Astrometric and photometric observations of comet 29P/Schwassmann--Wachmann 1 at the Sanglokh international astronomical observatory

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A B S T R A C T

Astrometric and photometric observations of the comet 29P/Schwassmann-Wachmann 1 were performed at the Zeiss-1000 telescope of the International Astronomical Observatory Sanglokh (IAOS) of the Institute of Astro-physics, Academy of Sciences of the Republic of Tajikistan in July–August 2017. Although the comet has a short period of revolution it is regarded to be an object of the Centaurs group. Comet was exhibited a new activity this period which we used for analysis of its features. The coordinates of comet were determined and the orbit was calculated, the apparent and absolute magnitudes in BVRI bands were determined, as well the comet color indices and the estimation of nucleus diameter were obtained. From investigations of morphological features we iden-tified two dust structures in the coma.

Introduction

A new short-period comet was discovered at the Hamburg Observatory in Germany on 15 November 1927. In honor of the discoverers, it was named comet 29P/Schwassmann-Wachmann 1, hereinafter on text 29P. The revolution period of 29P around the Sun is 14.6 years and it has been observed since then. Alternatively, for 29P the Tisserand parameter relatively Jupiter is \( T_J = 2.984 \) (CNEOS, 2019). These facts allowed classifying 29P as a short-period comet. However, then a new class of small bodies was identified, called the Centaurs, which includes objects having both the perihelion distance \( q \) and the semi-major axis \( a \) of their orbits located between the orbits of Jupiter (at the heliocentric distance of 5.2 au) and Neptune (at the distance of 30 au). These objects are also characterized by chaotic orbits (Bailey and Malhotra, 2009). It turned out that the indicated parameters of the 29P orbit satisfy this condition, and therefore 29P was assigned to the group of Centaurs (Jewitt and Kalas, 1998). The orbital elements of 29P are arranged in 1, where \( a \) is the semi-major axis, \( e \) is the eccentricity, \( q \), \( Q \) are the perihelion and aphelion distances, \( i \) is the inclination, \( \omega \) is the argument of perihelion, \( \Omega \) is the longitude of perihelion (CNEOS, 2019).

The duality of 29P is caused by a very small eccentricity value, as a consequence of which it moves around the Sun in almost circular orbit unusual for comets. To present more than 45 such objects are known, being ice bodies and locating between the orbits of Jupiter and Neptune. The orbit of 29P is outside the Jupiter orbit located at the heliocentric distance of 5 au. Note, in the Solar system this distance is considered to be the formal boundary, so-called “snow line”, starting from which the temperature becomes low enough so that the solid phase of water and other volatile compounds is stable even under the solar radiation.

It is assumed that the Centaurs are objects transferred from the Kuiper belt to the inner region of the planetary system, where they are appearing as short-period comets during ground-based observations (Jewitt and Luu, 1993; Jewitt and Kalas, 1998; Levison and Duncan, 1997; Jewitt et al., 1998). So, scientifically, the Centaurs are interesting as nearest ones, i.e. brighter and more accessible samples of the Kuiper belt objects.

The physical properties of 29P found from ground-based observations also point to its duality. It is known that the geometric albedo value usually varies from 0.02 to 0.12 for cometary nuclei, the average value is 0.07 (Jewitt, 1991). The geometric albedo of 29P found from photometric measurements in the visible spectral range is \( p_V = 0.13 \) (Cruckshank and Brown, 1983), that is completely atypical for the cometary nucleus. However, this albedo value is typical for objects of the Centaur group (Barucci et al., 2004). There are various estimations of the albedo value of 29P ranging from 0.02 to 0.17 that were measured in different radiation ranges. In particular, for the geometric albedo of cometary nucleus a value of 0.033 adopted (CNEOS, 2019).
A large scatter in the estimates of the effective size of 29P nucleus is associated with this dispersion in the geometric albedo values, because an albedo is used to determine the radius. Radius estimates found using the photometric data by ground-based observations of 29P and assuming the geometric albedo of 0.04 lie in the range from 21 to 52 km (Cruikshank and Brown, 1983; Lamy et al., 2004; Meech et al., 1993). For the rotation period of 29P there are also several estimates from 10 h (Luu and Jewitt, 1993) to 14 h (Meech et al., 1993). By the observations of 29P from 2008 to 2009 the rotation period of 11.7–12.1 h was obtained (Ivanova et al., 2012). The total absolute magnitude of 29P is $M_1 = 6.0 \text{m}$ and diameter is $d = 60.4 \text{km}$ (CNEOS, 2019).

Since a discovery, 29P has become known for numerous outbursts, i.e. a sudden strong increase in brightness when the comet’s magnitude in-creases by 2–5$^\text{m}$ (Whipple, 1980; Sekanina, 1982; Wyckoff, 1982; Ivanova et al., 2009, 2016). As a result of a continuous monitoring during 2002–2007 28 outbursts of 29P (an average of 7.3 outbursts per year) were registered, moreover, it was shown that there is no clear periodicity in the appearance of outbursts, which confirms the unpredictability of the activity of this comet (Trigo-Rodriguez et al., 2008). However, Miles et al. (2016) found some periodicity in the outbursts in long term monitoring of 29P. Outbursts of short-period comets are usually associated with a splitting of their nuclei, but this process is once and not long (Boehnhardt, 2004). Outbursts can also occur when comets pass perihelion near the Sun. However, the orbit of 29P locates quite far from the Sun so that the surface temperature of its nucleus is certainly below the sublimation temperature of water ice. Therefore, other physical processes very likely should cause the appearance of 29P outbursts.

According to Froeschle et al. (1983) outbursts of brightness may be associated with a crystallization of amorphous ice on the nucleus surface. Later this suggestion was strongly supported by the detection of CO gas emissions due to its release from amorphous ice (Senay and Jewitt, 1994). Additionally it was shown by Trigo-Rodriguez et al. (2008) that the outbursts are due to an increase of the gas-producing activity of 29P, and first of all, an increase in the generation of neutral CO gas. While as shown by Ivanova et al. (2016) the amount of gases released during the exothermic phase of a transition of water ices from amorphous to the crystalline state, is insufficient to form the observed outburst activity of 29P. Therefore, the reliable reasons for the activity of 29P are still not fully defined.

Only a small number of comets from the Centaurs group have been studied, so it is very important to develop a complex investigation of such objects. Since a source of the Centaurs is the Kuiper belt, it is of particular interest to study the composition of the ices of their nuclei and its comparison with the composition of the nuclei of long-period comets originating from the Oort cloud. As already noted the mechanisms responsible for the occurrence of cometary activity at remote heliocentric distances have not yet been established.

**Observations, data processing and results**

29P once again showed activity in 2017 and became available for observation. The astrometric and photometric observations of 29P were carried out at the Zeiss-1000 telescope of the International Astronomical Observatory Sanglok (IAOS) of the Institute of Astrophysics, Academy of Sciences, Republic of Tajikistan on 28 July - 1 August 2017. The telescope is equipped with a FLI Proline PL16803 CCD camera; the focal distance of the telescope (the Cassegrainian focus) is $F = 13.3 \text{m}$, and the scale of the image is 63 $\mu\text{m}$/arcsec. The sensor is arranged as a nominally

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**Table 1**

| Epoch    | $a$ (au) | $e$   | $q$ (au) | $Q$ (au) | $i$ (deg.) | $u$ (deg.) | $\Omega$ (deg.) |
|----------|----------|-------|---------|----------|------------|------------|-----------------|
| January 19, 2010 | 5.990 | 0.045 | 5.720 | 6.260 | 9.391 | 49.049 | 312.632 |

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**Table 2**

| Date, UT | $r$ (au) | $\Delta$ (au) | $PA$ (deg.) | $ph$ (deg.) | $N_x$ Band | $t$ (s) |
|----------|----------|---------------|-------------|-------------|----------|-------|
| 28.84, 2017 | 5.828 | 4.842 | 67.6 | 2.583 | 10 × V, 20 × R, 10 × 11 | 60 |
| 29.88, 2017 | 5.828 | 4.838 | 67.2 | 2.403 | 8 × V, 11 × R, 11 × 11 | 60 |
| 30.77, 2017 | 5.828 | 4.834 | 66.8 | 2.223 | 30 × B, 33 × V, 30 × 11 | 60 |
| 31.85, 2017 | 5.828 | 4.831 | 66.2 | 2.042 | 40 × B, 40 × V, 40 × 11 | 60 |
| 01.76, 2017 | 5.828 | 4.828 | 65.7 | 1.860 | 20 × B, 20 × V, 20 × 11 | 60 |

![Fig. 1. Resultant image of 29P in R band obtained at Zeiss-1000 telescope on July 30, 2017, exposure 1800 s.](image-url)
the outbursts of an object and thus can be considered as one of possible mechanisms that generated these outbursts. To determine the orbital parameters of 29P the astrometric measurements were included into observations. The astrometric reduction of the IAOS observations was performed using the APEKS-II software package developed at the Pulkovo Observatory (Deyvatkin et al., 2010). The package calibrates the exposures, distinguishes the images of the stars and the objects, and the image distortions produced by the optical system for orbit calculation, the mean-square errors \( \sigma_1 \) and \( \sigma_2 \) are taken into account with the six- and eight-constant methods respectively. The mean values of the apparent magnitudes of the object in the frames, the reference stars with the brightness corresponding to the standard stars (for the APASS catalog, the error for the standard stars \( \sigma_1 \)) is roughly 0.07". To measure the positions of the comet nucleus according to the following empirical formula (Snodgrass et al., 2006)

\[
m_a(1.1, 0) = m_a - 5\log(r\Delta) - \beta(\text{ph})
\]  

(1)

where \( m_a(1.1, 0) \) (or \( H \)) is the brightness of hypothetic point at unitary heliocentric and geocentric distances with the phase angle \( \text{ph} = 0 \) deg., \( m_a \) is the measured magnitude, \( r \) and \( \Delta \) are the helio- and geocentric distances of comet in au, \( \beta \) is the phase

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**Table 3**

| Date       | \((O - C)_1\) | \(\sigma_1\) | \((O - C)_1\) | \(\sigma_1\) |
|------------|---------------|---------------|---------------|---------------|
| 28.84, 2017| -0.023        | 0.18          | 0.073         | 0.038         |
| 29.88, 2017| -0.062        | 0.026         | 0.071         | 0.015         |
| 30.77, 2017| -0.063        | 0.25          | 0.086         | 0.019         |
| 31.85, 2017| -0.080        | 0.044         | 0.093         | 0.034         |
| 01.76, 2017| -0.056        | 0.016         | 0.035         | 0.019         |

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**Table 4**

Comparison of the initial orbit of 29P obtained from the Sanglokh observations to the MPC orbit \( (J2000.0) \).

| Orbital elements | SIAO (this work) | MPEC 2016-V116 | \( \Delta \) |
|------------------|------------------|----------------|-------------|
| Number of positions used for orbit calculation | 300 | 20553 | – |
| T (JD) | 2458564.1256 | 2458567.2912 | – |
| Epoch (JD) | 2457820.5 | 2457600.5 | – |
| \( e \) | 0.0417716 | 0.0416442 | 0.0001274 |
| \( q \) (AU) | 6.91622181 | 6.0151515 | 0.00107031 |
| \( q \) (AU) | 5.76491423 | 5.7646555 | 0.00025873 |
| \( i \) (deg.) | 9.37444 | 9.37658 | 0.00214 |
| \( \omega \) (deg.) | 48.75893 | 48.98332 | –0.22439 |
| \( \Omega \) (deg.) | 312.40993 | 312.40297 | 0.00666 |
| \( n \) (deg./day) | 0.06679105 | 0.06680885 | –0.0000178 |
| \( \sigma \) (arcsec) | 0.288 | 0.606 | – |

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Fig. 2. The apparent trajectory of 29P derived from observation data at the Sanglokh observatory during July 28-August 1, 2017.
The phase coefficient \( \beta = 0.035 \) mag/deg. was used (Lamy et al., 2004). The absolute brightness of 29P in the BVRI bands (the averages for one night) found in such a way are listed in Table 6, the light curves are presented in Fig. 4. As seen, the absolute magnitude of comet was practically permanent during monitoring.

The mean values of the color indices of 29P according to our observations as well as of other objects of the Solar System, like active Jupiter family comets [JFC] (Solontoi et al., 2012), active long-period comets [LPC] (Jewitt, 2015), Kuiper belt objects [KBO] (Tegler, 2015), active and inactive Centaurs [Centaurs] (Jewitt, 2015), and the Sun [Sun] (Holmberg et al., 2006) are listed in Table 7. As seen, the color indices of

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**Table 5**
The apparent brightness of 29P according to the Sanglokh observations in 2017.

| Bands | July 28, 2017 | July 29, 2017 | July 30, 2017 | July 31, 2017 | August 01, 2017 |
|-------|--------------|--------------|--------------|--------------|----------------|
| B     | 16.88 ± 0.04 | 16.91 ± 0.05 | 17.78 ± 0.05 | 17.77 ± 0.02 | 17.75 ± 0.04   |
| V     | 16.29 ± 0.04 | 16.41 ± 0.04 | 16.45 ± 0.05 | 16.50 ± 0.04 | 16.33 ± 0.04   |
| R     | 15.69 ± 0.03 | 15.83 ± 0.05 | 15.92 ± 0.05 | 16.05 ± 0.02 | 15.82 ± 0.04   |

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**Table 6**
The light curves of 29P in the BVRI bands according to the Sanglokh observations on 28 July-1 August 2017.
The surface of the nucleus (Trigo-Rodriguez et al., 2008). The systematic
that coma of 29P is continuously replenished with
space telescope which recorded dust jets of 29P while a lack of comet

29P determined by the IASOS monitoring are relevant to the mean color
indices of the active objects of the Centaurs group and Kuiper belt objects.
Color indices indicate a shift of the radiation maximum to the red
part of the spectrum, which implies the dominant contribution of dust
particles into the formation of coma. According to observations of the
cometary activity during the period 2002-2007 it was also concluded
that coma of 29P is continuously replenished with fine dust released from
the surface of the nucleus (Trigo-Rodriguez et al., 2008). The systematic
nature of this process is also confirmed by observations of the Spitzer
space telescope which recorded dust jets of 29P while a lack of comet
outbursts (Stansberry et al., 2004).
To estimate the size of 29P nucleus, we used the following empirical
expression between the apparent magnitude measured in the V band $m_V$
and the effective radius of cometary nucleus $r_N$ (expressed in meters)
(Russell, 1916)

$$A r_N = 2.238 \times 10^{22} R_s^2 \Delta I \cdot 10^2 \cdot (m_V - m_V + 50),$$

(2)

where $R_s$ is heliocentric distance in au. Once the absolute magnitude in
the V band $m_V(1.1, 0)$ was found then the radius can be calculated by a
simplified version of equation (2):

$$A r_N = 2.238 \times 10^{22} \cdot (R_s^2 \cdot (m_V - m_V + 50)$$

(3)

where $A$ is the geometric albedo and $m_V = -26.75$ is the apparent
magnitude of the Sun, both values are given in the V band. Since the
exact albedo value of 29P is not known we adopt the interval $0.13 > A > 0.03$ in our calculations for the nucleus size. The estimates of the
cometary nucleus diameter according to our absolute brightness
measurements $m_V$ in the V filter are presented in Table 8. Note we
presented the upper limit of effective diameter of 29P computed under
the assumption of two values of the geometric albedo. Actually, the size
estimation strongly depends on the geometric albedo and phase function
which are unknown for 29P.
As it was noted, when the geometric albedo value is assumed to
be 0.04 the estimate of the nucleus radius lies in the range from 21 to 52 km.
According to Cruikshank and Brown (1983) the nucleus radius is esti-
mated as 20 km when the geometric albedo value of 0.13. The estimates
of diameter obtained by our measurements range from 43.3 to 45.7 km
for $A = 0.13$, and 86.7–91.4 km when $A = 0.033$ and is quite consistent to
available data. To clarify the albedo and the size of the nucleus, more
observations of 29P are necessary.

**Morphology**
As was mentioned above, 29P presents outburst activity with big
numbers of structures in cometary coma (Berman and Whipple, 1928a, b;
Trigo-Rodriguez et al., 2010; Ivanova et al., 2016; Miles et al., 2016;
Picazzo et al., 2019). For our data obtained with R and I filters we used an
enhancement technique to segregate low-contrast structures in cometary
coma. Before applying the filtering, images were cleaned from
field stars around the cometary nucleus and coma. As a digital filter, we
used the Larson-Sekanina algorithm (Larson and Sekanina, 1984). Fig. 5
shows direct and processed images using digital filter. We applied the
digital filters to all individual exposures of the comet as well as to the
same composite image to help in evaluating whether revealed features

| Bands | July 28, 2017 | July 29, 2017 | July 30, 2017 | July 31, 2017 | August 01, 2017 |
|-------|--------------|--------------|--------------|--------------|----------------|
| $B$   | –            | –            | 10.45±0.05   | 10.45±0.02   | 10.45±0.02     |
| $V$   | 9.54±0.04    | 9.57±0.05    | 9.60±0.05    | 9.65±0.03    | 9.61±0.04      |
| $R$   | 8.95±0.04    | 9.07±0.04    | 9.13±0.04    | 9.18±0.04    | 9.01±0.02      |
| $I$   | 8.19±0.03    | 8.50±0.04    | 8.59±0.04    | 8.73±0.02    | 8.51±0.04      |

Fig. 4. The absolute magnitude $H$ (mean values per night) of 29P in BVRI bands
by the Sanglokh observations during 28 July-1 August 2017.

| Index | 28.07 | 29.07 | 30.07 | 31.07 | 01.08 | JFC | LPC | KBOs | active | inact. | Sun |
|-------|-------|-------|-------|-------|------|-----|-----|------|--------|-------|-----|
| Color | 29P in 2017 (this work) | | | | | | | | | | |
| $B$   | –     | –     | 0.85  | 0.80  | 0.84 | 0.75 | 0.78 | 0.92 | 0.80   | 0.93  | 0.64 |
| $V$   | 0.59  | 0.50  | 0.47  | 0.47  | 0.60 | 0.47 | 0.47 | 0.57 | 0.50   | 0.55  | 0.35 |
| $R$   | 0.76  | 0.57  | 0.54  | 0.45  | 0.50 | 0.43 | 0.42 | –   | 0.57   | 0.45  | 0.33 |
| $B-R$ | –     | –     | 1.32  | 1.27  | 1.44 | 1.22 | 1.24 | 1.49 | 1.30   | 1.47  | 0.99 |

Table 7
The mean color indices of 29P and other objects of the Solar System.

| Date     | $r$ (AU) | $\Delta$ (AU) | $\Delta$ (deg.) | $m_V$ (mag.) | $m_V(1.1, 0)$ (mag.) | $D$ (km) $A = 0.13$ | $D$ (km) $A = 0.033$ |
|----------|----------|---------------|-----------------|--------------|----------------------|---------------------|---------------------|
| 28.84, 2017 | 5.828    | 4.842         | 2.583           | 16.88±0.04   | 9.54±0.04            | 45.87±0.08          | 91.05±0.08          |
| 29.88, 2017 | 5.828    | 4.838         | 2.403           | 16.91±0.05   | 9.57±0.05            | 45.08±0.08          | 89.47±0.08          |
| 30.77, 2017 | 5.828    | 4.834         | 2.223           | 16.92±0.05   | 9.60±0.05            | 44.55±0.08          | 86.38±0.08          |
| 31.85, 2017 | 5.828    | 4.831         | 2.042           | 16.97±0.04   | 9.65±0.03            | 43.52±0.08          | 86.39±0.08          |
| 01.76, 2017 | 5.828    | 4.828         | 1.860           | 16.92±0.04   | 9.61±0.04            | 44.27±0.08          | 87.86±0.08          |

Table 8
Estimates of the size of the comet 29P nucleus by the IASOS observations.
Fig. 5. Images of comet 29P in the R and I filters obtained from July 28 to August 1, 2017. Frames a, c, e, g, i and A, C, E, G, I show the direct images of 29P in relative intensity in R and I filters, respectively. Frames b, d, f, h, j and B, D, F, H, J represent intensity images to which was applied the Larson-Sekanina algorithm (Larson and Sekanina, 1984; Samarasinha and Larson, 2014). North (N), East (E), sunward (☉), and velocity vector (V) directions are indicated on each direct frame.
are real or not. As it is seen in the figures, the cometary coma is more condensed in R filter than I filter. The bright coma is 5000 km across, although an elongation of the coma is visible in the north direction. After processing of images with digital filter, 29P exhibits two dust structures, which can be seen across the images at sunward and anti-sunward directions.

Conclusions

The astrometric and photometric observations of comet 29P carried out at the Sangokho observatory in 2017 yielded the following results:

1. The equatorial coordinates, geocentric trajectory and orbit of comet were determined.
2. The apparent magnitudes of comet in BVRI filters were obtained and the light curves were plotted.
3. The absolute brightness of comet in BVRI filters was determined. During the observational period the light curves showed no noticeable oscillations in the absolute brightness within the error measurements. The mean value of the absolute brightness of comet in the V and R filters was $9.60 \pm 0.04^m$ and $9.10 \pm 0.04^m$, respectively.
4. The color indices agree well with the currently available mean values for active objects of the Centaurs group asteroids. They point to the dominant contribution of the dust component into the coma which is redder in reflectance.
5. The estimates of the nucleus diameter by our observations are matching to available published estimations.
6. For our data obtained with R and I filters we used an enhancement technique to segregate low-contrast structures in cometary coma. It is shown that the cometary coma is more condensed in R filter than I filter; comet exhibits two dust structures at sunward and anti-sunward directions.

Declaration of competing interest

The authors declare that they have no conflicts of interest.

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