The Institute of Space and Astronautical Science
Report SP No. 15, March 2003

Gas-to-dust ratio and chemical composition in comet 55P/Tempel-Tuttle

By

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(1 February 2003)

Abstract: We carried out spectroscopic observations of comet 55P/Tempel-Tuttle, the parent body of the Leonid meteor stream, on 1998 January 23 and 24, using a mid-dispersion spectrograph in the wavelength ranges 4700–5500 Å and 5700–6500 Å. We detected species such as C_2, NH_2, and [OI]. To characterize the comet, we estimated the gas-production rates of C_2 and NH_2 relative to that of H_2O and the gas-to-dust ratio based on the Haser model. The dust color was also estimated by the method of Jewitt & Meech (1986).

The gas-production rates were $Q(NH_2/H_2O)$=0.23%, $Q(C_2/H_2O)$ = 0.10%. These values are typical for the Borrelly class which is characterized by the depletion of C_2 molecule relative to that of the Halley class. Since about 30% of detected comets belong to the Borrelly class, comet 55P/Tempel-Tuttele can not be a peculiar comet, at least from spectroscopic point of view.

The gas-to-dust ratio was $\log(Q(H_2O)/Af\rho)$= 26.7, which means this comet was gas-rich relative to comet Halley. The dust color was roughly estimated by using continuum windows, and the dust reddening was 9.6% per 1000 Å, which was consistent with other nine comets observed by Jewitt & Meech (1986).

It is plausible that comet 55P/Tempel-Tuttle is not an exotic comet at any rate, except the fact that it is the parent body of the Leonid meteor stream.

1. INTRODUCTION

The Leonid meteor shower is caused by the earth's encounter with the dust trail which originated from comet 55P/Tempel-Tuttle and has sometimes exhibited heavy storm activities. It is famous for the public and many publications of this meteor stream have been appeared in last a few hundred years. Howerver the fundamental nature of its parent body, comet 55P/Tempel-Tuttle, has been almost unknown until today. So far there has been no physical information about the gas and dust production rates (Hainaut et al. 1998).

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Thus we carried out spectroscopic observations of the parent body a few days after its closest approach to the Earth. The main purposes of our observation were to reveal the physical properties of this comet and to better characterize it as the parent of the Leonid meteor streams. From the obtained spectra, the gas production rate, gas-to-dust ratio and dust color were estimated.

2. OBSERVATIONS AND REDUCTION

2.1 Observations

The spectroscopic observations were performed on 1998 January 23 and 24 at Okayama Astrophysical Observatory, Japan. We employed the Spectro-Nebular Graph (SNG) mounted on the Cassegrain focus of the 188 cm Reflector equipped with the Site SI502AB CCD camera (512×512 pixels). The slit size was $300'' \times 1''.8$ and the effective spectral resolution was $R = 2000$ in the wavelength range 5700–6500 Å. We put the slit on the optical center of the comet's coma and oriented it along south-to-north. In order to correct the instrumental sensitivity, observations of the spectrophotometric standard stars were also carried out at nearly some air masses as those of the comet. Observational log of the comet is given in table 1. When stars fell on the slit, we interrupted exposure time until they left out the slit. The exposure times presented in the table are total.

Table 1: Observations conditions

Object	Date(UT)	Time(UT)	Exp.(s)	Wavelength range(Å)	r(AU)[1]	Δ(AU)[2]
55P	1998.1.23	12:18	1800	5700 – 6500	1.136	0.4241
55P		12:54	1800			
55P		13:57	1800			
55P	1998.1.24	13:56	1200	4700 – 5500	1.128	0.4455

[1] heliocentric distance at 13:00 (UT)
[2] geocentric distance at 13:00 (UT)

2.2 Date reduction

Date reduction was conducted with SNGRED (OAO software) and NOAO IRAF software library for the spectral analysis. For each object frame, the dark frame subtraction, the flat frame correction, the cosmic ray removal, and the wavelength calibration were carried out with the SNGRED. The sky subtraction and the wavelength sensitivity calibration were carried out with IRAF.

The sky component was measured far from the optical center. Because we generally can not use a region in the field of view sufficiently far from the center, there is some possibilities of remaining a small quantity of the cometary components. If we use the measured sky to extract the comet's component, measured signal is forced to become zero at the region far from the center and we will obtain the lower flux. To correct the over subtraction, because we could not perform to separate sky observations, we had to determine the 'true' cometary components in the measured region based on models used the temporary obtained flux (Fink 1994).

The reduced spectra are presented in Figure 1. The wavelength ranges are 4700 - 5500 Å and 5700 - 6500 Å. These spectra are normalized by dividing the flux at 5245 Å and 6450 Å, respectively. Some molecular emission bands, such as C_2 and NH_2, are noticeable. We measured the flux of C_2, NH_2, [OI], the continuum at 5780 Å, 6250 Å, and 6450 Å. The gas-production rates and the gas-to-dust ratio were calculated in accordance with Fink & Hicks (1996). The dust color was estimated by a method of Jewitt & Meech (1986).

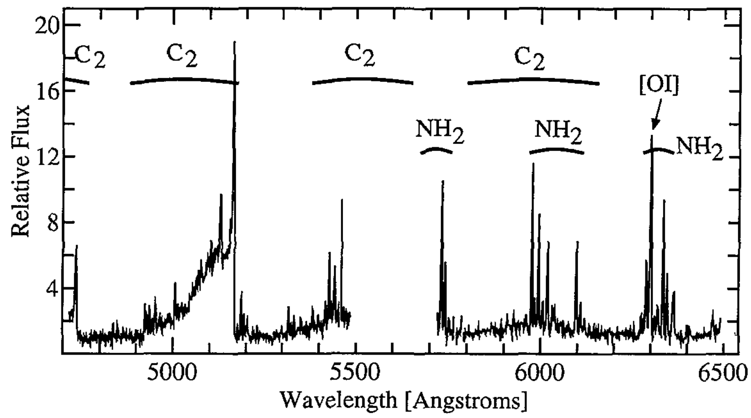

Fig. 1: Spectrum of comet 55P/Tempel-Tuttle

3. RESULTS AND DISCUSSION

3.1 Gas-production Rates and Gas-to-dust Ratio

We derived the gas production rates from the column densities that are converted from the flux. To calculate the column densities from the flux, physical parameters (g-factors) are necessary under the assumption that the coma is optically thin. We can then obtain the molecular column densities by means of integration of the molecular band intensities. In order to derive the gas production rates from the column densities, we are obliged to use some molecular reaction models. Here we adopted the Haser model (O'Dell & Osterbrock 1962), which has been widely accepted as the simple and the useful model to compare among various spectroscopic data of comets.

The Haser model assumes a simple process of photochemical reaction and the spherical symmetry. First, a parent molecule sublimates from the surface of a parent body due to solar radiation. Second, a parent molecule is dissociated into a daughter molecule by UV irradiation. Finally, a daughter is also dissociated into the other molecule. This process occurs one-dimensionally. All kinds of molecules move away from the nucleus with their respective and constant velocities.

The radial distribution of the density of a daughter molecule is determined by the velocity and the mean lifetimes of a parent molecule and a daughter. There is also the dilution effect of the radial distance increasing away from a cometary nucleus.

The gas-production rate is calculated using the scale length, which is defined by the product of the velocity and the mean lifetime. Unfortunately, different g-factors and scale lengths are frequently used by different authors. We therefore must be careful to make a comparison between our results and others. In this work, we adopt the same physical parameters used in Fink et al. (1999). Still the g-factors of NH_2 must be carefully noted. Tegler & Wyckoff

(1989) pointed out that there were significant uncertainties in the g-factors of NH_2 another Fink et al. (1999) used. Although we used the same g-factors for comparison, there is a reasonable value which revised by Kawakita & Watanabe (2002). Using revised g-factors, $Q(NH_2/H_2O)$ in Table 2 changes to be 2.4-times larger.

The gas production rates of NH_2 and C_2 relative to that of H_2O is presented in Table 2. The gas-to-dust ratio is also presented, which was derived from the ratio of production rate of H_2O derived [OI] emission lines and an index of dust production rate $Af\rho$ estimated from the continuum level at 6250 Å (A'Hearn et al. 1984).

Table 2: Gas production rates (%) and Gas-to-dust ratio (log scale)

Ratio	Tempel-Tuttle	Borrelly class	Halley class
$Q(NH_2/H_2O)$	0.23	0.19 – 0.38	0.08 – 0.26
Avg	—	0.25	0.16
$Q(C_2/H_2O)$	0.10	0.04 – 0.15	0.16 – 0.39
Avg	—	0.09	0.27
$\log[Q((H_2O)/Af\rho)]$	26.7	—	25.8

Fink et al. (1999) divided comets into four classes based on their spectroscopic observations. The gas production rates of 55P/Tempel-Tuttle are typical for the Borrelly class, which is characterized by the depletion of C_2 molecules relative to that of the Halley class. According to their classification, about 30% of observed comets belong to the Borrelly class (about 60% of them belong to the Halley class). As long as we trust this classification, we consider that comet 55P/Tempel-Tuttle is not an exotic comet at any rate, at least from spectroscopic point of view. So far there is no good interpretation on the C_2 depletion relative to that of the Halley-type comets, and it is still unknown what the C_2 depletion means to the physical and chemical process of the comet nucleus.

The gas-to-dust ratio, $\log(Q(H_2O)/Af\rho)$, was 26.7, and it means that this comet is gas-rich relative to comet Halley. This seems contradictory to our naive expectation that the parent comet of great meteor storms like the Leonids must be dust-rich.

3.2 Dust color

Following the method of Jewitt & Meech (1986), the dust color was roughly estimated by using continuum windows, are the wavelength regions free from molecular bands.

Jewitt & Meech (1986) defined the normalized reflectivity gradiant S' as the "continuum color",

$$S'(\lambda_1, \lambda_2) = \frac{dS/d\lambda}{S_{mean}} \tag{1}$$

where $dS/d\lambda$ is the reflectivity change rate in the observed wavelength interval λ_1 and λ_2, and S_{mean} is the mean reflectivity in the same range. The reflectivity $S(\lambda)$ is calculated by dividing the measured flux densities by the solar flux densities at λ. If we use two data points, $dS/d\lambda = (S_2 - S_1)/(\lambda_2 - \lambda_1)$ and $S_{mean} = (S_1 + S_2)/2$, thus the continuum color is represented by

$$S'(\lambda_1, \lambda_2) = \frac{2}{\lambda_2 - \lambda_1} \frac{S_2 - S_1}{S_2 + S_1} \tag{2}$$

When $S_2 > S_1$, namely continuum color is red, $S' > 0$. This behavior of the continuum color provides a simple measure of the dust color. Hereafter we will refer the continuum color as the "dust color".

We measured the continuum at 5780 Å and 6450 Å, the wavelength regions free from molecular bands (continuum windows: see Figure 1). The obtained dust color is: $S'(5780, 6450) =$ 9.6% per 1000 Å. The optical dust colors of nine comets are measured by Jewitt & Meech (1986) range from (5 ± 2) to (18 ± 2)% per 1000 Å. Thus we again consider that comet 55P/Tempel-Tuttle is not a peculiar comet.

3.3 Relation with the activity of the Leonid meteor shower

As mentioned above, comet 55P/Tempel-Tuttle can not be considered as an exceptional comet that has any striking physical nature. We therefore do not think that the activity of the Leonid meteor shower is caused by some physical characteristics of the parent body. Instead, the activity of the meteor shower may well be caused, for example, by the result of the gravitational interaction between the meteor stream and the large bodies such as Uranus and the Earth.

Therefore the parent body is not a peculiar comet; it means that the meteor materials and their behavior in the Earth's atomosphere may be typical. Yet, still some of general nature of the parent comet can be revealed by investigating the Leonid meteor shower.

4. CONCLUDING REMARKS

We carried out spectroscopic observations of comet 55P/Tempel-Tuttle, the parent comet of the Leonid meteor stream, on January 23 and 24 1998. To characterize the comet, we estimated the gas-production rate relative to that of H_2O, the gas-to-dust ratio, and the dust color. The chemical compositions are derived from the intensities of the emission bands such as C_2, NH_2, and [OI]. The Haser model was used for calculation.

The gas production rates are: $Q(NH_2/H_2O) = 0.23\,\%$, $Q(C_2/H_2O) = 0.10\,\%$. These values are typical for the Borrelly class comets which are characterized by the depletion of C_2 molecule relative to that of the Halley class comets.

The gas-to-dust ratio was estimated by using [OI] emission lines and continuum windows, the wavelength regions free from molecular bands. We obtained $\log(Q(H_2O)/Af\rho) = 26.7$, which means that this comet was gas-rich one relative to the comet Halley.

The dust color was roughly estimated by using continuum windows and the dust reddening was 9.6% per 1000 Å.

The gas production rates and the dust color indicated that comet 55P/Tempel-Tuttle might not be a exotic comet, which is not contradictory with the observed activity of the Leonid meteor shower. Thus the meteor materials and the behavior in the Earth's atomosphere like heavy flux and bright fire balls may be not striking too; yet it may be possible to yield some general nature of the parent comet by investigating the Leonid meteor shower.

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