Abstract no. IT-2b-1

GAS PRODUCTION CURVES AND THEIR INTERPRETATION

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The discovery of C/1995 O1 (Hale-Bopp) at 7 AU from the Sun provided the first opportunity to follow the activity of a bright comet over a large range of heliocentric distances r_h. Production rates of a number of parent molecules and daughter species have been monitored both pre- and post-perihelion. CO was found to be the major driver of the activity far from the Sun, surpassed by water within 3.5 AU whose production rate reached 10^{31} s^{-1} at perihelion. Gas production curves obtained for various species show many distinct behaviors with r_h.

Gas production curves contain important information concerning the physical state of cometary ices, the structure of the nucleus and all the processes taking place inside the nucleus leading to devolatilization. They are relevant to the study of several other phenomena such as the sublimation from icy grains, dust mantling or seasonal effects. For some species, such as H_2CO or HNC, they permit to constrain their origin in the coma.

In this paper we briefly discuss models of subsurface gas production in distant comets and predictions of how such a source may vary as the comet moves along its orbit, approaching perihelion and receding again. Features in the observed gas production curves of comet Hale-Bopp are interpretable in terms of either subsurface production (typical example: CO) or free sublimation (typical example: H_2O) with some species, like CH_3OH, apparently showing a mixture of these behaviors. Possible implications for the lateral activity pattern and vertical stratification of the cometary ices are reviewed.

Abstract IT-2b-2

DUST EMISSION

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Text of abstract not yet received.

Abstract CT-2b-1

POST–PERIHELION OBSERVATIONS OF COMET HALE–BOPP (1995 O1)

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Following extensive northern hemisphere observations from July 1995 to May 1997, our observational campaign of Comet Hale–Bopp (1995 O1) resumed from Perth Observatory in the second half of 1997. We plan to present preliminary results from narrowband photometry of the comet using the new, Hale–Bopp filter set, and will compare the comet's behavior after perihelion to that determined from measurements obtained prior to and near perihelion from Lowell Observatory. During this earlier interval, Comet Hale–Bopp typically produced gas and dust at rates of 20 and 100 times greater, respectively, than we observed at the same heliocentric distances for Comet Halley in 1985/86. Even at 7 AU, Hale–Bopp was producing dust at a rate greater than we have measured for any other comet at any distance during 21 years of photometry of more than 100 comets. Photometry of Hale–Bopp obtained near perihelion yield peak production rates (Q(X) molecules/sec) of: 4×10^{30} for OH, 1.5×10^{28} for CN, and 1.6×10^{28} for C_2. Peak dust production ($Af\rho$) was 1.2×10^{6} cm. The ratio of the trace species to water (as measured by OH) classifies this comet as "typical" in our current compositional taxonomy [cf. A'Hearn *et al.,* 1995, *Icarus* **118**, 223-270], similar to that of other long-period comets. From the observed production rate of OH, we calculate the minimum diameter of Hale-Bopp's nucleus to be 17 km. However, the presence of persistent jets in the coma suggests that most activity emanates from localized sources, implying that the actual diameter of the nucleus is substantially larger. This research was supported by NASA.

Abstract CT-2b-2

MODELLING GAS AND DUST RELEASE FROM COMET HALE-BOPP

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Numerical simulations of the evolving activity of comet Hale-Bopp are presented. A porous, spherical nucleus, 20 km in radius, made of amorphous ice, dust, and occluded gases is considered. The main effects included in the numerical code are: crystallization of amorphous ice and release of occluded gas, condensation, sublimation and flow of gases through the pores, changing pore sizes, and flow of dust grains. The model parameters, such as initial pore size, effective drag force on dust grains, dust grain size, are varied in order to match the observed activity of the comet. In all cases, a sharp rise in the activity of the nucleus occurs at large heliocentric distances pre-perihelion (depending on parameters), marked by an increase in the CO flux and in the rate of dust emission by several orders of magnitude. This is due to runaway crystallization taking place a few meters below the surface, accompanied by the release of the trapped CO (as well as other gases). The runaway is eventually quenched and a period of sustained, but variable activity ensues. The emission of water molecules is found to surpass that of CO at a heliocentric distance of 3 AU. Thereafter the activity is largely determined by the behaviour of the dust. If a dust mantle is allowed to build up, the comet's activity (and brightness) does not increase dramatically as it approaches perihelion; if most of the dust is ejected, the surface activity increases rapidly, producing a very bright comet.

Abstract CT-2b-3

THE FORMATION OF A LARGE SAMPLE OF GAS-LADEN AMORPHOUS ICE AS A COMET ANALOG

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Amorphous gas-laden ice is the prime constituent of comets, except their thermally crystallized outer layers. Up till now, very thin (μm to mm thick) amorphous ice samples were studied, as well as tens of cm thick samples of crystalline ice, sprayed as water droplets into liquid nitrogen, in the KOSI experiments. We present the first experimental results from a newly constructed machine which produces *a few cm thick sample of gas-laden amorphous ice.* The thermal behavior and gas evolution of this ice sample upon heating is described. This thick ice sample is the closest to a real comet and enables the study of large-scale processes in a comet nucleus.

Abstract CT-2b-4

ON THE RELATIONSHIP OF CHEMICAL ABUNDANCES IN THE NUCLEUS TO THOSE IN THE COMA

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One of the goals of comet research is the determination of the chemical composition of the nucleus because it provides us with the clues about the composition of the nebula in which comet nuclei formed.

It is well accepted that photo-chemical reactions must be considered to establish the abundances of mother molecules in the coma as they are released from the comet nucleus or from distributed dust sources in the coma. However, the mixing ratios of mother molecules in the coma change with heliocentric distance. Thus, to obtain the abundances in the nucleus relative to those in the coma, we must turn our attention to the release rates of mother molecules from the nucleus as a function of heliocentric distance. For this purpose, we assume three sources for the coma gas: the surface of the nucleus (releasing mostly water vapor), the dust in the coma (the distributed source of several species released from dust particles), and the interior of the porous nucleus (the source of many species more volatile than water). The species diffusing from the interior of the nucleus are released by heat transported into the interior. Thus, the ratios of volatiles relative to water in the coma are functions of the heliocentric distance and provide important information about the chemical composition of the nucleus.

We determine the abundance ratios of various mother molecules relative to water from many remote-sensing observations of the coma as a function of heliocentric distance. Comet Hale-Bopp is ideal for this purpose since it has been observed using instruments in many different wavelength regions over large ranges of heliocentric distances. The ratios of release rates of species into the coma are than modeled assuming various chemical compositions of the spinning nucleus as it moves from large heliocentric distance through perihelion. Since the heat flow into the nucleus will be different after perihelion than before perihelion, we can also expect different gas release rates after perihelion compared to those observed before perihelion. Since not all the data are available yet, we report on progress of these calculations.

Abstract CT-2b-5

LONG-TERM EVOLUTION OF THE OUTGASSING OF COMET HALE-BOPP FROM RADIO OBSERVATIONS

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C/1995 O1 (Hale-Bopp) has been observed on a regular basis since August 1995 at millimetre and submillimetre wavelengths using IRAM, JCMT, CSO and SEST radio telescopes. The observations of eight molecular species (CO, HCN, CH_3OH, H_2CO, H_2S, CS, CH_3CN, HNC) for which we monitored the production rates as a function of heliocentric distance (r_h) will be presented. This long-term monitoring extends from 7 AU pre-perihelion to 4 AU post-perihelion and is still going on. As comet Hale-Bopp approached and receded from the Sun, these species displayed different behaviours. Far from the Sun, the most volatile species were found in general relatively more abundant in the coma, but there was no precise correlation between the overabundances and the equilibrium sublimation temperatures of the species.

The HNC/HCN abundance ratio increased with decreasing r_h, up to more than 15% around perihelion, questioning its true value in cometary nuclei. A steep increase of the production rate as a function of heliocentric distance was also found for H_2CO and CS. Around perihelion, and less than 1.5 AU from the Sun, the relative abundances where rather stable and approached those found in other comets near 1 AU. Post-perihelion versus pre-perihelion production rates evolutions will be discussed.

The kinetic temperature of the coma, estimated from the relative intensities of the CH_3OH and CO lines, increased with decreasing r_h, from about 10 K at 7 AU to 110 K around perihelion. The expansion velocity of the gaseous species, derived from the line shapes, also increased with a law close to $r_h^{-0.5}$. These two parameters follow a symmetric evolution relative to perihelion, for observations extending up to 3 AU.