SOLAR SYSTEM

THE PHYSICAL PARAMETERS OF THE GAS AND DUST IN COMETARY ATMOSPHERES

Churyumov K.I., Ponomarenko V.O., Kleschonok V.V.

Taras Shevchenko National University of Kyiv Astronomical observatory
Observatorna str. 3, 04053 Kyiv, Ukraine
klivch@mail.ru, vasiliyponomarenko@gmail.com

ABSTRACT. The results of observations and studies of comets on the basis of the optical spectra with an average resolution were presented. Spectral material was mainly produced in 2009–2012 with the help 2-m telescope Zeiss (F_1 = 6.3 m; F_2 = 16 m) at high mountain astronomical station "Terskol" of Main Astronomical Observatory of National Academy of Sciences of Ukraine and the Institute of Astronomy RAS. The resolution of the spectra R ≈ 1500, R ≈ 4500, R ≈ 14000; wavelength ranges λλ = 3850–8000 ÅÅ.

Using the spectra of comets, based on the model Hazer, was performed the following work: carried out the identification of spectral emission lines, obtained physical parameters of the neutral gas atmosphere of comets. And also, physical parameters the dusty atmosphere.

Keywords: comet, spectrophotometric gradient, emission lines.

1. Introduction

The observations of comets, which are the objects of the research paper were obtained in 2009-2012 at the astronomical observatory "Terskol" of International Center of Astronomical, Medical and Ecological Research of National Academy of Sciences of Ukraine and the Institute of Astronomy RAS (Russia, the North Caucasus, 43°16′29″ n. l., 42°30′03″ e. l., Altitude 3136 m). The code observatory in the Minor Planet Center (MPC) – B18. Instrument for observations was 2-m reflecting telescope Zeiss (F_1 = 6.3 m; F_2 = 16 m) with outboard spectrometer-photometer of Cassegrain focus (the spectrograph slit had the height ≈ 11″ and the width ≈ 3″). In the spectrograph was installed the CCD camera FLI PL4301E (with chip 50×50 mm, field 11′×11′, 1247×1151 pixel). In the spectrograph set alternately the different modes: prism ($R \approx 1500$), echelle ($R \approx 14000$). All spectra were obtained in the optical range (380 nm ≤ λ ≤ 850 nm).

All studied comets can be divided into two dynamic groups: Jupiter-family comets (JFCs) and long-period comets (LPC) with retrograde motion. The orbital elements, some physical parameters and characteristics for observations JFCs are presented in Table 1, for LPC in Table 2. In the tables can see differences between the types of comets, which are displayed in the value of the angle of inclination of the orbit to the ecliptic plane, the eccentricity and the period of rotation, geocentric distance.

Table 1. Parameters of observations and orbital elements of JFCs

Parameter		22P	81P	103P
Heliocentric distance	*r*, AU	1.77	1.63	1.06
Geocentric distance	Δ, AU	0.78	0.68	0.13
Integral magnitude	*T*	≈ 12^m	9.8^m	9.1^m
Phase angle	s-t-o	10°	13°	56°
Elongation angle	s-o-t	160°	157°	116°
Position angle	PA	259°	274°	271°
Diameter of comet's nucleus	*D*, km	≈ 3	≈ 5	≈ 0.6
Geometrical albedo of surface	*A*	0.05	0.059	0.028
Eccentricity of orbit	*e*	0.54	0.538	0.694
Inclination to ecliptic	*i*	4.7°	3.24°	13.6°
Period of rotation	*P*, y.	6.43	6.42	6.46

Table 2. Parameters of observations and orbital elements of LPC

Параметр		C/2006 W3	C/2009 K5	C/2009 P1
Heliocentric distance	*r*, AU	3.13	1.50	2.09
Geocentric distance	Δ, AU	2.33	1.43	1.61
Integral magnitude	*T*	≈ 12^m	≈ 11^m	10.7^m
Phase angle	s-t-o	13°	40°	27°
Elongation angle	s-o-t	137°	75°	104°
Position angle	PA	160°	272°	122°
Eccentricity of orbit	*e*	1.00005	1.001	1.001
Inclination to ecliptic	*i*	127.1°	103.9°	106.2°

The calculations of the physical parameters of gas-dust cometary atmospheres were based on the Hazer's model. This model is used in the processing of the surface brightness profiles of the neutral atmosphere of comet obtained on the basis the photometric and spectroscopic observations (Haser, 1957). It is easy and convenient, as it includes a small number of parameters that can be determined theoretically or obtained from observations, which greatly simplifies the process of obtaining the physical quantities.

Hazer's model based on the following approximations:

1) the comet nucleus is spherical with a radius r_0; its substance is vaporized by absorption of solar radiation. The molecules leave the surface of the nucleus, moving in all directions with the radial velocity v_0;

2) the reason of reradiate energy is the mechanism of resonance fluorescence (under the action of the solar flux);

3) the decomposition of molecules occurs as a result of photodissociation under the law $n = n_0 e^{-t/\tau_0}$, where n_0 – the number of molecules, which are presented at the moment $t=0$; τ_0 – half-life for this type of molecules;

4) at a distance r from the comet's nucleus the density of molecules characterized by the expression $D(r) = D(r_0)\left(\frac{r_0}{r}\right)^2 e^{-\frac{t-t_0}{\tau_0}}$.

This model does not take into account the effects of solar radiation pressure on the molecules, anisotropic (non-radial) the escaping of parent molecules from the nucleus and non-radial movement of daughter molecules, as well as the distribution of velocities of their movement. The model can be used only to the photodegradation products and it is impossible in cases where the daughter molecules formed by the chemical reactions.

2. The identification of emissions in cometary comae

Was carried out a detailed identification of emission spectral lines in comae of comets 81P/Wild 2, 103P/Hartley 2, C/2007 N3 (Lulin), C/2009 K5 (McNaught). For identification were used the catalogues of Cochran (Cochran, 2001) and Brown (Brown et al., 1996). Most revealing is the identification that was conducted for the comet Hartley 2 and McNaught, since the lines in the spectra of comets were identified with the equal resolution ($R \approx 14000$) and in the equal wavelength ranges (λλ = 4690–7000 ÅÅ). At the time of observations the comet 103R had a higher integral magnitude and was on a much smaller heliocentric distance. In spite of this, the number of emission lines, that could be identified in this JFCs significantly less than their number in the C/2009 K5 (McNaught). We can assume that this fact is characteristic of the vast majority of JFCs in compared with LPC with retrograde motion and can be explained by the disintegration time or differences in origin between the two types of comets. The results of identification are presented in Table 3.

Also, the identification of spectral emission lines was carried out for the comet C / 2007 N3 (Lulin) based on the spectra with echelette (R ≈ 4500; λλ = 3800–9000 ÅÅ), and for the comet 81P/Wild 2 ($R \approx 14000$; λλ = 4700–8500 ÅÅ). The search of emission lines in the spectra of other comets are not implemented because their gas activity was weak.

We should also note the identification of the doublet Na (D_1 = 588.9 нм, D_2 = 589.6 нм) in the spectra of comets 22P/Kopff (r = 1.8 AU), 103P/Hartley 2 (r = 1.06 AU), C/2009 K5 (McNaught) (r = 1.5 AU). As is known, the identification of Na on heliocentric distance of > 1 AU is a rare phenomenon.

Table 3. Emission lines in the spectra of comets 103P/Hartley 2 и C/2009 K5 (McNaught)

Emission	Comet 103P	Comet C/2009 K5
C_2	928	1248
NH_2	162	189
H_2O^+	25	31
[OI]	3	3
Na	2	2
CN	24	36
no ident	651	675
All	1795	2184

3. Accuracy of spectrophotometry

For the processing the spectra of comets obtained with a CCD have been used specialized programs DECH95, DECH20T and other software designed or adapted for the processing of cometary spectra. The part of the work was done based on the MATLAB programs. At the stages plot charting and separate works in large data arrays used Microsoft Office Excel.

In accordance with the method of processing and features of observational material was analyzed possible errors. The error of measurement results was mostly accidental, since the systematic component was removed by corrections and reductions. The random component of measurement error for a single image is equal 10/1 and determined by the ratio the signal/noise ratio. However, due to the fact that during the night snapshot the object was obtained several times (were carried out reusable measurement), the random component of measurement error for each of the research subjects was reduced to a level that does not exceed 5%. In addition, to the final results was introduced error of measurement processing. Theoretically it determined that the error processing of measurement results does not exceed 6%. Therefore, the total maximum possible error (worst case) does not exceed 11%. Also, the error was evaluated by the method of comparison with exemplary measure, which was a star-standard. Methods of assessment lay in the fact that every night observation was obtained not one snapshot, but two snapshots of star-standards (solar-type star and a star with higher temperature – "divayzer"). With the help of single star-standard were calculated the fluxes from another star in absolute units. By means of comparison with spectrophotometric catalog of Burnashev (Burnashev, 1985) was determined an error of measurements and calculations. For the different stars and nights maximum error was equal 6–10%. Fig. 1 shows an example of a comparison performed measurements and calculations for the star HD 214923 (spectral class B8V) with the data of spectrophotometric catalog of Burnashev. The resolution of the observations that submitted in the work in many times greater than the resolution of the catalog, so the resulting intensity was approximated by the polynomial.

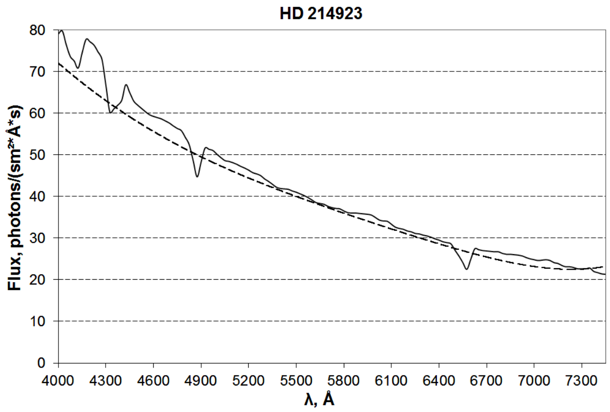

Figure 1: The intensity of the star-standart HD 214923: the continuous line shows the data of spectrophotometric catalog; the dotted line shows the results of measurements and calculations (1 Å = 0.1 nm)

4. The spectrophotometric gradient

It was also built the ratio of the reflected by comet the solar continuum in absolute units (excluding the standard emissions and the luminescent continuum) to the original spectrum of the Sun for all the studied comets. Thus obtained spectrophotometric gradients indicate on differences in the reflective characteristics of dust between the considered JFCs and LPC with retrograde motion (Fig. 2). The figure shows that the considered comets of the Oort cloud better reflect the short-wave radiation in the visible spectral range. This may be due to an excess in their atmospheres of highly dispersed dust particles < 0.5 microns. These particles have a lower temperature and better dissipate the short wavelengths (in accordance with the mechanisms of Mie and Rayleigh). The scattered light can make a significant contribution to reducing the reflection properties of the cometary dust in the LPC, which are discussed in the work. The spectrophotometric

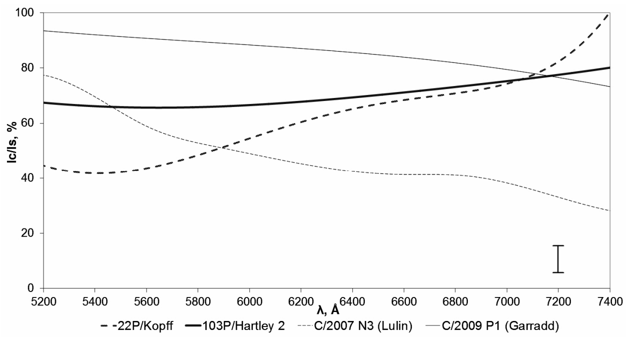

Figure 2: The spectrophotometric gradients for JFCs (22P, 103P) and LPC with retrograde motion (C/2007 N3, C/2009 P1)

gradients of the investigated JFCs increasing with wavelength in the visible range. To explain the phenomenon can loss the JFCs of a significant amount of light dust particles < 0.5 microns due to active gassing and reusable approaches to the Sun. Heavy, inert, the coarse dispersed dust (> 0.5 microns), which dominates in the atmospheres of these comets, will reflect light of Sun almost uniformly (with a small directly proportional to the wavelength). In Fig. 2 we can see, that the spectrophotometric gradients for short-period comets 22P and 103P are increasing, and for long-period comets C/2007 N3 and C/2009 P1 are falling (in the visible spectral range).

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