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LIGHTCURVE OF COMET AUSTIN(1989C1) AND ITS DUST MANTLE DEVELOPMENT

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Abstract

Brightness variations of comet Austin(1989c1) were investigated in terms of the variations of water production rate. We translated the visual brightness data into water production rates using Newburn's semi-empirical law. The curve of the water production rates as a function of heliocentric distance was compared with the model calculations that assumed energy balance between the solar incident and vaporization of water. Thermal flow in a dust mantle at a surface of the nucleus is also included in the model. The model calculations including the dust mantle are more favorable for the observed rate than non-dust mantle cases. The extinction after the perihelion passage suggests that the dust mantle developed gradually.

1 Introduction

Visual magnitude observations of comets are one of the useful indices to understand cometary activities. We have a great deal of visual estimations of the brightness of comets. These cometary magnitudes, however, do not compare directly with other physical quantities such as gas production rates. To perform these comparisons, Newburn(1983) developed a semi-empirical method which translates a cometary brightness into a water production rate. Roettger *et al.*(1990) verified the method by comparing translated water production rates from visual observations for some recent comets with those observed by the IUE(*International Ultraviolet Explorer*) and found them to be in good agreement for the some comets studied. We have applied this technique to the lightcurve analysis of comet Austin(1989c1). The comet showed an asymmetric lightcurve, in which it became fainter after its perihelion passage. This type of brightness variation is often recorded in the case of new comets that are first coming into the inner solar system from the Oort cloud (see Whipple, 1977 for example). Comet Austin was probably a "new" comet(*IAU Circular*, No.4919). We will illustrate such an asymmetric lightcurve using a dust mantle model that was described by Mendis and Brin(1977). In the model, released dust particles, which could not exceed their escape velocity, accumulate on the surface. As a result the mantle acts as a insulating layer from the solar incident because of its low thermal conductivity. We will consider that the mantle developing would be responsible for the asymmetric lightcurve that is extinct after the perihelion.

2 Data Reduction

The visual observations of comet Austin that we used were the values that were reported in the IAU circular and the HAL(Hoshi-no-hiroba Astro Letter, the circular of a Japanese amateur observers group) and were also contributed by the comet section of the Astronomical Union of Universities(also an amateur group in Japan). Totally, the number of usable observations we used were 535, eliminating some extremely inaccurate data, which deviated more than 3 magnitudes from others. Fig. 1 shows the visual magnitudes of the comet reduced to 1-AU geocentric distance as a function of heliocentric distance. We can see in the figure that the comet became fainter after the perihelion.
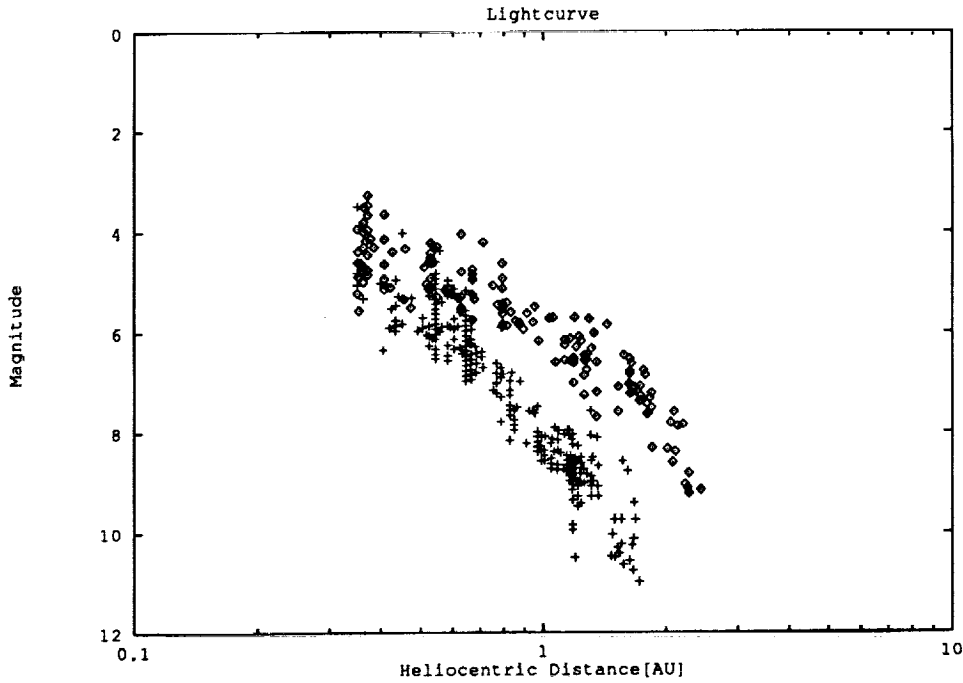
Figure 1: Visual magnitudes of comet Austin(1989c1). The plotted data are reported in IAU Circular, HAL(Hoshi-no-hiroba Astro Letter) and contributed by AUU(Astronomical Union of Universities). Diamond symbols and plus symbols indicate pre and post perihelion data respectively.

To compare the visual magnitude data with water production rates, we applied Newburn's semi-empirical method (Newburn, 1983) that aimed to reduce visual magnitude observation m_v into a water production rate Q_{H_2O}. We can obtain the rate by,

$$Q_{H_2O}(m_v) = \frac{1}{2}\left[\frac{10^{0.4(m_\odot - m_v)}}{\tau_{C_2}(1 + ar^n)R}\right]^{1/2} \times 1.4968 \times 10^8,$$ (1)

where τ_{C_2} is the lifetime of C_2 at 1 AU, $m_\odot$ is the magnitude of the sun, r is the heliocentric distance in AU. ar^n is the relative contribution of dust and gas to the visual magnitude, and R is the fluorescence efficiency of C_2. The values that we used for these parameters are the same as Roettger et al.(1990). The reduced water production rates using this method are plotted in Fig.2. To check the validity of the translated data, we compared them with IUE post perihelion data (Budzin et al.,1990), and found that they were in agreement, although the IUE data were somewhat larger than the reduced rate.

3 Model Calculations

We can then compare directly the water production rates obtained from visual brightness data with those from model calculations. The dust mantle model that we used here is a subset of Mendis and Brin's model(1977). The model is based on an energy balance between the solar incident and used by sublimation of water ice when a dust mantle, that has a low thermal conductivity, covers the surface to the depth Δ. The mantle surface temperature T_s is mainly governed by radiative equilibrium, while the ice core temperature T_e is controlled by the sublimation of ice. The energy balance through the dust mantle is written in the following equations,

$$\frac{1 - As}{r^2} J \cos\theta = \epsilon_s \sigma T_s^4 - K(T)\Delta T|_s$$ (2)

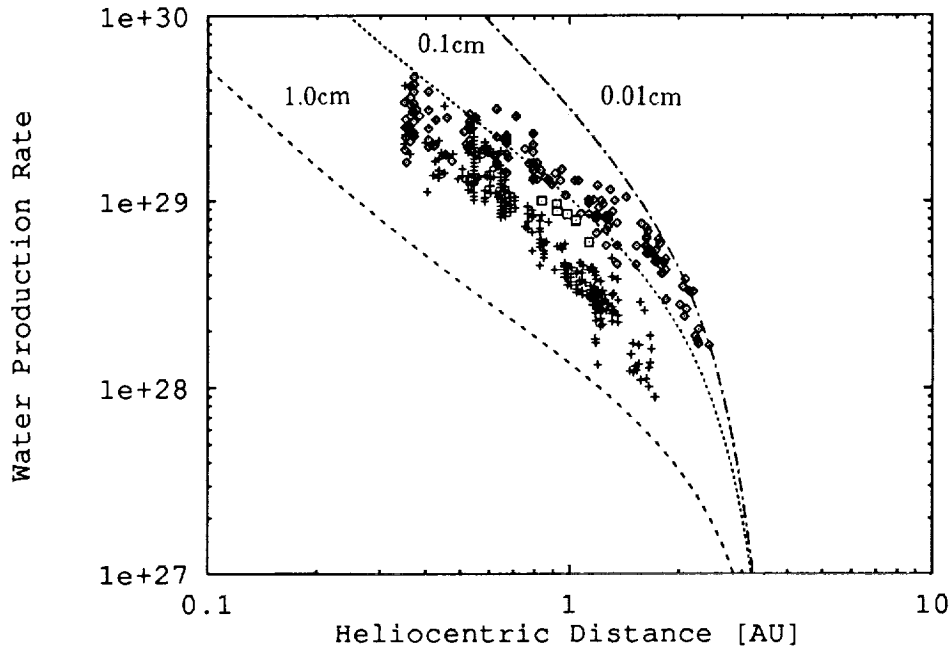$$-K(T)\Delta T|_{s=c} = \frac{L}{N_0}\dot{Z}(T_e),$$ (3)

Figure 2: Reduced and calculated water production rates. The plotted curves are computed production rates for the dust mantle case. The values in the graph are depths of the dust mantle. The symbols are as the same as the Fig.1. The IUE data that were observed after the perihelion are also plotted as square symbols.

where A_s and ϵ_s are the albedo at visible and infrared emissivity respectively. We assumed $A_s = 0.05$ and $\epsilon_s = 0.9$. σ is the Stefan-Boltzmann constant. J is the solar constant and L is the latent heat of water vapor. N_0 is the Avogadro number, $Z(T_e)$ is the sublimation rate at the icy core surface of the nucleus. We calculated L and Z according to Cowan and A'Hearn(1979). θ is the solar incident angle. If we consider a rapidly rotating nucleus, the averaged value for $\cos\theta$ is 0.25. The heat conducted through the non-volatile mantle is represented as the term $(-K(T)\Delta T|_s)$. The thermal conductivity K is given by,

$$K(T) = K_c + 4\sigma\epsilon_s l T^3, \tag{4}$$

where the K_c is the bulk conductivity of the mantle material and l is the intergrain distance. We assumed $60.0 \text{ ergcm}^{-2}\text{s}^{-1}\text{K}^{-4}$ and $100\mu\text{m}$ for the the conductivity and the distance respectively.

Solving the above set of equations, we can evaluate the water production rate per unit area at a given heliocentric distance. If the nucleus is spherical, we can simply translate it into a total production rate by assuming its radius. To adjust the calculated rates with the observed rates using the above value at the early part of its inbound, where the mantle would not have been well developed, we took 3km radius for the the nucleus.

As our model does not include the accretion process of dust particles on the surface of the nucleus, the depth of the mantle is assumed to be constant. Instead, we calculated the rate at several depth cases. Fig. 2 shows the computed production rates for several mantle thickness and the reduced production rates from the visual observations. From the case of our calculation, it suggest that the surface of the nucleus was initially mantle free, and the mantle developed gradually as the comet was approaching the sun. Near the perihelion, the thickness of the mantle grew several millimeters, but the rate of the mantle developing became to decrease after the perihelion. This change would be caused by the insulating effect of the well developed mantle layer.

4   Concluding Remarks

We showed that the water production rate can be related to the visual brightness variation of Comet Austin. These data give us useful information to understand cometary activity. In Fig. 2, the variation of the water production rate versus heliocentric distance showed asymmetry that was less active after the perihelion. Our model calculations suggest that this asymmetry might be caused by a developing dust mantle layer on the surface of the nucleus, because this layer reduced the sublimation rate at the icy core surface as a result of its low thermal conductivity. The thickness of the dust mantle layer would gradually be increased by accretion of the emitted dust particles in the inbound trajectory. After the perihelion passage, the developed dust mantle might act as a insulating layer against the sublimation of ice.

When did the dust mantle initially start to develop? Watanabe *et al.*(1990) reported that comet Austin showed a dust tail at a large heliocentric distance in its inbound. Their dynamic analysis of the dust tail revealed that the dust particles that formed the tail were ejected at ~ 11 AU. Such active dust release would also create the dust mantle. Our model calculations and the observed range of the heliocentric distances, however, could not determine when the dust mantle started to develop. Brightness observations at farther distance from the sun are needed to improve our knowledge of comets.

Acknowledgements

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