Optical polarimetry and photometry of comet 17P/Holmes

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ABSTRACT
Comet 17P/Holmes was observed for linear polarization using the optical polarimeter mounted on the 1.2-m telescope atop Gurushikhar peak near Mt. Abu during the period 2007 November–December. Observations were conducted through the International Halley Watch narrow-band (continuum) filters. During the observing run, the phase angle was near 13° at which the comet showed negative polarization. On the basis of the observed polarization data, we find comet 17P/Holmes to be a typical comet with usual dust characteristics. We note that radial rate of change of brightness in coma in red band is higher than that in blue band; it has decreased by a factor of 3.6 and 2.5, respectively, in red and blue bands during the November–December run, indicating relative increase in the abundance of smaller dust particles outward. Radial brightness variation seen near the nucleus on November 6 is indicative of the presence of a blob or shocked region beyond 10 arcsec from the nucleus which has gradually smoothened by December 13. The brightness distribution is found steeper during November 5–7 as compared to that on December 13.

Key words: methods: observational – techniques: polarimetric – comets: general – comets: individual: comet 17P/Holmes.

1 INTRODUCTION
Physical properties of cometary dust can be obtained from the solar radiation scattered by the cometary dust which, in the process, gets polarized. The degree of polarization and its direction mainly depend on the size distribution, composition of the particles, phase angle and the wavelength of the incident solar radiation. However, the real situation is not that straightforward. In an attempt to study the detailed behaviour of polarization with phase, Dollfus et al. (1988) synthesized the polarization observation data on 1P/Halley by various researchers and derived curves of polarization as a function of the phase angle. Phase curve below about 20° shows negative polarization while it is positive at higher phase angles. They find slight modification in the polarization phase curve as one moves away from the nucleus indicating the change in the nature of the dust particles. Also, an anomalously high transient polarization was noted between 1985 October 17 and 30, at the phase angle of 25°, attributed to sudden release of large number of smaller particles. On the basis of this work on 1P/Halley, Dollfus (1989) derived the physical properties of the dust grains indicating the presence of large particles – aggregates comprising of sub-micron-sized grains, very rough and dark. These rather large grains are mixed with the clouds of small particles and they are usually responsible for almost all the polarization effects in visible light, except during temporary specific dust release events (as seen in the case of 1P/Halley during 1985 October 17–30) by the nucleus (Dollfus 1989). The complex behaviour of the dust is also seen in comet C/1995 (Hale-Bopp), especially the region around the nucleus shows complex structure (Hadamcik & Levasseur-Regourd 2003). Though the comets, in general, show similar polarization behaviour with phase angle, they are divided into three classes based on the maximum in polarization (Levasseur-Regourd 1999). Varying polarization observed in the coma or in the features (jets, shells, etc.) indicates a diversity of dust particles. Issues related to the dust characteristics are adequately reviewed by Kolokolova et al. (2004).

One of the main objective behind the study of comets is to understand the origin of the Solar system. Since comets spend substantial part of their life away from the Sun, their subsurface material is considered pristine. Space mission Deep Impact was launched on 2005 January 12 to study the composition of the interior of the comet 9P/Tempel 1 by colliding a part of the spacecraft with the comet (Meech et al. 2000; A’Hearn et al. 2005b). At 5:52 UTC on 2005 July 4, the impactor of the Deep Impact probe successfully collided with the comet’s nucleus, excavating huge amount of debris from the interior of the nucleus (A’Hearn et al. 2005a,b).

On 2007 October 24, nature itself provided a similar opportunity, albeit at a much grander scale. Comet 17P/Holmes underwent unprecedented outburst on 2007 October 24, after about 5 months of perihelion passage (Santana 2007). The comet brightenings are well documented in the literature and in general are associated with an eviddent fragmentation of cometary nucleus (e.g. Sekanina 2002a,b, and the references therein). But, the magnitude and the characteristics of the outburst occurred in comet 17P/Holmes has dwarfed all the events seen earlier.

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The periodic comet 17P/Holmes was discovered on 1892 November 6 by E. Holmes during a huge outburst, which was followed by another similar event in 1893 January. When discovered, the comet was around 5 months past perihelion. The 2007 October 24 outburst also occurred about 6 months after the perihelion passage (2007 May 4) of the comet. The heliocentric distances of the comet at the time of the two outbursts were nearly similar (2.39 and 2.44 au, respectively, in 1892 and 2007). During the outburst, huge amount of dust and gas ejected out from the comet’s subsurface. Comet 17P has typical composition as discussed by A’Hearn et al. (1995), but the dust-to-gas ratio has been found very high on 2007 November 1 (Schleicher 2007) and is attributed either due to the finite lifetimes of the gas molecules released at the onset of the outburst as compared to the long-lived dust grains or due to a portion of the dust tail remaining within the photocenter apertures due to projection effects from the comet’s small phase angle.

As discussed above, polarization studies have proven to be very useful in inferring the dust properties of comets. While the data at large phase angles are substantive, there is a lack of the observations at small phase angles which hinders the study of the polarization behaviour in the negative branch of polarization–phase curve. In the past, we have made a detailed study on comets Hale-Bopp and WM1/LINEAR at low phase angles (Ganesh et al. 1998; Joshi et al. 1995), but the dust-to-gas ratio has been found very high on 2007 November 1 (Schleicher 2007) and is attributed either due to the atmospheric scintillation effects (e.g. sky transparency fluctuations) or due to a portion of the dust tail remaining within the photocenter apertures due to projection effects from the comet’s small phase angle.

We compare our observations with recently reported results on this comet by Rosenbush et al. (2009) and also discuss the polarization behaviour with that of other comets observed at similar phase angles.

2 OBSERVATIONS AND ANALYSIS

Photopolarimetric observations of comet 17P/Holmes were made during the period 2007 November 5–7 and on December 13 with a two-channel photopolarimeter (Deshpande et al. 1985; Joshi et al. 1987), which has been fully automated recently (Ganesh et al. 2008), mounted on the 1.2-m telescope of Mt. Abu Observatory operated by Physical Research Laboratory (PRL), Ahmedabad. PRL polarimeter works on rapid modulation principle. A rotating superachromatic half-wave plate in front of a fixed Wollaston prism modulates the polarized component of the incident light at a frequency of 10 Hz. Another identical Panchatnam half-wave plate is put between the rotating half-wave plate and the Wollaston prism to eliminate any wavelength dependence of optic axis of half-wave plate. Rotating half plate rotates at discrete steps with 1 ms sampling time. One full rotation of half-wave plate is completed in 96 steps and thus one modulation cycle involves 24 steps (i.e. 24 ms) and the data are folded and accumulated in 24 bins. With the rapid modulation, the atmospheric scintillation effects (e.g. sky transparency fluctuations) are eliminated.

The instrument is equipped with IAU’s International Halley Watch (IHW) continuum filters (3650/80, 4845/65, 6840/90 Å) (Osborn et al. 1990) and Johnson–Cousins’ BVR broad-band filters. The IHW filters acquired for comet Halley have been used for these observations. These filters have been in regular use for

Table 1. Polarization observations of comet 17P/Holmes.

| Date     | JDT    | r     | Δ    | α     | Filter (Å) | Aperture (arcsec) | Diameter (km) | IT (s) | P per cent | ϵ per cent | θ° | Mag |
|----------|--------|-------|------|-------|------------|------------------|---------------|--------|------------|------------|----|-----|
| November 5 | 10.326 87 | 2.485 602 | 1.620 252 | 13.9 | 6840 | 10 | 11.751 | 400 | −1.17 | 0.50 | 19 | 10.05 |
| November 6 | 11.288 74 | 2.485 386 | 1.620 319 | 13.6 | 6840 | 26 | 30.553 | 400 | −1.09 | 0.18 | 22 | 9.28 |

Note. Listed entries are Julian date (JDT), heliocentric range (r), geocentric range (Δ), phase angle (α), filter, aperture (arcsec), diameter (km), total integration time (IT s), degree of polarization (P per cent), error in polarization (ϵ per cent), position angle (θ°) in equatorial plane, magnitude at the time of observations. JDT = JD – 2 454 400.
observations of several other comets (Joshi et al. 1987; Sen, Joshi & Deshpande 1991; Ganesh et al. 1998; Joshi et al. 2002, 2003). The filters have been carefully stored in dry atmospheric conditions to preserve their transmission characteristics. The observations made with the same set of filters facilitate better comparison with other comets observed earlier, hence their continued use is justified.

The online data reduction performed after each integration invokes a least-squares fit to the counts (comet-sky) obtained from

![Comet 17P Holmes Ephemeris](image)

**Figure 1.** Top panel shows phase angle ($\alpha$) while bottom panel shows the apparent heliocentric ($r$) and geocentric ($\Delta$) ranges relative to the observer during the observing run.

![Polarization versus phase plot](image)

**Figure 2.** Polarization versus phase plot. (Left-hand panel) 4845 Å filter data from Kiselev et al. (2005) and this work (Right-hand panel) same as in left-hand panel but for wavelength range 6000 < $\lambda$ < 7000. Observations are labelled with different symbols for all comets. Second-order polynomial fit to the data from the catalogue is shown as solid curve. In case of multiple observations in the catalogue at the same phase, an average value is taken; observations with uncertain position angle measurements are not included.
the two photomultiplier tubes as a function of the rotating half-wave plate position. The mean error in polarization is estimated from actual deviation of the counts from the fitted curve. To further reduce the error, several such measurements were taken and averaged. The error bars represent this error and instrumental error (obtained by observing several zero polarization standards during each night and found to be <0.03 per cent). Regarding the sky polarization, on an average it was ∼5–6 per cent (±3 per cent) but the sky as seen through the 26-arcsec aperture is ∼4-mag fainter compared to the comet observed through the same aperture. These numbers were consistent during the observing run. Hence, the error communicated due to the sky to the comet data is negligible. Nonetheless, to take care of the sky polarization, observations were made alternately centred on the photocentre of the comet and on a region of the sky more than 30-arcmin away from the comet (along the antitail direction). All the observations were made under dark sky conditions. The errors in the position angle are obtained using the equation 8.5.4 given by Serkowski (1974).

The observations were taken with apertures (non-metallic diaphragms centred on the photocentre of the comet) of different sizes – 10, 20, 26 and 54 arcsec with the projected diameter varying from 11 750 to 69 925 km (see Table 1) to study the behaviour of the dust as a function of radial distance from the comet nucleus. All the observations were made under dark-sky conditions, and the comet was much brighter than the sky resulting in negligible contribution by the sky to the observed degree of polarization of the comet. Nonetheless, to take care of the sky polarization, observations were made alternately centred on the photocentre of the comet and on a region of the sky more than 30-arcmin away from the comet (along the antitail direction).

Polarization standard 9 Gem was observed to calibrate the observed position angle. Comet’s IHW magnitudes were obtained using the observations of solar-type stars, namely HD 29461, HD 76151. Polarization values, corrected position angle and IHW magnitudes in continuum bands are given in Table 1.

3 RESULTS AND DISCUSSION

The various quantities obtained from our observations on the comet 17P/Holmes are listed in Table 1, namely the degree of polarization (P per cent) and its error (εP per cent), the position angle (θ), brightness magnitudes along with observing time (JDT), filter, aperture size, total integration time and the orbital parameters at the time of observation. The values listed in Table 1 have been carefully checked for any inconsistency. Fig. 1 shows the heliocentric and geocentric ranges and the phase angle (α) at the time of observation, which were obtained using the JPL’s HORIZONS system (Giorgini et al. 1997). As mentioned earlier in Section 2, we have made observations through various apertures for sampling the comet. However, 26-arcsec aperture is used more often and if not mentioned.

![Figure 3. Wavelength dependence of polarization as observed using the continuum filters through different apertures. Observing date is marked on each panel and the bottom panel shows annotation used for different apertures. Observed points are joined with different type of lines: dot for 10 arcsec, short dash for 20 arcsec, long dash for 26 arcsec and dot–long dash for 54 arcsec apertures to distinguish them.](https://academic.oup.com/mnras/article-abstract/402/4/2744/1748496)
specifically we will use this aperture for further discussion. This aperture corresponds to a projected diameters $\sim 30,550$ km during 2008 November 5–7 and $\sim 33,670$ km on 2008 December 13. The sampled area is large and while small-scale inhomogeneities are expected to average out, large structures in coma might still show up. The polarization values in the blue narrow-band are associated with larger errors due to poor signal-to-noise ratio. To address the possibility of continuum BC band contamination by molecular emission, which might affect the degree of polarization, we used the spectra provided by Buil (private communication).\(^1\) Examining the spectrum of November 1, a very weak emission feature (<3 per cent of the continuum) appears to partly overlap with the BC band. Even if we take the upper limit of 3 per cent contamination of the BC band by this feature, it will change the degree of polarization by $<0.05$ per cent. In fact, in the present case, any such correction will increase the absolute value of the polarization that will improve the fit. Molecular production rate in 17P/Holmes is reported to decay exponentially with time (Schleicher 2009), the contribution of molecular emission will further reduce at later date (e.g. November 5–7 and December 13) compared to 2007 November 1 when the spectrum was taken. Hence, we have ignored the contamination of the BC band by molecular emission.

During our observing run, the phase angle remained less than 20° and observed polarization is negative. In the following, we discuss the wavelength and phase-angle dependence of polarization and compare the present results with the results of Rosenbush et al. (2009).

### 3.1 Polarization–phase-angle dependence

Fig. 2 presents $P$ per cent versus $\alpha$ curve for $\alpha < 25^\circ$, for the comets in the blue band (4845 Å) and the red band (6000 < $\lambda$ < 7000). Since our observations are made at low phase angles where the polarization is negative, we have limited the plots to phase angle < 25°. Also plotted are the data from Kiselev’s catalogue (Kiselev et al. 2005) for the comets which have been observed by various researchers in blue and red bands (all narrow- and broad-bands). As observations in narrow continuum bands at the low phase angles are scanty, we considered all the observations made in red filters (6000 < $\lambda$ < 7000) to generate an average $P$ per cent versus $\alpha$ curve for $\alpha < 25^\circ$. Unpublished data, as mentioned in the catalogue, and the data for which $P$ per cent > 0.0 for $\alpha < 20^\circ$ and the outliers from the main trend have been ignored. The best polynomial fit thus generated is presented in Fig. 2 with solid curve.

The present observed values of the polarization in 17P are shown in two curves with solid circles with error bars ($\pm \sigma$). For plotting purpose, all the data obtained through the same filter but with different apertures are averaged taking the weight equal to $1/\sigma^2$. In both, red and blue domains, our observed polarization values lie close to the best-fitting curves. These observations are suggestive of usual nature of the comet 17P/Holmes.

\(^1\)See his web site http://www.astrosurf.com/buil/
3.2 Wavelength dependence of polarization

Though the negative branch of polarization–phase ($P_{\text{per cent}}$–$\alpha$) curve is not very sensitive to the change in wavelength ($\lambda$), the composition might lead to a mild dependence. To study any such wavelength dependence of polarization, observed $P$ per cent in continuum bands is plotted against the wavelength in Fig. 3. The observation date, the phase angle and the aperture used are marked in the figure. The observations made through different apertures are plotted with different symbols. As expected for the low phase angle, polarization is negative (i.e. the polarization vector lies in the scattering plane). Looking at Fig. 3, we do not see, within the observed errors, any significant dependence of $P$ per cent either on wavelength or on the aperture size. However, one can note a mild trend of increase in $P$ per cent (decrease in the absolute value of polarization) on November 5 in the observation with 10-arcsec aperture and a mild decrease in $P$ per cent on November 7 trough 20-arcsec aperture. This might indicate time evolution of the cometary grains. As discussed above, the $\lambda$-dependence of $P$ per cent is to be taken cautiously.

On October 25, the polarization is found to change from $-0.7$ per cent in 4845-band to 0.0 per cent in 6840-band, while on October 27 and November 3 the polarization does not show any change with wavelength (Zubko et al. 2009); its value remaining at $-1.0$ per cent level. This has been attributed to the decrease in the number density of smaller particles. We also do not notice any significant change in polarization with wavelength during 2007 November 3–7 and on December 13. However, Rosenbush et al. (2009) have reported steep wavelength dependence of polarization during the period 2007 October 27–November 22. The possible reason for this discrepancy is further discussed in Section 3.3.

3.3 Comparison with other results

Rosenbush et al. (2009) have reported the results based on the polarization observations made during the period 2007 October 27–November 22. In the following, we compare our observations with theirs and comment on the findings.

(i) On 2007 November 5 (phase angle $\sim 13.8$), Rosenbush et al. (2009) have reported $P$ per cent in WRC filter while we observed in BC and RC bands. It is noted that absolute value of degree of the linear polarization reported by them is systematically lower than our values.

(ii) Using their observations in WRC (7228/1140 Å) and BC (4845/65 Å) bands on 2007 October 27, Rosenbush et al. (2009) estimate large ($-0.77/1000 \text{ Å}$) spectral gradient. Though the spectral trend in the negative polarization regime is not clearly established, they term it as atypical spectral behaviour not shown by normal comets. Throughout our observations in RC and BC bands, we do not note such ‘atypical’ trend.

Based on their observations of relatively much lower absolute polarization and atypical spectral behaviour, they claim comet 17P/Holmes to be of unusual type which is contrary to our
findings. In the light of this, we very carefully checked our observations for any systematic error, sky subtraction, etc., both for the comet and polarization standard star observations. We find our results to be thoroughly consistent. The average degree of polarization during November 5–7 is \(\sim -1.2\) per cent but on December 13 \(P\) per cent appears to go below \(-1.5\) per cent. These values are close to the values generally observed in other comets at such low phase angles, e.g. comet Halley (Sen et al. 1991), Hale-Bopp (Ganesh et al. 1998), LINEAR WM1 (Joshi et al. 2002, 2003). The data points lie close to the best fit \((P\) per cent versus \(\alpha\) curve), to further supporting the argument that 17P/Holmes is a usual comet. On the other hand, Rosenbush et al. (2009) have made almost all their observations in broad-bands (\(WRC, R, I\)). Their only observation in \(BC\) ‘narrow-band’ on 2007 October 27 gives polarization value which is very close (within \(1\sigma\)) to the typical phase-polarization curve for comets (cf. Fig. 2) and also agree with polarization values obtained by us at later date. It is, therefore, very likely that the broad-band continuum flux is contaminated by the gas emission, lowering the absolute value of the degree of polarization. Strong gas emission has been detected during the outburst of 17P/Holmes (e.g. Bockelée-Morvan 2008; Biver et al. 2008; Schleicher 2007), which supports the argument given above for the lower absolute value of the polarization reported by Rosenbush et al. (2009).

Though the comet 17P/Holmes has high dust-to-gas ratio, its abundance has ‘typical’ composition (Schleicher 2007). Therefore, within the limitations of the observed polarization data, it appears that 17P/Holmes is similar to other typical comets and follows the average \(P\) per cent–\(\alpha\) curve at low phase angles (i.e. \(\alpha < 20\)). The gas production rates and the dust characteristics in 17P/Holmes studied by others using narrow-band photometry and spectroscopy indicate similarity between 17P/Holmes and other typical comets (e.g. Biver et al. 2008; Lin et al. 2009; Schleicher 2009; Watanabe et al. 2009). These further support the inference drawn in the present study on the basis of polarization data.

3.4 Spectral energy distribution and the light curve

Fig. 4 shows the continuum energy distribution of 17P/Holmes. In this figure, we have plotted normalized magnitudes \((H_\Delta)\) which are corrected for extinction and instrumental effects and referred to a geocentric distance \((\Delta)\) of 1 au by subtracting the term 5 Log(\(\Delta\)). For comparison, energy distribution of a solar analogue star (HD 76151), which was observed during the observing run, is also plotted. It is seen (cf. Fig. 4) that during the period 2008 November 5–7, the comet colour is similar to the solar colour. However, on December 13 the colour is marginally bluer, indicating the increase in relative abundance of small particles. This can be explained assuming that in due course the larger particles might have fragmented to smaller particles thus enhancing the relative abundance of smaller particles.

Let us now discuss the light curve of comet 17P/Holmes. Fig. 5 shows the evolution of brightness in continuum bands through various size apertures, plotted in different panels. Clearly, there is decrease in brightness with time, but the interesting finding is the relative dimming in red band being more compared to blue band which is more apparent in 10-arcsec aperture. The brightness of

![Figure 6](https://academic.oup.com/mnras/article-abstract/402/4/2744/1748496/2750_U_C_Joshi__S_Ganesh_and_K_S_Baliyan)

**Figure 6.** Radial brightness variation as projected on the sky on 2007 November 6. Error bars are \(\pm 1\sigma\).
Optical photopolarimetry of comet 17P/Holmes

Central coma (10 arcsec) has reduced by ~1.4 and 1 mag in red and blue waveband amounting to reduction by a factor of ~3.6 and 2.5 in respective bands. The mean spectrum is bluer on 2007 December 13 compared to what is observed during 2007 November 5–7.

Observations on November 6 and December 13 were made through four apertures (10, 20, 26 and 54 arcsec) which allowed us to investigate the radial distribution of brightness. A simple approach is adopted to estimate the brightness at a particular radial distance from the nucleus (the brightest point is taken as the nucleus). Brightness in the annular region is estimated by subtracting brightness in successive apertures which is then normalized to 1 arcsec and this brightness is assigned to the mean annular distance between the two apertures. The radial brightness distribution thus obtained is plotted in Figs 6 and 7, respectively. On November 6, the brightness in the inner region of the coma, as expected, is decreasing with radial distance, but beyond 12 arcsec from the nucleus it starts increasing, indicating the distribution of light to be non-uniform. This might be due to the influence of some blob moving outwards from the comet nucleus or a shocked region. Such trend is not seen in December 13 data. Compared to the brightness distribution on November 6, it falls sharply close to the nucleus and then beyond 7 arcsec from nucleus, the decrease in the brightness is gradual. Since we have carried out aperture photometry, it is difficult to precisely indicate the region of sharp and gradual fall in the brightness. There is a signature (a kink) in the brightness distribution on December 13 which might be due to some arc or shocked region near 10–12 arcsec from the nucleus.

Montalto et al. (2008) have studied early motion (i.e. 2007 October 26 to 2007 November 20 period) of the outburst material with the CCD images in BVRI bands which shows the second blob moving out from the nucleus. The 2007 November 5 image of 17P/Holmes (Montalto et al. 2008) shows a bright spot close to the nucleus (cf. their fig. 1) which might have faded later on. This might explain the rise in brightness seen in radial distribution on November 6 in our observations.

4 CONCLUSIONS

This work reports on the linear polarization and the brightness distribution observations in the coma of comet 17P/Holmes at phase angle near 13°–14°, leading to the following conclusions.

(i) Like other comets, 17P/Holmes shows negative polarization at low phase angle (i.e. below 20°). Based on the polarization values, we believe that 17P/Holmes is not unusual comet as claimed by Rosenbush et al. (2009) and the dust seems to be of the same nature as found in other comets. The discrepancy could possibly be due to the gas emission contamination in the broad-band observations.

(ii) Though there is indication that the value of polarization decreases towards longer wavelength, we infer that, within the errors, the wavelength dependence of polarization as observed through different-sized apertures is typical of comets.

(iii) Radial distribution of brightness in the coma shows higher variation with time in the red waveband as compared to that in the blue waveband; it has decreased by a factor of 3.6 and 2.5.

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Figure 7. Radial brightness variation as projected on the sky on 2007 December 13. Error bars are (±σ).
respectively, in red and blue bands indicating increase in the relative abundance of smaller dust particles away from the nucleus.

(iv) Radial brightness distribution shows the non-uniform distribution of material near the comet nucleus on November 6, which has gradually smoothened by December 13. Also the brightness distribution has become steeper from November 5–7 run to December 13 run.

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