DISCOVERY AND STUDY OF COMET 67P/CHURYUMOV–GERASIMENKO, THE MAIN TARGET OF THE ROSETTA SPACE MISSION

K. Churyumov

Astronomical Observatory, National Taras Shevchenko University of Kyiv
3 Observatorna Str., 04053 Kyiv, Ukraine
e-mail: klim.churyumov@observ.univ.kiev.ua

Rosetta, a European space vehicle, which was 15 years in development, headed for short-period Comet 67P/Churyumov–Gerasimenko in February 2004. In September 1969 S. Gerasimenko and the author went to the Alma-Ata Astrophysical Institute to carry out a survey of short-period and new comets. At a later date of that month, the author examined the exposure of Comet 32P/Comas Sola made on September 11.92 UT, 1969 and found a cometary object near the plate centre. The author assumed it to be the expected short-period Comet 32P/Comas Sola. Later explorations at the Kyiv University revealed that this comet's position differed from predicted calculations for Comet 32P by 1.8°. It was a new comet. The comet had an apparent magnitude of 13 and the faint tail about 1 arcmin in length at a position angle of 280°. On the basis of the observations of Comet 67P obtained in Nizhny Arkhyz with the help of the 6-m BTA reflector of the SAO RAS, some physical parameters of the cometary plasma tail (coefficients of diffusion $D_{||}$, $D_{\perp}$ and induction of magnetic field B) were determined (Jan. 12.105 UT, 1983: $D_{||} = (5.07 \cdot 10^{14} - 1.21 \cdot 10^{15})$ cm^2/s, $D_{\perp} = (5.73 \cdot 10^{13} - 1.37 \cdot 10^{14})$ cm^2/s, $B = (46 - 111)$ nT; Jan. 13.124 UT, 1983: $D_{||} = (4.67 \cdot 10^{14} - 1.14 \cdot 10^{15})$ cm^2/s, $D_{\perp} = (4.30 \cdot 10^{13} - 1.05 \cdot 10^{14})$ cm^2/s, $B = (55 - 134)$ nT). The author hope that the Rosetta space mission will obtain valuable data for solving the fundamental scientific problem on the origin and evolution history of the Solar System.

DISCOVERY AND THE FIRST OBSERVATIONS OF COMET 67P/CHURYUMOV–GERASIMENKO IN 1969–1970

During August and September 1969 the author took part in the third Kyiv University astronomical expedition to the Alma-Ata Astrophysical Institute [3] together with Svetlana Gerasimenko, a post-graduate student, and Lyudmila Chirkova, a laboratory assistant. The purpose of the expedition was to carry out visual and photographic searches for new comets in the morning and evening Everhart (1967) zones and also to make photographic observations of the well-known short-period comets 4P/Faye (1969 VI), 32P/Comas Sola (1969 VIII), 45P/Honda–Mrkos–Pajdusakova (1969 V), and two new comets Kohoutek (C/1969 O1-A = 1969b) and Fujikawa (C/1969 P1 = 1969 VIII). The observations were made with the 50-cm $F/2.4$ Maksutov telescope and 17-cm $F/1$ Schmidt camera. Altogether, we took about 100 plates suitable for integral photometry and the determination of accurate positions of the above-mentioned comets.

Still in Alma-Ata, I noted on September 20 a cometary object with a magnitude of 13 on the plate derived on September 11 for 32P/Comas Sola. In Kyiv, on October 22, the author together with Svetlana Gerasimenko found that the object position differed from the position of 32P/Comas Sola given in ephemeris by 1.8°. Then we saw 32P/Comas Sola close to its ephemeris position, suggesting that the object we had noted was a new comet. Examination of other plates for 32P/Comas Sola – two on September 9 (Fig. 1) and two on September 21 – immediately revealed a new object, and although it was near the edge, it still had a cometary appearance and showed a motion among stars. Professor Sergey Vsekhsvyatskij cabled the news concerning our discovery to the IAU Central Bureau for Astronomical Telegrams. The comet discovered was given the preliminary designation 1969h, and later the final designation C/1969 R1. At present, it has the constant designation 67P in the Catalogue of cometary orbits [6].

On the basis of the first accurate positions reduced by N. A. Shmakova (Leningrad) from our measurements Brian Marsden [4, 5] calculated six ephemerides from two parabolic and four elliptic orbits. On October 31, 1969

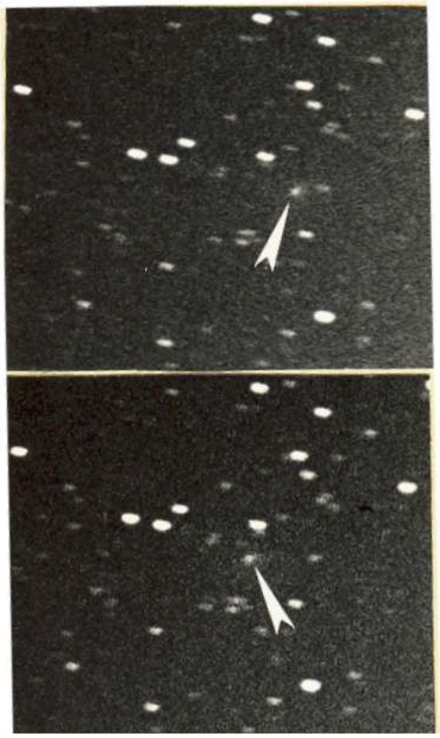

Figure 1. The first couple of images of Comet 67P/Churyumov–Gerasimenko on September 21, 1969

the comet was photographed by Scovil (USA). That observation, and then observations made by T. Seki (Japan), E. Roemer (USA), and B. Milet (France), closely confirmed one of elliptic orbits. Thus, the object discovered proved to be one of members of Jupiter's family of short-period comets. Later, improved elements of the elliptic orbit of Comet C/1969 R1 for study its evolution were calculated by N. Belyaev and K. Churyumov [1]. Table 1 gives results of exploration of the cometary orbit evolution during the time interval T from 1800 to 2000 [2] and presents the following information: standard dates and moments of encounter of the comet with Jupiter, T_c, Jovian distance, Δ_{min}, longitude of perihelion, π, longitude of assending node, Ω, inclination of orbit, i, eccentricity, e, perihelion distance, q, period of revolution around the Sun, P. One can see from Table 1 that the comet has an interesting unusual history of its orbital motion. Up to 1840 its perihelion distance was 2.2 AU and then the comet was no longer observable from the Earth. That year there was an encounter with Jupiter to 0.29 AU, and the orbit shifted outwards to a perihelion distance of 2.9 AU. From there, it slowly decreased further to 2.75 AU, from which, in 1959, a close Jupiter encounter (to 0.052 AU) moved the comet into orbit with perihelion at just 1.28 AU. The fact that the comet had a close encounter with Jupiter in 1959 [2] is very important because it was not until this encounter that Comet 67P could be discovered in 1969 with the help of ground-based telescopes.

The most remarkable peculiarities of orbital evolution of Comet 67P is the very close encounter of the comet with Jupiter on February 4.3, 1959 which was characterized by $\Delta_{min} = 0.052$ AU. Thanks to this encounter, all the orbital elements were essentially changed and the comet was discovered after 1.5 revolution after this encounter.

From nine plates we determined the absolute integral magnitude, H_y, and the photometric parameters, n. Parameters H_y and n were found by the least-squares method to be: $H_y = 11.91 \pm 0.54$, $n = 4.0 \pm 0.8$.

Large residuals point to a high activity of the comet.

The comet was seen in 1969/70, 1976, 1982/83, 1989, 1996, and 2002/2003. It is unusually active as for a short-period object and has a coma and often tail even at perihelion, which are a result of a significant decrease in perihelion distance. During the 2002/2003 apparition the tail was as long as ten arcminutes, with a stellar central condensation in a faint extended coma. Even seven months after perihelion, the tail continues to be very well developed.

Table 1. Evolution of the orbit of Comet 67P/Churyumov–Gerasimenko during 1800–2000

T_c	Δ_{min}, AU	π	Ω	i	e	q, AU	Q, AU	P, yr
1800 Jan. 25		77°	57°	25°	0.43	2.21	5.49	7.56
1817 Mar. 10	1.48							
1825 June 23		77	57	25	0.41	2.29	5.53	7.74
1840 Sept. 17	0.29							
1850 Aug. 31		88	55	24	0.35	2.81	5.82	8.97
1875 Apr. 22		88	55	24	0.35	2.80	5.85	8.99
1876 May 17	1.09							
1900 Apr. 11		90	54	23	0.34	2.93	5.94	9.35
1923 Oct. 9	0.96							
1925 Sept. 7		85	53	23	0.37	2.72	5.89	8.92
1928 Apr. 27	1.86							
1950 Nov. 15		84	52	23	0.36	2.75	5.90	9.01
1959 Feb. 4.3	0.052							
1969 Sept. 16		62	50	7	0.63	1.28	5.72	6.55
1975 July 7		62	50	7	0.63	1.30	5.73	6.59
2000 Jan. 17		62	50	7	0.63	1.29	5.73	6.58

INVESTIGATION OF PLASMA TAIL OF COMET 67P/CHURYUMOV–GERASIMENKO (1982 VIII)

Original plates with images of Comet 67P/Churyumov–Gerasimenko were obtained by I. D. Karachentsev and K. I. Churyumov on January 12.105 UT and 13.124 UT, 1983 with the 6-m telescope BTA of the Special Astrophysical Observatory of the Russian Academy of Sciences (SAO RAS) at Mount Pastukhov. These plates are the first observations of a comet with one of the most powerful ground-based telescopes. The BTA is located at the gorge of Seven Brooks at a height of 2070 m. The diameter of its main mirror is 6.05 m and its focal distance is 24 m. A Ritchy cassette with a corrector and field lens was used. The pictures of Comet 67P/Churyumov–Gerasimenko are derived on emulsion Kodak IIaO with hypersensitivity in H_2.

Figure 2. The image of Comet 67P/Churyumov–Gerasimenko on January 13, 1982

For quantitative estimation of some physical parameters of the plasma tail of the comet, the diffusion model [7, 8] was used. The magnetic induction was estimated with the use of the formula derived by Natalia Shabas [9]:

$$B = 2 \cdot 10^{11} \frac{T}{D_{||}} L_{||} / (L_{\perp} \cos\beta)[nT], \tag{1}$$

where $D_{||}$ and $D_{\perp}$are the coefficients of longitudinal and transversal diffusion, respectively; $L_{||}$ and $L_{\perp}$ are the longitudinal and the transversal characteristic scales, β is the angle between the tail axis and its projection onto the plane of the sky.

Here, the longitudinal $L_{||}$ and transversal $L_{\perp}$ scales are chosen as follows:

$$L_{||} = 2\sqrt{D^{*}_{||}\tau}, \quad L_{\perp} = 2\sqrt{D_{\perp}\tau}, \tag{2}$$

where τ is the average lifetime of glowing particles.

The temperature of the cometary plasma was assumed to be $5 \cdot 10^5$ K and $2 \cdot 10^6$ K for the minimum and maximum estimates of the magnetic induction, respectively [10],

$$T = 5 \cdot 10^{-12} B D_{//} \sqrt{\frac{D_{\perp}}{D_{||}}} [\mathrm{K}]. \tag{3}$$

In our case, these temperatures of the cometary plasma give $B_1 \approx (46 - 111)$ nT and $B_2 \approx (55 - 134)$ nT.

The obtained estimates of the magnetic field induction, $B \cong 111$ nT for January 12, 1983 and $B \cong 134$ nT for January 13, 1983, probably exceed real values of B in the cometary plasma tail. However, a good agreement between the theoretical and observed data seems to be proof of the plasma nature of the comet tail in question. Moreover, the comet tail looks rather narrow and straight without a noticeable expansion that may be a proof of a high magnetic field that keeps the cometary plasma in a narrow cylinder. The tail shape that practically did not change during the day makes it more probable to consider this tail as a strongly magnetized plasma jet.

The author believes that this peculiarity of magnetic fields in plasma tail of Comet 67P is closely connected with magnetic properties of the surface layers of the cometary nucleus. I hope that this problem will be successfully solved with the help of the device ROMAP installed aboard the Rosetta Lander when it will land on the Comet 67P nucleus in 2014.

CONCLUSION

Short-period Comet 67P was discovered on October 22, 1969 with the use of five plates obtained by Klim Churyumov and Svetlana Gerasimenko on September 9, 11, and 21, 1969 with the 50-cm $F/2.4$ Maksutov telescope in Alma-Ata. Some physical parameters of the comet plasma tail (coefficients of diffusion $D_{||}$, $D_{\perp}$ and induction of magnetic field B) were determined (January 12.105 UT, 1983: $D_{||} = (5.07 \cdot 10^{14} - 1.21 \cdot 10^{15})$ cm^2/s, $D_{\perp} = (5.73 \cdot 10^{13} - 1.37 \cdot 10^{14})$ cm^2/s, $B = (46 - 111)$ nT; January 13.124 UT, 1983: $D_{||} = (4.67 \cdot 10^{14} - 1.14 \cdot 10^{15})$ cm^2/s, $D_{\perp} = (4.30 \cdot 10^{13} - 1.05 \cdot 10^{14})$ cm^2/s, $B = (55 - 134)$ nT).

Acknowledgements. The work was partially supported by the Fundamental Research State Fund of the Ministry of Ukraine for Education and Science (grant 2002).

[1] *Belyaev N. A., Churyumov K. I.* Unit of three apparitions of periodic Comet Churyumov–Gerasimenko // Kyiv Kometnyj Tsirkuliar.–1982.–N 296.–P. 2.

[2] *Belyaev N. A., Churyumov K. I.* Evolution of orbit of short-period Comet Churyumov–Gerasimenko // Kyiv Kometnyj Tsirkuliar.–1982.–N 296.–P. 3.

[3] *Churyumov K. I., Gerasimenko S. I.* Physical observations of the short-period comet 1969 IV // The motion, evolution of orbits, and origin of comets: Proc. of Symposium 45 of the IAU / Eds G. A. Chebotarev *et al.*.–1972.–P. 27–34.

[4] *Marsden B. G.* // IAU Circ.–1969.–**2181**.–P. 1.

[5] *Marsden B. G.* // IAU Circ.–1969.–**2187**.–P. 1.

[6] *Marsden B. G., Williams G. V.* Catalogue of cometary orbits, 1999.–13th ed.–127 p.

[7] *Nazarchuk G. K., Shulman L. M.* Diffusion model of cometary tails // Problemy Kosmicheskoy Fiziki.–1968.–N 3.–P. 34–39.

[8] *Nazarchuk G. K.* Analysis of surface-brightness distribution in the tail of comet 1956h // Astrometriya and Astrophysica.–1969.–N 9.–P. 77–99.

[9] *Shabas N. L.* Physical parameters of the plasma tail of Comet 67P/Churyumov–Gerasimenko // Visnyk of Kyiv Univ. Ser. Astronomy.–1999.–N 35.–P. 80–83.

[10] *Wegmann R., Schmidt H. U., Hubner W. F., et al.* Cometary MHD and Chemistry // Astron. and Astrophys.–1987.–**187**.–P. 339–350.