WIDE FIELD IMAGING OF ION TAIL OF COMET C/HALE–BOPP

D. KINOSHITA*
Department of Physics, University of Tohoku, Aoba, Sendai, 980-77 Japan
(E-mail: daisuke@pub.mtk.nao.ac.jp)*

J. WATANABE and H. FUKUSHIMA
National Astronomical Observatory, Osawa, Mitaka, Tokyo, 181 Japan

T. SEKIGUCHI
Graduate University for Advanced Studies, Osawa, Mitaka, Tokuo, 181 Japan

N. YAMAMOTO
Department of Physics, Science University of Tokyo, Shinjuku, Tokyo, 162 Japan

S. ABE
Solar-Terrestrial Environment Laboratory, University of Nagoya, Toyohashi, Japan

(Received 4 February 1998; Accepted 2 April 1998)

Abstract. A sequential imaging observation of the ion tail of Comet C/Hale–Bopp 1995O1 was carried out in February–March 1997 with a wide-field CCD imaging camera using narrow band filters for two ion species; CO^+ and H_2O^+ along with those for blue and red continuum. From the surface photometry of the ion tail of two species, we derived a relationship between plasma density and distance from the nucleus. The local velocity of the ion flow as a function of the distance from the nucleus was also estimated on the basis of some assumptions. We report preliminary results of our analysis, and discuss some characteristics of cometary plasma and its interaction with interplanetary magnetic field (IMF).

May the source be with you!

Keywords: Cometary plasma, solar wind, interplanetary magnetic field

Abbreviations: IMF – Interplanetary Magnetic Field

1. Introduction

The ion tail of comets is a natural probe for the interplanetary magnetic field (IMF). The major component of the ion tail are CO^+ and H_2O^+ ions, and which interact with the IMF. Hence, photometric observations of the ion tail of a bright comet give us important information about, not only the motion of ion particles, but also of the IMF.

Comet C/Hale–Bopp 1995O1 was discovered by two amateur astronomers, Alan Hale and Thomas Bopp, on 23.264 July 1995 (UT) and 23.30, respectively (IAU Circular No. 6187). The apparent magnitude was obtained as 11 soon after

TABLE I
Specification of 4 filters

Filter	λ_0 (Å)	$\Delta\lambda_{1/2}$ (Å)	$T_{\max}$ (%)
CO^+ emission	4256	46	59.4
H_2O^+ emission	6997	180	86.5
Blue continuum	4858	60	71.1
Red continuum	6827	49	82.5

the discovery, however the comet was located at the heliocentric distance of 7 AU. This fact means the absolute magnitude of this comet is -2. We could expect that this is one of the brightest comets in our whole history.

2. Observation

An imaging observation of the ion tail was carried out from 18h 54m UT through 19h 39m UT on 9 March 1997. Because the surface brightness of the ion tail was too faint to be observed at Mitaka in Tokyo, we developed a portable wide-field imaging observational system and set it up at the Kiso Observatory. The Kiso Observatory belongs to the Institute of Astonomy, University of Tokyo, and it is located at $\lambda = 137°37'42''$ (9h10m30s), $\phi = +35°47'39''$, and 1130 m above sea level. We used Santa Barbara Instruments Group's SBIG ST-6 for CCD camera. The ST-6 has a peltier element cooling system, and it works with air circulation. A 35-mm camera lens of Tamron 24 mm (f/2.5) was attached to this CCD. The pixel number was 375×242, and the pixel spacing was 23 μm $\times$ 27 m, corresponding to $3'.29 \times 3'.87$. The field of view was $20°.4 \times 15°.5$. We used four filters of CO^+, H_2O^+ emission, blue and red continuum, as shown in Table I.

3. Reduction

Reduction was performed by astronomical image processing software library *NOAO IRAF* running on the workstations at Astronomical Data Analysis Center of National Astronomical Observatory of Japan and Bubble Chamber Physics Laboratory of the University of Tohoku and on one of the author's personal computers. Both dark subtraction and flat-fielding are applied to the raw data. As our data are wide field images, we applied correction of air mass for each pixel. After the adjustment of point spread function, we subtracted the continuum images from the emission images.

4. Analysis

Ion particles in cometary plasma are accelerated by the magnetic field due to the solar wind. When we assume the distribution of magnetic field in the ion tail as

$$B = B_c \left\{ \tanh\left(\frac{x}{x_c}\right) \right\}^{1/2},$$

where B_c is a constant value depends on IMF.

We have the relationship between the velocity of cometary plasma V and the distance from the nucleus of comet x (Minami and White, 1986) as

$$V = \frac{V_{sw}\left\{\cosh\left(\frac{x}{x_c}\right) - 1\right\} + V_T}{\cosh\left(\frac{x}{x_c}\right)},$$

x_c is also a constant value expressed as

$$x_c = \frac{m_i \rho_c V_T}{B_c^2} \frac{\sigma_1 + \sigma_2}{\sigma_1 \sigma_2}.$$

Here, V_T is the initial thermal velocity, V_{sw} is the velocity of solar wind, m_i is the mass of the particle, ρ_c is the density of the cometary plasma in the coma, σ_1 is the electric conductivity of cometary plasma, σ_2 is the electric conductivity of solar wind plasma.

The density of cometary plasma becomes lower the larger the distance from nucleus of the comet due to the acceleration of the particles. We write the density of cometary plasma ρ as

$$\rho = \rho_c \frac{V_T}{V},$$

when plasma flow has the velocity V. We finally obtain the density ρ

$$\rho = \rho_c V_T \frac{\cosh\left(\frac{x}{x_c}\right)}{V_{sw}\left\{\cosh\left(\frac{x}{x_c}\right) - 1\right\} + V_T},$$

as the function of the distance from nucleus x.

We plotted the column density as a function of x in the tail in Figure 1. We performed parameter fitting to get best fitted curve that is also drawn in Figure 1. As a result of the fitting, the solar wind velocity was estimated to be 808 km sec^{-1}. With using these parameters, we plotted the velocity of plasma flow versus distance from theh nucleus of the comet in Figure 2.

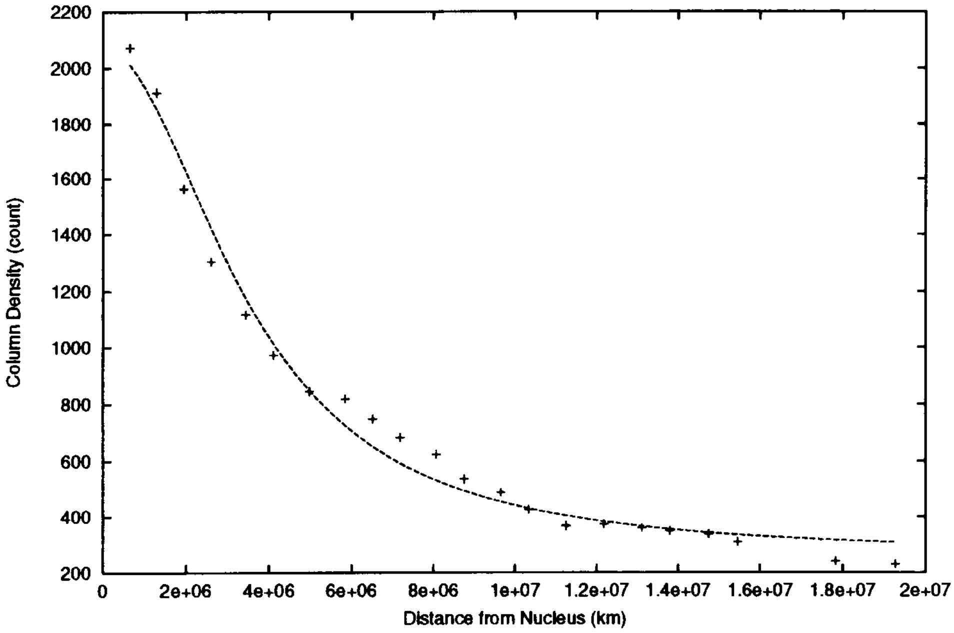

Figure 1. Distance from the nucleus and column density (unit of CCD count) derived from CO^+ image.

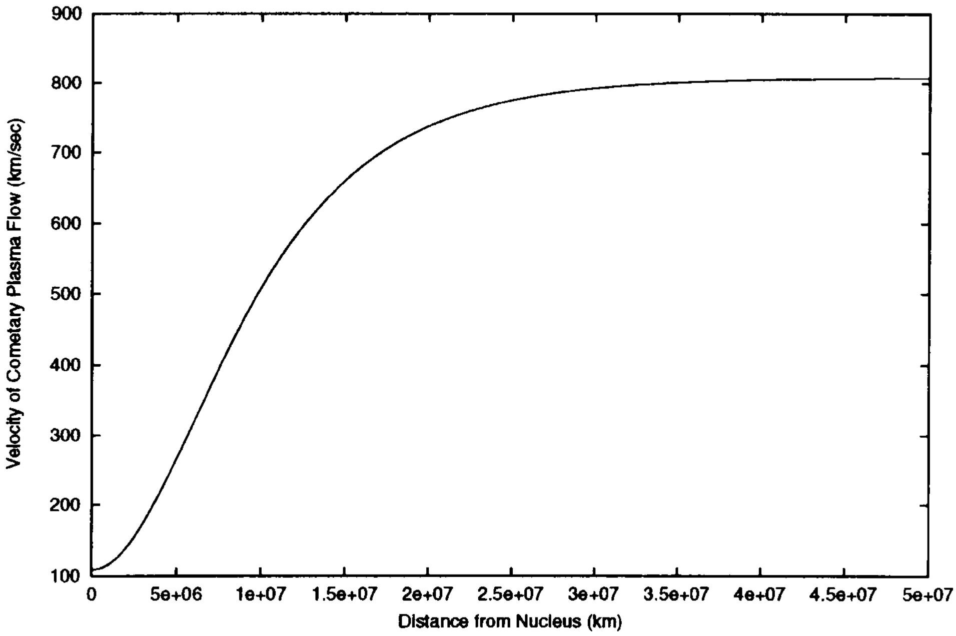

Figure 2. Distance from the nucleus and velocity of the plasma flow.

5. Discussion

By parameter fitting, we obtained 109 km sec^{-1}, for the initial thermal velocity. This is not a reasonable value for the thermal velocity in the coma. On the other hand, cometary plasmas are photodissociating and each ion species has their own finite lifetime. We did not consider this effect in this analysis. We are now working on a new theory including photodissociation effects. These are the problems to be solved in future analysis.

6. Conclusion

We carried out wide field imaging of comet C/Hale–Bopp 1995O1 with a portable CCD observation system at Kiso Observatory, Japan. Using relationship between the density of cometary plasma and the distance from the nucleus, we obtained local solar wind velocity around the comet as 808 km sec^{-1}.

Acknowledgements

We would like to express our hearty thanks to Kiso Observatory for kind support to our observations, to the Hayakawa Fund of the Japanese Astronomical Society for helping with my travel to the Canary Islands, and to the Linux community for the development of the UNIX-like computing environment based on a PC.

References

Brandt, J. and Chapman, D.: 1981, *Introduction to Comets*, Cambridge University Press.
Genet, R.: 1983, *Solar System Photometry Handbook*, Willmann-Bell, Inc.
Minami S. and White, R. S.: 1986, *Geophys. Res. Letters* **13**, 849.
Saito, T., Yumoto, K., Hirao, K., Minami, S., Saito, K., and Smith, E.: 1987, *A & A* **187**, 209.
Kivelson, M. and Russell, C.: 1995, *Introduction to Space Physics*, Cambridge University Press.
Narlinkar, J.: 1997, 'World Scientific', *Physics of Comets, 2nd Edition*.