Quasi-Hilda Comet 231P/LINEAR-NEAT: Observation at aphelion using Himalayan Chandra Telescope (HCT)

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Abstract
Comet 231P/LINEAR-NEAT observed around aphelion at 4.88 AU, using 2.0 m Himalayan Chandra Telescope at Mt. Saraswati, Hanle, India. CCD aperture photometry performed and $R_C$-band magnitude $21.37 \pm 0.08$ mag obtained. Comet 231P surface brightness profiles compared with field star and found similar, within low level noise in the data; its implicate no cometary activity. We measured dust production levels in term of the quantity $Af\rho$, which was estimated 5.0 cm. Most of the comet observed at perihelion but not aphelion, if we need to calculate total comet dust contribution in the solar system, this type of study may play important role.

1 Introduction
A Quasi-Hilda Comet (QHC) is a Jupiter family comet (JFC) that interacts strongly with Jupiter and undergoes extended temporary capture by it. These comets are associated with the Hilda asteroid zone in the 3:2 inner mean-motion resonance with Jupiter. While Di Sisto et al.(2005) suggested that the Hildas and Quasi-Hilda Comets could be closely related to JFCs according to their dynamical behavior[1]; Toth give an update on orbital properties of eliptical comets
in Hilda-like orbits and Quasi-Hilda asteroids \cite{2}. The comet 231P/LINEAR-NEAT discovered on NEAT Polomar images obtained on 2003 March 10.36 UT and posted on NEO confirmation page, was reported by K Lawence, a nuclear condensation of diameter about 7" and tail about 8" long toward the West. The cometary nature was confirmed by J. Yong at Table Mountain on 2003 March 12.4 UT. The comet 231P is a distant one, with period of 8.08 year.

In recent studies shows that short-period comets active between 3 to 7 AU \cite{3, 4, 5, 6}. These observation surveys aimed an investigation of bared nucleus, but surprisingly high numbers of comets exhibited coma and even dust tails at large ($r_h \geq 3$) heliocentric distance, where volatile sublimation rate is expected to be low, Chiron is known to be active at solar distance between 8-14 AU \cite{7} and was seen to display substantial out-gassing near aphelion at 17.8 - 18.8 AU between 1969 & 1977 \cite{8}. According to Meech et al. (2004), the Oort cloud comet C/1987 H1(Shoemaker) exhibited an extensive tail at all distances between 5-18 AU \cite{9}. Ohtsuka et al.(2008) studied that Jovian tidal force acting on comet 147P/Kushida-Muramatsu with their QHCs and peri-jove passages and inferred that there seems no reason to be believe that 147P was affected by Jovian tides \cite{10}. Dahlgren & Lagerkvist (1995), Dahlgren et al. (1997,1999) reported on their photometric survey of the color distribution of the Hilda asteroids \cite{11, 12, 13}. They showed that about 36 \% of the Hildas could be classified as D-type, 28 \% as P-type and only 2\% as C-type. Cheng Y (20013) serendipitous discovery of coma activity of comet 212P which is a Quasi-Hilda object in cometary-like orbit\cite{14}.

Cometary dust particles, trapped in the volatile ices of the nucleus since their formation, contain information on the conditions in the pre-solar nebula. These dust grains are the source of a major component of interplanetary dust and large grains are observed in cometary dust trails forming relatively long lasting meteoroid streams, which gradually dissipate into the zodiacal dust complex. As Sykes (1992) pointed out that dust trails are likely to be the principal mass loss mechanism for comets\cite{15}. Therefore, dust trails may enhance our present understanding of the physical composition of comets, from dirty snowballs to frozen mud balls. To study the dust production, mass loss rate around aphelion, taxonomical type and correlate this information to other family comets which is not studied, previously. For these reasons, it is important to study dust trails, in order to investigate the said issues. We planned to carry out a comprehensive observation of QHCs at aphelion. Here, we reported photometry result of comet 231P/LINEAR-NEAT observed at Himalayan Chandra Telescope (HCT). The dust production estimated which is computed by means of the quantity $Af\rho$.

2 Observation

We used 2.0 m Himalayan Chandra Telescope stands on Mt. Saraswati, Digparatsa Ri, Hanle in south-eastern Ladakh in the eastern Jammu and Kashmir state of India. We observed with the Himalayan Faint Object Spectrograph (HFOSC) at images scale of $0.29''$pixel$^{-1}$ with 2048 $\times$ 4096 pixels CCD camera.
Figure 1: Orbit of the comet 231P: Black dot denotes the position of the Sun and * means the positions of the comet at the time of the observations.

| UT date    | RA      | DEC     | Filter | Exptime | $\alpha$ [deg] | $r_h$ [AU] | $\Delta$ [AU] |
|------------|---------|---------|--------|---------|---------------|-----------|--------------|
| 2014/07/25.85 | 22:46:78 | -12:53:57 | R      | $180 \times 5$ | 7            | 4.88      | 4.02         |

at the f/9 Cassegrain focus of the telescope through Johnson-Cousins R filter and seeing limited image quality was variable with the range of 0.8 to 1.8 full width at half maximum (FWHM) with 180 s exposure time and total no. of exposure was 5 (i.e. 900 seconds). The journal of photometric observation shown in the Table[1] and we observed comet 231P around aphelion at 4.88 AU in order to address the cometary activity issue around aphelion; please, see Fig[1] for the mean orbital position of comet 231P, as a part of our QHCs observation programme around aphelion, we showed observation position of comet.

2.1 Data Reduction

All the images were reduced with median images of bias and sky flat using NOAO’s Image Reduction and Analysis Facility (IRAF) software package[16]. The pixel-to-pixel sensitivity variation was removed from the data frames using nightly sequences of bias and flats. The variation in sensitivity of the detector was $\pm$ 5% from the average. From the comet 231P images, the instrumental magnitude obtained using aperture photometry. The flux calibration was done using standard stars in the Landolt catalog[17] mainly or field stars listed in the USNO–A2.0 catalogue, occasionally. The comet 231P and stars position were matched with USNO–A2.0 catalogue[19] using WCSTools from NOAO’s
Figure 2: Image showing comet 231P, made up of 5 × 180 s exposures and image scales is 23 × 23 arcseconds in the X and Y directions. The comet appears to inactive; the frames are combined in such a way as to remove background sky, fixed objects and cosmic rays.

IRAF software package. For the each of observing session, the diameter of the aperture for the aperture photometry was chosen on the basis of our measurement of the seeing disk size, so that the photometry remains unaffected by trailing [20].

3 Result

3.1 Appearances

We selected R_C-band images taken at HCT (see Fig[2]) and examined a weak coma component existence by comparing the surface brightness-profile of comet 231P with PSF of stars as explained in the [21] paper. Both normalized surface brightness profile were similar, however small differences at the low signal level attributed to noise in the data (see Fig[3]).
Figure 3: Normalized surface brightness profile of 231P, showing surface brightness in magnitudes per square arcsecond against photocentric distance in arcsecond.
3.2 Surface Brightness Profiles and Search of Cometary Activity

As shown in Fig. 3, the surface brightness profiles of the near nuclear coma with respect to the radial distance $\rho$. The total R$_C$-band comet 231P, measured in an aperture equivalent in radius to $\rho = 5.073 \times 10^3$ km at the distance of the comet in given in the table 2. We created model point source then added come of varying level and finally convolved these in seeing. The coma level were parametrized by [21, 22, 23, 24]

$$\eta = \frac{C_c}{C_n} = \frac{I_c}{I_n}$$  \hspace{1cm} (1)

where $C_c$ and $C_n$ are the scattering cross-section of coma and nucleus, respectively, which is corresponds to the ratio of the flux density scattered by the coma $I_c$ to the flux density scattered by the nucleus cross-section $I_n$. This is able to characterize varying nucleus and coma contribution levels on preconvolution models. The parameter $\eta$ can take on the value $\eta \geq \eta$, where $\eta = 0$ denotes no comet activity, here we found $\eta = 0.01$. The comparison of said mode to comet 231P profile produces no indication of cometary activity within the detection limit.

3.3 Comet Absolute Magnitude and $Af\rho$ parameter

The absolute magnitude of comet 231P derived which correspond to the magnitude at an hypothetical point in the space at solar phase angle of $\alpha = 0$ deg, heliocentric distance of $r_h = 1$ AU and an observer distance of $\Delta = 1$AU. This magnitude given as

$$m_R(1,1,0) = m_R - 5 \log_{10}(r_n\Delta) - 2.5 \log_{10}\Phi(\alpha)$$  \hspace{1cm} (2)

where $m_R$ denotes apparent magnitude in R$_C$-band. We adopted empirical scattering phase function in order to correct the phase darkening effect; $2.5 \log_{10}\Phi(\alpha) = \beta \alpha$, where $\beta = 0.035 \text{ (mag deg}^{-1})$ is assumed.

An $Af\rho$ technique was used as proxy for the dust production rate [25]. An $Af\rho$ is a product of band albedo ($A$), filling factor ($f$)within aperture field of view and the linear radius of the aperture $\rho$, projected on the sky-plane at the object distance.

$$Af\rho = 4 \frac{\Delta^2 r^2}{\rho} \frac{F_{obj}}{F_{\odot}}$$  \hspace{1cm} (3)

Here $F_{\odot}$ is the solar flux at 1 AU; $F_{obj}$ is the comet flux measured within the given aperture, $\Delta$ and $r$ are the geocentric and heliocentric distances, respectively. The calculated magnitude, an $Af\rho$ parameter and dust production rate are given in the Table 2.
Table 2: Photometry Result: Comet 231P magnitude, $Af\rho$ parameter and dust production rate

| UT date   | $r_h$ [AU] | $\Delta$ [AU] | $m_R$ [mag] | $Af\rho$ | $Q_{dust}$ [kgs$^{-1}$] |
|-----------|------------|---------------|-------------|-----------|-------------------------|
| 2014/07/25.85 | 4.88      | 4.02          | 21.37 ± 0.08 | 5.00     | 5                       |

Table 3: Measured $Af\rho$ parameter and dust production rate

| Comet | $r_h$ [AU] | $Af\rho$ [cm] | $Q_{dust}$ [kgs$^{-1}$] | References     |
|-------|------------|---------------|-------------------------|----------------|
| 231P  | 4.88       | 5.00          | 5                       | This work      |
| 29P   | 6.25       | 3865.4        | 431                     | Shi J C et al. (2014) |
| 29P   | 5.97       | 4637.4        | 182                     | Ivanova et al. (2009) |
| 228P  | 3.473      | 44            | 6.9                     | Shi J C et al. (2014) |
| 228P  | 3.474      | 71.4          | 11.2                    | Shi J C et al. (2014) |
| 117P  | 3.29       | 670           | –                       | Epifani E M et al. (2008) |
| 36P   | 3.90       | 11            | –                       | Epifani E M et al. (2007) |
| 129P  | 4.50       | 4.558         | –                       | Lowry & Fitzsimmons (2005) |
| 74P   | 4.24       | 298           | –                       | Lowry & Fitzsimmons (2001) |
| 159P  | 3.98       | 199           | –                       | Epifani E M et al. (2007) |

4 Discussion

This work based on the aperture photometric study and its derived parameter like dust production and cometary activity around aphelion. Previously study have not been studied in sufficient detail in this regard of QHCs. This is not good idea to compare our result with other member of QHCs, but it may comparable with JFCs. Please, see the Table 3 for more comparison.

Since the main goal of our observing program was to search for signs of cometary activity in distance comets. We have calculated dust production rate using $Q_{dust} = \frac{Af\rho(a_{dust}v_{ej}\sigma)}{3p}$ and compared with available data of QHCs and JFCs; where $a_{dust}$ ($\mu$m) is the grain radius, $p$ is the geometric albedo of the dust grain, $v_{ej}$($ms^{-1}$) is the grain ejection velocity, $\sigma$ ($gcm^{-3}$) is grain density. We assume, $a=1$ cm (Grun 2001) [27], $p=0.04$, $v_{ej}=50$ $ms^{-1}$ and $\sigma=0.49gcm^{-3}$ (Niimi 2012) [28] but we adapted $\sigma=0.6gcm^{-3}$ from Snodgrass C (2008) because of it is derived from JFCs and seem to be more realistic; the dust production rate, $Q_{dust} = 5kgs^{-1}$, we found. As the dust production rate calculated by Shi J (2014) [29] for comet 228P/LINEAR on 2011, April 5 was $Q_{dust} = 11.2kgs^{-1}$, and on 2011, April 6 was $Q_{dust} = 6.9kgs^{-1}$, were as our value $Q_{dust} = 5kgs^{-1}$ is within the range as found by Shi J (2014), which is comparable with QHCs and seem to be more realistic, under the above circumstance.
The variation of the $Af\rho$ parameter and dust production rate mostly mean the variation of the activity of comets at different epoch. Observed comet 117P/Helin-Roman-Alu, $Af\rho = 670$ cm at 3.29 AU [30], similarly, comet 36P/Whipple, $Af\rho = 11.0$ cm at 3.9AU [31]; comet 129P/Shoemaker-Levy-3 , $Af\rho = 4.5$ cm at 4.55 AU [6]; comet 74P/Smirnova-Chernykh , $Af\rho = 298.0$ cm at 4.24 AU [4] which appear to be large as we observed.

5 Concluding remarks

The ground base observation program of Quasi-Hilda comet; 231P/LINEAR-NEAT was observed around aphelion passage, we attempted to address the question whether 231P active or not at aphelion. An apparent $R_C$-band magnitude was $21.37 \pm 0.08$ mag. The measured $Af\rho = 5$ cm confirmed that the comet 231P was strongly dormant, according to the $Af\rho$ criterion. The measured dust production rate was about $5 \text{ kgs}^{-1}$.

6 Future Work

As a part of ground base observation program, we propose and planned to observe all member of QHC; in order to address it’s cometary activity, dust production rate and mass lose rate around aphelion.

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