Imaging polarimetry of Comet C/2012 L2 (LINEAR)

P. Deb Roy\textsuperscript{a,*}, H. S. Das\textsuperscript{a,**}, Biman J. Medhi\textsuperscript{b}

\textsuperscript{a}Department of Physics, Assam University, Silchar 788011, India
\textsuperscript{b}Aryabhata Research Institute of Observational Sciences, Manora Peak, Nainital 263129, India

Abstract

We present the polarimetric results and analysis of comet C/2012 L2 (LINEAR) observed at 31\degree.1 phase angle before perihelion passage. The observations of the comet were carried out using ARIES Imaging Polarimeter (AIM-POL) mounted on the 1.04-m Sampurnanand telescope of ARIES, Nainital, India on 11 and 12 March, 2013 using R photometric band (\(\lambda = 630\) nm, \(\Delta \lambda = 120\)nm). The extended coma of the comet (\(\sim 65000\) km) shows a significant variation in the intensity as well as polarization profile in all considered directions which suggest that the dust particles originate from the active areas of the nucleus. The elongation of the coma is prominent along the Sun-comet position angle. The polarization of Comet C/2012 L2 (LINEAR) does not show steep radial dependence on the aperture size during both the nights of observation. A jet extended in the antisolar direction is well observed in both intensity and polarization map.

Keywords: comets – dust – scattering – polarization – extinction

\textsuperscript{*}Corresponding author
\textsuperscript{**}Principal corresponding author
Email addresses: pari.hkd@gmail.com (P. Deb Roy), hsdas@iucaa.ernet.in (H. S. Das), biman@aries.res.in (Biman J. Medhi)
1. INTRODUCTION

Comet C/2012 L2 (LINEAR) was discovered by the Lincoln Near Earth Asteroid Research (LINEAR) Survey on 1st June, 2012. The perihelion and aphelion distance of the comet are about 1.51 au and 1166.64 au respectively from the Sun\(^1\). The Comet C/2012 L2 (LINEAR) may belong to inner Oort-cloud family since the inner Oort-cloud extends as close as 1000 au. The comet came close to the Earth (1.74 au) on the 26th January, 2013. The visual magnitude of the comet was 13.65 and 13.64 on 11 and 12 March, 2013\(^2\).

The polarimetric study of comet gives a well defined idea about the physical properties of cometary dust grains. Numerous comets have been studied including Oort-cloud objects over a wide range of phase angle and wavelength in past through imaging polarimetry to understand features in the coma. Recently, an Oort-cloud comet C/2009 P1 (Garradd) has been studied by Das et al. (2013) and Hadamcik et al. (2013) at phase angle (\(\sim 28-35^\circ\)) to obtain the intensity and polarization profiles of the comet. A strong jet feature with a uniform aperture polarization has been observed by both the investigators along with a noticeable variation in intensity and polarization profile in all considered directions of the coma.

To explain the observed photopolarimetric characteristics of comets, modeling of comet dust has been proposed by many researchers which helped a lot in understanding comet dust properties in detail (e.g., Das & Sen (2006), Kimura et al. (2006), Bertini et al. (2007), Levasseur et al. (2007), Das et al.).

\(^1\)http://www.minorplanetcenter.net/iau/mpec/K13/K13F47.html

\(^2\)
Most importantly no polarimetric study of dynamically new Comet C/2012 L2 (LINEAR) has been reported so far. In this paper, we present the results of optical polarimetric study of this comet at 31°.1 phase angle before perihelion passage. The organization of the paper is as follows: in Section 2 we present observation and data reduction, in Sections 3 and 4 results and discussion are presented and conclusion in Section 5.

2. OBSERVATION AND DATA REDUCTION

The optical imaging polarimetric observation of the Comet C/2012 L2 (LINEAR) was carried out on March 11 and 12, 2013 using 1.04-m Sampurnanand Telescope of Aryabhatta Research Institute of Observation Sciences (ARIES), Nainital, India (AST: lat.=29°22′N, long.= 79°27′E, altitude= 1951m). The 1.04 m Sampurnanand Telescope has a Cassegrain focus with a focal ratio of f/13. The focal plane instrument used was the ARIES Imaging Polarimeter (AIMPOL) (Medhi et al. (2008), Pandey et al. (2009)) which consists of a Wollaston prism used to split the incident unpolarized beam into two orthogonally polarized ordinary and extraordinary components and a rotatable half-wave plate (HWP) used to alter the polarization state of the light wave. The observations of Comet C/2012 L2 (LINEAR) were carried out in broad band R filter (λ = 630 nm, Δλ =120nm) on 11th and 12th of March, 2013. A CCD camera of 1024 × 1024 pixels was used during the observation with a resolution of 1.73 arcsec per pixel and the field of view is about 8 arc minute diameter on the sky. The gain and the read-
out noise of the CCD are 11.98 e\(^{-}/\text{ADU}\) and 7.0 e\(^{-}\), respectively. Four sets of exposures of each 60 s were made on both the nights of observation. The detailed description of the instrument is given in Rautela et al. (2004) and Medhi et al. (2008, 2010).

2.1. Observational procedure

The geometrical parameters during the observation on March 11 and March 12, 2013 are presented in Table 1. These parameters are collected from NASA-JPL’s HORIZONS system. We observed both high polarized star (HD251204) and unpolarized star (HD65583) to find out the position of polarization plane and the instrumental polarization. The observed standard stars were taken from Serkowski (1974), Turnshek et al. (1990) and HPOL.\footnote{http://www.sal.wisc.edu/HPOL/tgts/HD251204.html} The data for these stars are depicted in Table 2. The standard star's polarization (p), position angle (θ) from the literature and their observed value of polarization (p\(_{\text{obs}}\)) and position angle (θ\(_{\text{obs}}\)) are given in the fourth, fifth, sixth and seventh column in the Table 2. Since the zero position of HWP is not perfectly aligned with the north-south direction it is very much important to determine the offset angle properly for the better accuracy of the result using the relation, θ\(_{\text{o}}\) = (θ – θ\(_{\text{obs}}\)) and the same is given in the eighth column of the Table 2.

The observed images are analyzed using standard IRAF routines. Each image is bias and flat field corrected. The photometric center of each observed images has been found out with a precision of 0.1 pixel. The Wollaston prism and the rotatable half-wave plate allow to form the two orthogonally polar-
Table 1: Log of the observation at AST. UT date, geocentric distance ($\Delta$), heliocentric distance ($r$), apparent visual magnitude ($m_v$), phase angle ($\alpha$), extended sun - comet radius vector position angle ($\phi$), projected diameter for 1 pixel ($D$), filter used in the observation and the exposure time of the observation (time taken for 1 exposure $\times$ number of exposures during the observation.)

| UT date        | $\Delta$ (au) | $r$ (au) | $m_v$  | $\alpha$ (°) | $\phi$ (°) | $D$ (km pixel$^{-1}$) | Filters | Exposure |
|----------------|---------------|----------|--------|---------------|------------|------------------------|---------|----------|
| March 11, 2013 | 1.92          | 1.71     | 13.65  | 31.1          | 67.8       | 2404                   | R       | 60 s x 4 |
| March 12, 2013 | 1.93          | 1.70     | 13.64  | 31.1          | 68.1       | 2412                   | R       | 60 s x 4 |

Table 2: Linear polarization of the standard polarized and unpolarized star in R-filter. Polarization($p$) and position angle ($\theta$) are from the literature, $p_{obs}$ and $\theta_{obs}$ for the measurements, $\theta_o$ is the offset angle.

| UT date        | Filters | Standard Star | $p$ (%) | $\theta$ | $p_{obs}$ (%) | $\theta_{obs}$ | $\theta_o$ |
|----------------|---------|---------------|---------|----------|---------------|----------------|-----------|
| March 11, 2013 | R       | HD251204      | 4.79±0.4| 152.9    | 4.85±0.3     | 154.9±1.7     | -2        |
| March 11, 2013 | R       | HD65583       | 0.05    | 149.3    | 0.12±0.18    | 146±41        | 3.3       |
| March 12, 2013 | R       | HD251204      | 4.79±0.4| 152.9    | 4.86±0.32    | 154.9±1.7     | -2        |
| March 12, 2013 | R       | HD65583       | 0.05    | 149.3    | 0.13±0.18    | 146±40        | 3.3       |
ized components of a single object in the CCD camera. The set of images for each orientation of the fast axis are combined after the proper alignment to increase the signal to noise ratio of each polarized component. The data reduction procedures are systematically discussed in Das et al. (2013).

3. RESULTS

3.1. Intensity Images

The intensity images are produced by adding two polarized components with a proper alignment. The total intensity is given by $I = I_e + I_o$, where $I_e$ is the intensity of extraordinary and $I_o$ is the intensity of ordinary image. The intensity image with contours along with the rotational gradient treated image are shown in the Figure 1 (a–d). The position angle of the Sun–comet radius vector is $67.8^\circ$ and $68.1^\circ$ on 11th and 12th March respectively.

The intensity along the different directions explores the various evolutionary mechanisms working in the cometary coma. It is noticed that the intensity is higher in the tailward direction as compared to the solar direction. We also analyzed the intensity profile in north-west and south-east
direction in which a variation in the profile is noticed. The variation of the profile can be well inferred from the change in the slope value delimited in Table-3. The slope varies from $-0.85$ to $-1.61$ and has also variations between different directions in the coma.

The change in the slopes is a regular phenomenon for an isotropic coma. The variation in the intensity profile is mainly due to the solar radiation pressure which sorts the particles according to their cross-section and mass. The sublimation of ice or organic material coated grains may change the physical properties of the dust particles as they recedes from the nucleus which would also lead to this variation.

The elongation of the extended coma is prominent along the Sun–comet radius vector. The intensity image is treated with the Larson-Sekanina’s rotational gradient technique \cite{Larson & Sekanina (1984)} to find the special feature like jet activity present in the comet. It can be noticed from Fig. 1c and d that a jet is extended in the antisolar direction on both the nights. A change in the direction of the jet between two nights is being noticed which is most likely due to the rotation of the nucleus.

3.2. Linear polarization

3.2.1. Aperture polarization

The aperture polarization values are estimated from the integrated flux measured corresponding to all the polarized components through increasing apertures from the photocenter.

Since the comet is not so bright, four different exposures of 60 s at R-filter are made on both nights of observation to increase the signal to noise ratio. Then all the images corresponding to a particular angle of rotation of
Figure 1: Intensity map with contours for (a) 11th March and (b) 12th March, 2013. The false color rotational gradient treated image for (c) 11th March and (d) 12th March, 2013. The ‘+’ mark denotes the photocenter of the comet. The arrow shows the position angle of the Sun—Comet radius vector which is 67°.8 and 68°.1 on 11th and 12th March respectively. Scale: 60000km × 60000km.
Figure 2: Cuts through the coma sunward, tailward, south-east, north-west and radial profile for two nights of observation. Vertical line represents the seeing radius ($S_R$) limit for each observed night.

Table 3: Intensity profile variation throughout the coma.

| Radial distance to the photometric center (in km) | 9000 | 12000 | 15000 | 18000 | 21000 | 24000 | 30000 |
|--------------------------------------------------|------|-------|-------|-------|-------|-------|-------|
| Solar direction                                  |      |       |       |       |       |       |       |
| March 11, 2013                                   | -1.40| -1.47 | -1.50 | -1.50 | -1.51 | -1.52 | -1.53 |
| March 12, 2013                                   | -1.50| -1.57 | -1.58 | -1.60 | -1.61 | -1.61 | -1.62 |
| Tailward direction                               |      |       |       |       |       |       |       |
| March 11, 2013                                   | -0.85| -0.92 | -1.00 | -1.10 | -1.14 | -1.16 | -1.20 |
| March 12, 2013                                   | -0.90| -1.05 | -1.15 | -1.20 | -1.25 | -1.30 | -1.31 |
| North-West direction                             |      |       |       |       |       |       |       |
| March 11, 2013                                   | -1.30| -1.43 | -1.41 | -1.26 | -1.20 | -1.16 | -1.10 |
| March 12, 2013                                   | -1.45| -1.54 | -1.58 | -1.29 | -1.23 | -1.15 | -1.00 |
| South-East direction                             |      |       |       |       |       |       |       |
| March 11, 2013                                   | -1.20| -1.48 | -1.52 | -1.54 | -1.30 | -1.18 | -1.10 |
| March 12, 2013                                   | -1.47| -1.51 | -1.54 | -1.54 | -1.40 | -1.31 | -1.05 |
Table 4: Linear polarization in percent at different apertures. UT date, Filters used in the observation, aperture diameter (D) and the observed position angle of the polarization vector ($\theta_{\text{obs}}$).

| D (in km) | UT date          | Filter | 12000 | 20000 | 30000 | 40000 | 50000 | 60000 | $\theta_{\text{obs}}$ |
|-----------|------------------|--------|-------|-------|-------|-------|-------|-------|------------------------|
|           | March 11, 2013   | R      | 2.3±0.4 | 2.6±0.3 | 2.6±0.3 | 2.6±0.3 | 2.8±0.3 | 160.3±3.3 |
|           | March 12, 2013   | R      | 2.4±0.3 | 2.4±0.3 | 2.2±0.3 | 1.9±0.3 | 2.0±0.3 | 1.9±0.2  | 148.1±4.4 |

HWP are combined to build a polarization component. Thus four polarized components are produced for four different angles of rotation 0°, 22.5°, 45° and 67.5° of HWP. Finally with all the properly aligned polarization components, the aperture linear polarization values are estimated. The polarization ($p_{\text{obs}}$) corresponding to different apertures and the polarization angles ($\theta_{\text{obs}}$) obtained for both nights of observation are shown in Table 4. The polarization values obtained for comet C/2012 L2 (LINEAR) is found to be almost uniform with the change of aperture which is pointing towards significant dust domination that overpowers the influence of gas.

It has been noticed that a change in the aperture polarization between the two dates is being observed with values typically ranging from (2.8±0.3) per cent to (1.9±0.2) per cent in the outer coma. This change may happen due to the variation in the jet activity, the possible gaseous contamination through the broadband red filter ($\Delta\lambda = 120$ nm) which results in depolarization and also due to the change in dust properties of the comet.
3.2.2. Polarization map

Polarization maps have been constructed with the four properly aligned polarized components for March 11 and 12, 2013 at R filter and is shown in Figure 3. The higher polarization of about 5% is noticed in the near nucleus region. The polarization is found to be uniform within the field of view of about 10,000 km near the photocenter on both nights of observation which shows the uniformity in the dust properties in the near nucleus region. The variation of polarization between 2% and 1% is observed in the outer coma of the comet. A strong jet is also noticed in the polarization map with a slight extension in the antisolar direction which shows higher polarization of 3–4% as compare to the surrounding coma on both the nights.

3.2.3. Polarization profile

The variation in the polarization profile with the photocentric distance for both the nights of observation is shown in Figure 4. A significant variation in the polarization profile is being observed in all possible directions for both the nights. The higher polarization is noticed in the inner coma of the comet. Polarization decreases gradually up to a certain distance with an increase in the photocentric distance (i) up to 12,000 km in the sunward direction and up to 15,000 km in the tailward direction on 11 March 2013 and (ii) up to 11,000 km in the sunward and up to 14,000 km in the tailward direction is being observed on 12 March 2013. The polarization value in the north-west and south-east direction is falling with the increase in the photocentric distance (i) up to 8000 km and 12,000 km respectively in the first night and (ii) 8000 km and 13,000 km respectively in the second night of observation. Polarization is found to vary in the outer coma of Comet C/2012 L2 (LINEAR) in all
Figure 3: Polarization maps (the levels are in %) at 31.1° phase angle at R- filter on (a) March 11, 2013 and (b) March 12, 2013. The ‘+’ mark denotes the photocenter of the comet. The white arrow shows the position angle of the Sun – Comet radius vector which is 67°.8 and 68°.1 on 11th and 12th March respectively. Scale: 60000km × 60000km.

directions for both the nights of observation. The variations are within the errors when the photocentric distance is within 30,000 km. But when this distance is greater than 30,000 km, the polarization value is being found to be higher in the tailward direction as compared to the sunward direction on the first night of observation whereas a completely opposite trend is being detected on the other date. The error in polarization is almost consistently lower in the inner coma of the comet in all possible directions as compared to the slightly higher value in the outer coma of the comet. The variation in the polarization profile indicates the non uniformity in the polarization distribution which is due to change in the dust intrinsic properties endures
in different apertures in all possible directions specially in the outer coma of the comet.

4. Discussion

The intensity profile of the Comet C/2012 L2 (LINEAR) yields some important results which show a significant variation in the intensity feature of the comet in all possible directions. The intensity varies slowly in the inner and outer coma of the Comet C/2012 L2 (LINEAR) in tailward direction as compare to the sunward direction where the intensity falls steeply in the outer coma on both the nights of observation. The variation in intensity is also being detected between the north-west and south-east direction. The deviation of the profile in all possible directions from the standard canonical nature is due to the ongoing different evolutionary processes which collectively effect
the light scattering properties of the dust grains. Temporal changes in the dust production is the primary reason for intensity variation. Sublimation of the ice or organic coated grains when they accelerated away from the nucleus due to the solar radiation pressure result in the shrinking of the grains which would also cause this variation (Tozzi et al. (2004), Farnham et al. (2009)).

The variation of slopes in all direction is a feature of the asymmetric coma strictly directed away from the Sun. The Comet C/2012 L2 (LINEAR) also shows a variation in the aperture polarization between the two dates with values typically ranging from (2.8±0.3) per cent to (1.9±0.2) per cent in the outer coma. This change is due to the variation in the jet activity, the possible gaseous contamination through the broadband red filter and also due to the change in dust properties of the comet (grain size, porosity, refractive indices). In the jet-like structures, the polarization is generally high while it is comparatively lower in the circumnucleus halo than in the surroundings (Renard et al. (1990), Tozzi et al. (1997), Hadamcik & Levasseur-Regourd (2003), Jones & Gehrz (2000)).

Many investigators studied variation of polarization with change of aperture size for some dusty and gaseous comets at lower phase angle. Rosenbush et al. (2002) studied the gaseous comet C/2001 A2 (LINEAR) which shows high positive polarization in the near nucleus region at 26°.5 and 36°.2 phase angle where dust concentration is very high but in the outer coma gas dominates which result in the steep fall in polarization value. The similar trend of strong radial dependence of polarization with increasing aperture size is also being observed for gaseous Comets C/1996 Q1 (Tabur) (Kiselev et al. (2001)) and 2P/Encke (Kiselev et al. (2004), Jewitt (2004)). It is also observed that
dusty comets do not show steep radial dependence of polarization with increasing aperture size (see, e.g., Manset & Bastien (2000). Kolokolova et al (2007) summarized published polarization data for different gas and dust rich comets and showed that they have a major difference in the polarization behavior with increasing the aperture size. Comet C/2012 L2 (LINEAR) does not show steep radial dependence of polarization on the aperture size at phase angle 31°. This is also observed in dusty comet C/2009 P1 (Garradd) at comparable phase angle (Das et al. (2013) and Hadamcik et al. (2013). Since no polarimetric observation has been reported so far for Comet C/2012 L2 (LINEAR) at larger phase angle, it is not possible to comment about the class of this comet at phase angle 31°.

Jet activity is a special feature of active comets which is prominently detected in both the rotational gradient treated image and in the polarization map of the Comet C/2012 L2 (LINEAR) with a variation in the direction of the extension between the two nights of observation. Jet shows high positive polarization values as compare to the whole coma polarization on both the nights. The high polarization usually found in the jets coming out from the nucleus is mainly due to the presence of small Rayleigh grains which are accelerated to higher speed from the surface of the nucleus by the gas drag due to their small cross-sectional area. The average polarization between 2.3% and 2.8% is being estimated throughout the apertures on March 11, 2013 whereas the insignificant variation in the aperture polarization between 2.4% and 1.9% is also being found in the inner and the outermost coma of the Comet C/2012 L2 (LINEAR) on March 12, 2013. Since the polarization is sensitive to the physical properties of the cometary grains so the nonuniform-
mity in the polarization distribution in all possible directions of the cometary coma explores the different grain population.

5. Conclusions

1. The integrated aperture polarization of the Comet C/2012 L2 (LINEAR) at phase angle 31° does not show steep radial dependence on the aperture size during both the nights of observation. Since no polarimetric observation has been reported for Comet C/2012 L2 (LINEAR) at higher phase angles, it is very difficult to comment about the class of the comet at this phase angle.

2. The variation in the intensity profile is observed in all considered directions of Comet C/2012 L2 (LINEAR) with a change in the slope between $-0.85$ and $-1.61$ throughout the coma. The variation in the intensity profile is mainly due to the solar radiation pressure which sorts the particles according to their cross-section and mass. Further, sublimation of the ice or organic coated grains may change the physical properties of the dust grains.

3. A prominent jet with a change in the direction of extension between the two nights is being detected in both the rotational gradient treated image and in the polarization map. The variation is most likely due to the rotation of the nucleus.

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