Study of the magnetic field in the plasma tails of comet 67P/Churyumov-Gerasimenko, main target of the Rosetta mission

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JENAM-2004, Granada, Spain

September 15, 2004
The Rosetta mission to comet 67P/Churyumov-Gerasimenko
On March 2, 2004 Rosetta space mission successfully started from the Kourou cosmodrom to comet 67P/Churyumov-Gerasimenko. Upon entering orbit around the nucleus observations will be made as the comet becomes more active as it journeys towards the Sun. A lander, named Philae, will be deployed and attempt to make the first ever controlled landing on a comet. On its 10 year journey Rosetta will fly-by two asteroids – 2867 Steins in Sept. 2008 and 21 Lutethia in July 2010. Rosetta will be the first spacecraft to orbit a comet's nucleus. It will be the first spacecraft to fly alongside a comet as it heads towards the inner Solar System. Rosetta will be the first spacecraft to examine from close proximity how a frozen comet is transformed by the warmth of the Sun. Shortly after its arrival at Comet 67P/Churyumov-Gerasimenko, the Rosetta orbiter will despatch a robotic lander for the first controlled touchdown on a comet nucleus. The Rosetta lander's instruments will obtain the first images from a comet's surface and make the first in situ analysis of the relict matter of the Solar system.
Launch of Ariane with Rosetta 2 March 2004
Cosmodrome Courou. S.I. Gerasimenko, Jean-Jack Dordan (general director of ESA) and K.I. Churyumov: Rosetta flies!
Discovery of comet 67P/Churyumov-Gerasimenko
During August and September 1969 we (chief of the expedition K.I.Churyumov, post graduated student S. I. Gerasimenko and laboratory assistant L.M. Chirkova) took part in the third Kyiv University astronomical expedition to the Alma-Ata Astrophysical Institute (Churyumov and Gerasimenko, 1972). The purpose of the expedition was to carry out visual and photographic searches for new comets in the morning and evening sky zones and also to make photographic observations of the well-known short-period comets 4P/Faye (1969 VI), 32P/Comas Sola (1969 VIII), 45/PHonda-Mrkos-Pajdusakova (1969 V) and the two new comets Kohoutek (C/1969 O1-A =1969b) and Fujikawa (C/1969 P1 = 1969 VIII).
The observations were made with a 50-cm $f/2.4$ Maksutov telescope and a 17-cm $f/1$ Schmidt camera. Altogether we took about 100 plates suitable for integral photometry and the determination of exact positions of the above-mentioned comets.
The Volodymyr kathedral church
Kyiv Shevchenko National University
Still in Alma-Ata, we noted on September 20 a cometary object of magnitude 13 on a plate taken September 11 for 32P/Comas Sola. Back in Kyiv on October 22 we together Svetlana Gerasimenko found that the object was 1.°8 from the position of 32P/Comas Sola given in the ephemeris. Then we saw P/Comas Sola close to its ephemeris position, suggesting that the object we had noted was a new comet.
Examination of other plates for P/Comas Sola - two on September 9 and two on September 21 - immediately revealed the new object, and although it was near the edge, it still had its cometary appearance and showed motion among the stars. Professor Sergey Vsekhsvyatskij cabled news of our discovery to the IAU Central Bureau for Astronomical Telegrams. The new comet was given the preliminary designation 1969h, and later the final designation C/1969 R1. Now it has constant designation 67P in the Catalogue of cometary orbits of Marsden and Williams, 1999.
Discovery of Comet 67P/Churyumov-Gerasimenko

September 11.92010 UT, 1969. The plate, which helped us to discover comet 67P/Churyumov-Gerasimenko
Discovery of comet 67P/Churyumov-Gerasimenko

First two images of comet 67P
Sept. 9, 1969
Discovery of Comet 67P/Churyumov-Gerasimenko

September 21.92752 UT, 1969

September 21.94795 UT, 1969
Exploration of comet 67P/Churyumov-Gerasimenko
On the basis of the first exact positions, reduced by N. A. Shmakova (Leningrad) from our measurements, Brian Marsden (Marsden, 1969) calculated six ephemerides from two parabolic and four elliptical orbits. On October 31, 1969 the new comet was photographed by Scovil (U.S.A.). This observation, and then observations by T. Seki (Japan), E. Roemer (U.S.A.), and B. Milet (France), closely confirmed one of the elliptical orbits. Thus the new comet proved to be one of members of the Jupiter family of short-period comets. Later elements of the elliptical orbit of comet C/1969 R1 are as follows (Belyaev, Churyumov):
The orbital elements of comet 67P/Churyumov-Gerasimenko in 1969
T=1969 Sept. 11.03770 ET Epoch=1969 сент. 16.0 ET
ω=11.20017°
Ω= 50.35917° }1950.0
i=7.14565°
e=0.633018
a=3.501454 A.U.
н°=0.150428986
P=6.552 y.
The comet has been seen also in 1976, 1982/83, 1989, 1996 and 2002/2003 apparitions.

The comet experienced a very favorable appearance during 1982, with the closest distance from the sun occurring on November 12 (1.3062 AU) and the closest distance to Earth (0.3910 AU) occurring on November 27. Interestingly, the comet continued to brighten throughout December as it headed away from both the sun and Earth, with amateur astronomers finding total magnitudes of 9 to 9.5. Around Christmas, Alan Hale (California) was even able to detect the comet with 10x50 binoculars.

The comet's 1989 appearance was its longest observed apparition. Recovered on 1988 July 6, it was last seen on 1991 May 16, at which time it was situated 4.02 AU from Earth and 4.98 AU from the Sun.
The 1996 appearance was another rather favorable one, although the comet never came closer than 0.9040 AU from Earth (1995 October 7). The comet had become brighter than magnitude 13 at the end of 1995 and continued to brighten. It passed perihelion on 1996 January 17, and with the distance from the Earth and Sun increasing thereafter, it continued to brighten for another month. After reaching a maximum brightness of nearly 10.5 in February the comet faded and had dropped below magnitude 13 my mid-April. The coma diameter never exceeded two arc minutes during this apparition.

The comet is unusually active for a short period object and has a coma and often tail even at perihelion, which are almost certainly a result of the comet's big decrease in perihelion distance. During the 2002/2003 apparition the tail has been as long as 10 arcminutes, with a stellar central condensation in a faint extended coma. Even 7 months after perihelion the tail continues to be very well developed.
1. The orbit of comet 67P/Churyumov-Gerasimenko.
2. The image of comet 67P, obtained 13 Jan. 1982 with 6-m telescope
Orbital evolution of comet 67P/Churyumov-Gerasimenko

- \( T_c \) \( \Delta_{\text{min}} \) \( \Pi \) \( \Omega \) \( I \) \( e \) \( q \) \( Q \) \( P \)

<table>
<thead>
<tr>
<th>Year</th>
<th>( T_c )</th>
<th>( \Delta_{\text{min}} )</th>
<th>( \Pi )</th>
<th>( \Omega )</th>
<th>( I )</th>
<th>( e )</th>
<th>( q )</th>
<th>( Q )</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950 Nov. 15</td>
<td>84 52 23</td>
<td>0.36</td>
<td>2.75</td>
<td>5.90</td>
<td>9.01</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1959 Fev. 4.3</td>
<td>0.052</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1969 Sept. 16</td>
<td>62 50 7</td>
<td>0.63</td>
<td>1.28</td>
<td>5.72</td>
<td>6.55</td>
<td></td>
<td></td>
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How it is seen from Table the comet has an interesting unusual history of its orbital motion. Up to 1840 its perihelion distance was a 2.2 AU and the comet was then unobservable from 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 it in to an orbit with perihelion at just 1.28 AU. The fact that the comet had a close encounter with Jupiter in 1959 very important because only after this encounter comet 67P could be discovered in 1969 with the help of terrestrial telescopes.
Gasproductivity in comet 67P

\[
\begin{align*}
\log Q(\text{CN}) &= 25.86 - 3.13 \log r \\
\log Q(\text{OH}) &= 28.70 - 5.91 \log r
\end{align*}
\]

<table>
<thead>
<tr>
<th>Comet</th>
<th>(\frac{Q(\text{OH})}{Q(\text{CN})})</th>
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<tbody>
<tr>
<td>“normal”</td>
<td>650 ± 240</td>
</tr>
<tr>
<td>1P/Halley</td>
<td>370 ± 100</td>
</tr>
<tr>
<td>67P/Churyumov-Gerasimenko</td>
<td>1090 ± 43</td>
</tr>
</tbody>
</table>
The original plates with the image of comet P/Churyumov-Gerasimenko were obtained by I.D.Karachentsev and K.I.Churyumov January 12.105 UT and 13.124 UT, 1983 with a 6-m telescope BTA of the Special Astrophysical Observatory of Russia’s Academy of Sciences at Mount Pastukhov. These plates are first observations of a comet with one of the biggest ground based telescope.

For quantitative estimation of some physical parameters of the plasma tail of comet Churyumov-Gerasimenko the diffusion model (Nazarchuk and Shul’man,1968).
The diffusion model permits one to analyze the photometric structure of cometary plasma tails. Assumptions on the physical conditions in plasma tails have already been formulated for some comets on the basis of this model.

The diffusion model is based on the following assumptions. The cometary nucleus with its surroundings is considered a point source of matter; this assumption is acceptable because of the small size of a cometary nucleus as compared with its tail. The Green function for an instantaneous source is used. It is assumed that the center of mass of any instantaneously emitted package of particles moves with a uniform acceleration along the axis of the comet’s tail, the outflow of matter has begun infinitely long ago, and the source power \( C \) is constant.
A cometary ion is also considered to acquire random momenta from inhomogeneities of self-consistent fields which move through the tail; i.e., the process of the interaction between cometary ions and the solar wind is assumed to be macrostochastic. Then the motion of a cometary ion is a superposition of diffusion and transport to the tail. In this case, the Green function has the form of an anisotropic function for exponentially disappearing particles:
\[ G = \frac{1}{4\pi t^* \sqrt{D^* D}} \times \exp \left( -\frac{\left(x-a(t^*)^2/2\right)^2}{4D^* t^*} - \frac{y^2}{4D_\perp t^*} - \frac{t^*}{\tau} \right) \]

\[ D^* = D_\parallel \cos^2 \beta + D_\perp \sin^2 \beta \]

where \( t^* \) is the age of the particle package; \( D^* \) is the coefficient of diffusion along the comet’s tail in the plane of the sky; \( D_\parallel \) and \( D_\perp \) are the coefficients of longitudinal and transversal diffusion, respectively; \( \tau \) is the average lifetime of glowing particles; and \( \beta \) is the angle between the tail axis and its projection onto the plane of the sky.
Two theoretical (solid) and observed (stars and circles) cross photometric profiles of the plasma tail of comet 67P/Churyumov-Gerasimenko on Jan. 12, 1983.
The magnetic induction was estimated by the formula of N.L. Shabas:

\[ B = 2 \times 10^1 \frac{T}{D} \frac{L_{\parallel}}{L_{\perp}} \frac{1}{\cos \beta} \text{[nT]} \]
Parameters of magnetic field in comet 67P

| Date, UT | $D ||$, cm/s | $D \perp$, cm/s | $B$, nT |
|----------|--------------|----------------|---------|
| Jan. 1983 | 12.105       | $5.07 \times 10^{14}$ | $5.73 \times 10^{13}$ | $46 \div 111$ |
| Jan. 1983 | 13.124       | $4.67 \times 10^{14}$ | $4.30 \times 10^{13}$ | $55 \div 134$ |
The obtained upper estimates of induction of the magnetic field $B \approx 111$ nT for Jan. 12, 1983 and $B \approx 134$ nT for Jan. 13, 1983 probably surpass real values of B in the cometary plasma tail. However good coincidence of 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 in favor of the 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 to be a strongly magnetized plasma jet.

We think that this peculiarity of magnetic fields in plasma tail of comet 67P is tight connected with the magnetic properties of the surface layers of the cometary nucleus. I hope that this problem will be successful solved with the help of the device ROMAP installed on the ROSETTA Lander Philae, when it will land on the comet 67P nucleus in 2014.
The Lander Philae will land on the nucleus of comet 67P in November 2014 and its device ROMAP will measure a magnetic field of the comet nucleus.