11 | −8.556 | — | 26.220 | — | 134 |
| | | | | | ±0.029 | — | | | |
| Apr 5.743 | 4.095 | 0.790 | 0.390 | 111.36 | −8.106 | −8.701 | 26.612 | 25.385 | 274 |
| | | | | | ±0.020 | ±0.038 | | | |

by Newburn and Spinrad (1989). They were transformed into the production rates ($Q$) using Haser's model. According to Festou *et al.* (1990), the following characteristic scale lengths of the parent molecules ($l_p$) and of the daughter molecules ($l_d$) were taken; for $C_3$ $l_p = 4 \times 10^3\ r^2$, $l_d = 1.4 \times 10^5\ r^2$; for $C_2$ $l_p = 2.5 \times 10^4\ r^2$, $l_d = 1.2 \times 10^5\ r^2$, where $r$ is the heliocentric distance in AU. The velocity of the outflow from the comet nucleus was determined by Delsemme's formula $v = 0.58\ r^{-0.5}$ (km s$^{-1}$) (Delsemme, 1982).

## 3. RESULTS

The photometric results are listed in Table I. The time of observations, the projected diaphragm radius at the comet, $\rho$, the heliocentric $r$ and geocentric distance $\Delta$, the phase angle $\alpha$, the fluxes in the $C_2$ and $C_3$ emission bands $F_\lambda$, and the corresponding production rates $Q$ are given there. In the last column the equivalent width $W_{4845}$ (Krishna Swamy, 1986) describing the gas-to-dust ratio is given. This parameter is rather susceptible to geometric effects because the dust is strongly concentrated near the nucleus, while the molecular species have a much flatter spatial distribution. Nevertheless, the degrees of polarization of different comets may be compared according to their gas-to-dust ratios if widths $W_{4845}$, as well as polarization, are observed with the same diaphragms.

To describe that dust production, we use the product $p\Phi(\alpha)f\rho$ (Jockers *et al.* 1993), where $p$ is the geometric albedo, $\Phi(\alpha)$ is the phase function, $f$ is the filling factor (A'Hearn *et al.* 1984), and $\rho$ is the projected diaphragm radius at the comet. It is worth mentioning that our product $p\Phi(\alpha)f\rho$ is a factor of 4 smaller than the parameter $Af\rho$ introduced by A'Hearn *et al.* (1984). The observed dust fluxes, the value $p\Phi(\alpha)f\rho$ for the 3650, 4845, and 6840 Å continuum bands and colors UC-BC and BC-RC are given in Table II.

A comparison of our data for the production rates of species $C_2$ and $C_3$ shows a good agreement with the data obtained by Osip *et al.* (1996). The value $p\Phi(\alpha)f\rho$ was about 10 times larger than that for comet P/Giacobini–Zinner 1985 XIII (Storrs *et al.* 1992) at the same heliocentric distance.

The results of the polarimetric observations are presented in Table III. We list the date of observations, the heliocentric distance, the projected aperture radius at the comet, the filter, the linear polarization degree $P$, the position angle $\theta$ of the polarization vector, their statistical mean-square errors, the phase angle $\alpha$, the position angle of the scattering plane $\psi$, and the angle $\theta_r$ as defined by Chernova *et al.* (1993).

The approximation of polarimetric data for the comet Hyakutake by the second degree polynomial provides $P_{max}$ and $\alpha_{max}$ of 24.0%, 93.4°; 26.1%, 94.1°; and 15.2%, 88.3° in filters 4845 Å, 6840 Å, and 5140 Å, respectively. The gas-to-dust ratio, $W_{4845}$, was sufficiently small according to Table I, indicating that the comet had a strong continuum. This was also suggested by Schleicher (private communication) who found that the log $Q$(OH)/$Af\rho$ ratio was 25.2 on March 25, similar to the value found for P/Halley (A'Hearn *et al.* 1995). Because of this, the depolarizing influence of the molecular emissions on polarimetric data in the continuum filters was negligibly small and hence the position of polarization maximum depended only upon the properties of the cometary dust particles. On the contrary, the leak of the cometary continuum in the 4060 and 5140 Å filters was rather large; therefore the observed polarization degree for the $C_2$ emission was almost two times larger than the polarization degree $P_{max} = 7.7\%$ expected from the resonance-fluorescent mechanism of scattering.

The degrees of polarization of Comet Hyakutake in the ultraviolet, blue, and red continuum bands are presented in Figs. 1–3, respectively. In the same figures the corresponding polarimetric data for several comets (Chernova *et al.* 1993) are given, as well as the data for P/Halley from the IHW CD-ROM digital archive in the UC filter and the data for Hyakutake (Joshi *et al.* 1997). Figure 2 was also supplemented by the data for Comet West 1976 VI in the filter 5300/50-Å (Kiselev and Chernova, 1978) and data by Michalsky (1981) interpolated for wavelength 4850 Å. It should be noted that the 5300/50-Å filter had rather

**TABLE II**
**Dust Data for Comet Hyakutake 1996 B2**

| Date, UT (1996) | $\log(F_\lambda)$(erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$) | | | $\log[p\Phi(\alpha)f\rho]$ (cm) | | | Color (mag) | |
|---|---|---|---|---|---|---|---|---|
| | 3650 | 4845 | 6840 | 3650 | 4845 | 6840 | UC-BC | BC-RC |
| Mar 25.961 | — | −10.684 | −10.723 | — | 2.910 | 2.992 | — | 0.26 |
| | — | ± 0.028 | ± 0.013 | | | | | ±0.06 |
| Apr 5.744 | −10.873 | −10.544 | −10.647 | 3.297 | 3.396 | 3.413 | 0.17 | 0.10 |
| | ± 0.021 | ± 0.028 | ± 0.021 | | | | ±0.06 | ±0.06 |

broad wings. Because of this, gas contamination might occur in this filter. The dependence of the polarization of Comet West on diaphragm size and the discrepancy between the data of Kiselev and Chernova (1978) and of Michalsky (1981) offer evidence for gas contamination. In the range of small phase angles 1.6°–18.1° (see Fig. 3) we used the polarization data for P/Halley obtained with the wide-band R filter (6855/1080 Å). Their accuracy is the best available for all measurements. The "flat" wavelength dependence of the cometary polarization in this range of

**TABLE III**
**Polarimetric Data for Comet Hyakutake 1996 B2**

| Date, UT 1996 | r AU | log $\rho$ km | Filter Å | P ± $\sigma_P$ % | | $\theta \pm \sigma_\theta$ deg | | $\alpha$ deg | $\varphi$ deg | $\theta_r$ deg |
|---|---|---|---|---|---|---|---|---|---|---|
| Mar 25.006 | 1.048 | 3.513 | 6840 | 15.94 | 0.26 | 129.5 | 0.5 | 57.70 | 219.4 | 0.1 |
| 25.026 | 1.048 | 3.513 | 4845 | 13.93 | 0.27 | 129.3 | 0.6 | 57.96 | 219.2 | 0.1 |
| 25.914 | 1.029 | 3.521 | 4845 | 18.61 | 0.19 | 119.4 | 0.4 | 69.56 | 209.6 | −0.2 |
| 25.924 | 1.029 | 3.521 | 5140 | 12.18 | 0.15 | 119.3 | 0.4 | 69.68 | 209.4 | −0.1 |
| 25.937 | 1.029 | 3.521 | 6840 | 21.27 | 0.18 | 119.9 | 0.3 | 69.85 | 209.3 | 0.6 |
| 25.950 | 1.028 | 3.521 | 3650 | 17.96 | 1.22 | 118.5 | 1.8 | 70.02 | 209.1 | −0.6 |
| 25.957 | 1.028 | 3.521 | 4060 | 14.62 | 0.46 | 119.3 | 0.9 | 70.11 | 209.0 | 0.3 |
| 25.960 | 1.028 | 3.521 | 4845 | 19.81 | 0.39 | 119.3 | 1.0 | 70.15 | 208.9 | 0.4 |
| 25.962 | 1.028 | 3.521 | 5140 | 12.33 | 0.30 | 119.5 | 0.8 | 70.17 | 208.9 | 0.6 |
| 25.964 | 1.028 | 3.521 | 6840 | 21.74 | 0.42 | 119.7 | 0.6 | 70.20 | 208.9 | 0.8 |
| 27.747 | 0.990 | 3.618 | 6840 | 26.30 | 0.18 | 150.4 | 0.3 | 89.78 | 60.5 | −0.1 |
| 27.769 | 0.990 | 3.618 | 4845 | 23.92 | 0.18 | 149.5 | 0.3 | 89.97 | 59.8 | −0.3 |
| 27.787 | 0.989 | 3.621 | 5140 | 14.75 | 0.16 | 149.2 | 0.4 | 90.12 | 59.4 | −0.2 |
| 27.799 | 0.989 | 3.621 | 3650 | 18.61 | 2.53 | 154.9 | 3.9 | 90.22 | 59.0 | 5.9 |
| 27.801 | 0.989 | 3.621 | 4060 | 18.12 | 0.76 | 149.1 | 1.2 | 90.24 | 59.0 | 0.1 |
| 27.802 | 0.989 | 3.621 | 4845 | 24.36 | 0.64 | 150.7 | 0.8 | 90.25 | 58.9 | 1.8 |
| 27.803 | 0.989 | 3.621 | 5140 | 15.24 | 0.36 | 148.4 | 0.7 | 90.25 | 58.9 | −0.5 |
| 27.804 | 0.989 | 3.621 | 6840 | 24.66 | 0.59 | 148.1 | 0.7 | 90.26 | 58.9 | −0.8 |
| 28.035 | 0.984 | 3.638 | 6840 | 26.80 | 0.19 | 145.0 | 0.3 | 92.09 | 54.5 | 0.5 |
| 28.053 | 0.984 | 3.638 | 4845 | 24.32 | 0.20 | 144.2 | 0.3 | 92.22 | 54.2 | 0.0 |
| 28.067 | 0.983 | 3.641 | 5140 | 15.27 | 0.16 | 144.1 | 0.4 | 92.32 | 54.1 | 0.0 |
| 28.074 | 0.983 | 3.641 | 6840 | 26.89 | 0.30 | 143.9 | 0.4 | 92.38 | 54.0 | −0.1 |
| 31.734 | 0.903 | 3.875 | 6840 | 24.71 | 0.18 | 135.7 | 0.3 | 107.41 | 45.4 | 0.3 |
| 31.836 | 0.901 | 3.881 | 4845 | 20.75 | 0.45 | 136.9 | 0.6 | 107.60 | 45.4 | 1.5 |
| 31.861 | 0.901 | 3.882 | 5140 | 12.22 | 0.43 | 136.6 | 1.0 | 107.65 | 45.4 | 1.2 |
| Apr 4.740 | 0.814 | 4.058 | 4845 | 21.25 | 0.23 | 135.1 | 0.4 | 111.21 | 45.2 | −0.1 |
| 4.757 | 0.813 | 4.059 | 6840 | 24.03 | 0.19 | 135.3 | 0.4 | 111.21 | 45.2 | 0.1 |
| 4.772 | 0.813 | 4.059 | 5140 | 11.19 | 0.14 | 135.3 | 0.4 | 111.22 | 45.2 | 0.1 |
| 5.736 | 0.791 | 4.095 | 5140 | 9.76 | 0.25 | 134.1 | 0.7 | 111.36 | 45.0 | −0.9 |
| 5.737 | 0.791 | 4.095 | 6840 | 23.48 | 0.44 | 135.0 | 0.5 | 111.36 | 45.0 | 0.0 |
| 5.738 | 0.791 | 4.095 | 4845 | 22.64 | 0.46 | 135.2 | 0.6 | 111.36 | 45.0 | 0.2 |
| 5.739 | 0.791 | 4.095 | 4060 | 16.26 | 0.84 | 135.1 | 1.5 | 111.36 | 45.0 | 0.1 |
| 5.743 | 0.790 | 4.095 | 3650 | 15.86 | 1.70 | 142.6 | 3.1 | 111.36 | 45.0 | 7.6 |
| 7.774 | 0.743 | 4.161 | 6840 | 24.04 | 0.26 | 134.2 | 0.4 | 111.13 | 44.4 | −0.2 |

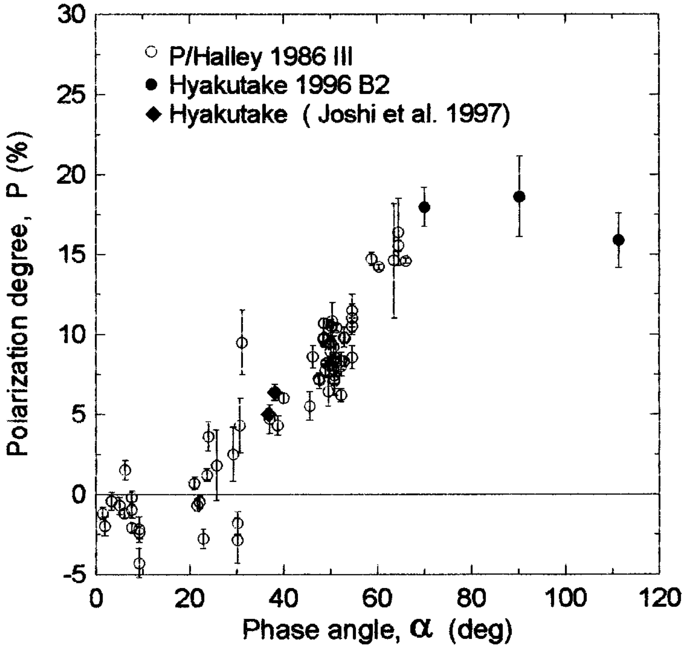


**FIG. 1.** Phase dependence of polarization for dusty comets measured in the UC filter. Open circles: data from LHW CD-ROM digital Archive; filled circles: present work; filled rhomb: data from Joshi *et al.* (1997).

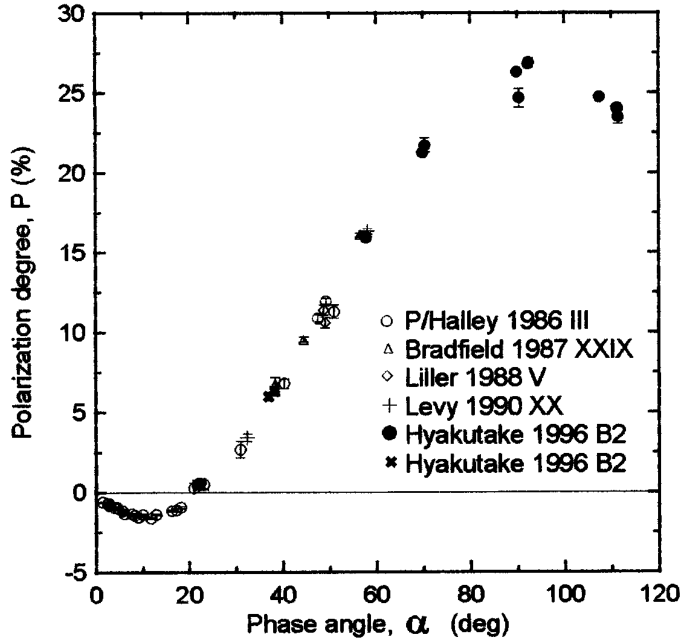


**FIG. 3.** Phase dependence of polarization for dusty comets measured in the RC filter. All data are from Chernova *et al.* (1993).

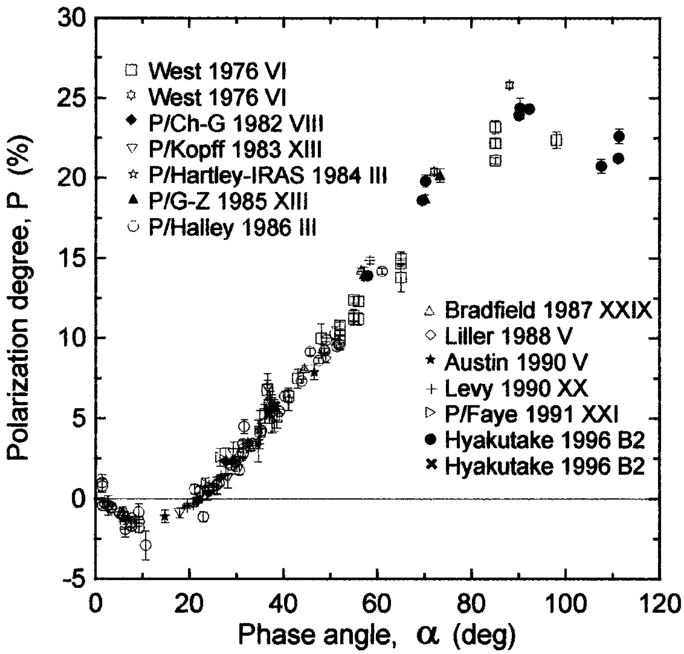


**FIG. 2.** Phase dependence of polarization for dusty comets measured in the RC filter. Most data are from Chernova *et al.* (1993). Data for Comet West 1976 VI in the filter 5300 Å (Kiselev and Chernova, 1978) and in the filter 4850 Å (Michalsky, 1981) are added. Crosses: data for Hyakutake from Joshi *et al.* (1997); filled circles present data for Hyakutake.

angles and the low values of $W_{4845}$ for comet P/Halley at the same time permit us to do this. As can be seen from Figs. 2–3, the polarization data for Comet Hyakutake are in good agreement with data for the dusty comets in the 37°–73° overlap region and these data complement each other very well. The UC-BC and BC-RC colors of Comet Hyakutake are close to those of comets P/Giacobini–Zinner 1985 XIII and Levy 1990 XX (Kolokolova *et al.* 1997). The dust-poor comets usually show blue colors (see, e.g., Sanzovo *et al.* 1996). Consequently, by the polarimetric as well as colorimetric properties of dusty particles, and according to the gas-to-dust ratio, Comet Hyakutake belongs to the group of dusty comets consisting of West 1976 VI, P/Churyumov–Gerasimenko 1982 VIII, P/Kopff 1983 XIII, P/Hartley–IRAS 1984 III, P/Giacobini–Zinner 1985 XIII, P/Halley 1986 III, Bradfield 1987 XXIX, Liller 1988 V, Levy 1990 XX, and P/Faye 1991 XXI. In such a case, taking into consideration the results from Chernova *et al.* (1993), the complete phase dependences of polarization of the dusty comets can be obtained for two continuum domains in the phase angle range 0°–110°. Their parameters are $P_{min} = -1.5\%$ and $\alpha_0 = 22.1°$, almost independent of wavelength; $h = 0.34$ per cent per degree; $P_{max} = 24.0\%$, and $\alpha_{max} \simeq 94°$ for the blue filter; and $h = 0.41$ per cent per degree, $P_{max} = 26\%$, and $\alpha_{max} \simeq 94°$ for the red one. As for the ultraviolet continuum, one can only say that the polarization maximum is in the vicinity of 19%.

It is common knowledge that the wavelength dependence of polarization changes with the phase angle. For phase angles $\alpha \leq 30°$ it is nearly constant but for $\alpha > 30°$ $P(\lambda)$ increases with phase angle increasing. Using the current observations of Comet Hyakutake and the available data for Comets P/Halley 1986 III, Bradfield 1987 XXIX, and Liller 1988 V (Chernova *et al.* 1993), we have found that the increase of $dP(\lambda)/d\lambda$ in the 30°–94° phase angle range and between 4845 and 6840 Å is 0.023 ± 0.002% per 1° within 1000 Å.

## 4. DISCUSSION

The active regions (jets) of the inner coma of Comet Hyakutake were observed by Tozzi *et al.* (1997). As is evident from the observations of Comet Okazaki–Levy–Rudenko (1989r) (Eaton *et al.* 1991), Comet Levy 1990 XX (Renard *et al.* 1992), and Comet P/Swift–Tuttle 1992 XXVIII (Goldberg and Brosch, 1995), the polarization degree of jets tends to be higher than that of the surrounding parts of the coma. As a rule, the areas with higher polarization degree are rather small and do not perceptibly affect the aperture polarimetry. The assurance that the aperture polarimetry can rather well provide the information on the mean polarimetric properties of cometary dust particles is based on the similarity of the polarization phase dependences of many dusty comets. Indeed, the scatter of data in the composite polarization phase dependence of the comets is not too significant, despite the different accuracies of different observations the diversity of cometary gas-to-dust ratios and the appearance of jets in the comae.

Up to the present work, the position and value of the maximum of the polarization in the cometary continuum were poorly studied. There were only three dusty comets with polarimetric observations at phase angles greater than 90°. They are Comet Bennett 1970 II (Kharitonov and Rebristyi, 1973), Comet West 1976 VI (Kiselev and Chernova, 1978; Oishi *et al.* 1978; Michalsky, 1981) and Comet Austin 1982 VI (Myers and Nordsieck, 1984). The spectropolarimetric observations by Kharitonov and Rebristyi were not very accurate, while observations by Oishi *et al.* and Myers and Nordsieck were carried out in broad wavelength intervals. It is particularly important that Comet Austin 1982 VI had a low continuum flux and a large decrease in the dust production rate at that time when its phase angles were large (see Myers and Nordsieck, 1984). Because of this fact, only data for Comet West could be used for the combined polarization phase dependence. That is why the values of $\alpha_{max}$ obtained by Levasseur-Regourd *et al.* (1996) (see Figs. 3a and 3b) are essentially extrapolated.

Previously, it was assumed that the maximum of cometary polarization is close to 90° (Dobrovolsky *et al.* 1986) or corresponds to the maximum of polarization of atmosphereless bodies (Dollfus, private communication). Levasseur-Regourd *et al.* (1996) have found that $\alpha_{max}$ is equal to 103° and 95° in the green and red domains, respectively. We have shown that the maximum of polarization of dusty comets occurs at about 94°. Possibly, $\alpha_{max}$ slightly depends on wavelength in the visible region of spectra, and the value of $P_{max}$ increases in the red. A knowledge of the $P_{max}$ and $\alpha_{max}$ for comets is very important at least from two points of view. First, the calculated models may be limited in number because the real models should fit the observed maximum of polarization. Second, as was shown by Kolokolova *et al.* (1997), the maximum of polarization indicates the composition of dust material (complex refractive index).

Discussion of the parameters $P_{max}$ and $\alpha_{max}$ for dust-poor comets is not a subject of this paper. Nevertheless, it should be emphasized that both the differences of gas-to-dust ratios among the comets and the problem of gas contamination in the continuum filters complicate the study of the polarization phase dependence of dust-poor comets (Kiselev and Chernova, 1996). It is interesting to note that the gas-to-dust ratio for comet Austin 1990 V changed in large ranges with the heliocentric distance. During our observations (Chernova *et al.* 1993) the comet was quite dusty. But a low maximum of polarization, observed by Kikuchi *et al.* (1990), occurred for large gas-to-dust ratios. Therefore, the intermediate-band observations by Kikuchi *et al.* (1990) could be explained more naturally by the changing of the gas-to-dust ratio rather than by the changing of the dust properties in the comet with heliocentric distance, as speculated by Mukai *et al.* (1991).

It might be good to compare the polarimetric properties of the dust particles of the comets with those of the atmosphereless bodies. In contrast to comets, the polarization maxima for the S-type atmosphereless bodies (NEAs) and for the whole Moon and Mercury as well as are close to 9% at around 100°–110° (Dollfus and Bowell 1971; Dollfus and Auriere 1974; Kiselev *et al.* 1990). $P_{max}$ is greater in the blue than in the red domain, while $\alpha_{max}$ is wavelength-independent at least for the whole Moon (Dollfus and Bowell, 1971).

Dollfus (1989) has indicated that polarimetric properties of comets are close to those of the C-type asteroids. They have at least similar values of $P_{min}$. Unfortunately, the position and degree of the maximum polarization of the C-type asteroids are still unknown. There are no observations at phase angles larger than 40°. A weak increase of $P(\lambda)$ is observed for the positive branch of polarization for the C-type asteroids (Myers *et al.* 1985). Simultaneously, the slope and the inversion angle decrease slightly with increasing wavelength (Chernova *et al.* 1993). Thus one cannot say what the wavelength polarization dependence of C-type asteroids will be at large phase angles.

It is well known that the polarimetric properties of the asteroids at large phase angles are determined by Umov's law. This indicates a combination of Fresnel single scattering and multiple scattering. As a result, the polarization degree is inversely proportional to albedo. The albedo of the S-type asteroids increases with wavelength, while the albedo of the C-type asteroids is almost constant in the visible range of spectra (Tedesco *et al.* 1989). The polarization maximum of the S-type asteroids lies approximately at twice Bruster's angle. Reflectivity of dusty comets is slightly increasing with wavelength (Lamy, 1985) and polarization is increasing also. Does this mean that Umov's law does not hold for cometary dust particles? As a first approximation cometary dust particles may be considered independent Mie scatterers, while asteroid dust particles form a surface. Therefore the unpolarized component of light arising under multiple scattering by a rough surface is absent for comets. The higher maximum polarization degree and the observed wavelength polarization dependence of comets can thus be explained. A direct comparison of the scattering processes for the dust particles of cometary atmospheres with those for the asteroid dust particles is hardly possible. Cometary particles are actually aggregated structures involving many submicrometer grains. The scattering process for these particles is more complicated. Multiple scattering within aggregate-structured dust particles produces negative polarization, the opposition effect, and a maximum polarization around 90° (see, e.g., Tishkovets 1994; Vaida and Desai 1996; Xing and Hanner 1996; Tishkovets 1997).

## 5. CONCLUSIONS

The results of photometric and polarimetric observations of Comet 1996 B2 hyakutake were presented.

1. It is shown that Comet Hyakutake belongs to the group of dusty comets involving West 1976 VI, P/Churyumov–Gerasimienko 1982 VIII, P/Kopff 1983 XIII, P/Hartley–IRAS 1984 III, P/Giacobini–Zinner 1985 XIII, P/Halley 1986 III, Bradfield 1987 XXIX, Liller 1988 V, Levy 1990 XX, and P/Faye 1991 XXI.
2. The degree and position of the polarization maximum for Comet Hyakutake and hence for the group of dusty comets were found for ultraviolet (≈19%), blue (24%), and red (26%) domains of the continuum at a phase angle close to 94°. Consequently, at present the complete synthetic phase dependence of the polarization of dusty comets is known in the range 0°–110°.
3. $P_{\max}$ increases with wavelength and $\alpha_{\max}$ is slightly wavelength-dependent.

Polarimetric observation of the C-type NEAs 1580 Betulia and 2100 Ra-Shalom is particularly important in the future. So far only these C-asteroids give a rare possibility of ground-based observations at large phase angles.

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