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Development of pressure measurement method of impact-induced vapor clouds

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Introduction:

Impact vaporization is thought to have played an important role in both the origin and the evolution of planetary atmospheres. Extensive research has revealed many aspects of impact vaporization processes. However, little has been understood about chemical reaction in impact-induced vapor clouds yet. One of the main reasons for this is that there is no experimental method to measure directly the thermodynamic state of impact-induced hot vapor. However, impact flash spectroscopy has been developed to overcome this difficulty. The existing experimental techniques and analytical methods allow determining temperature, line-of-sight column density, the degree of ionization, and chemical composition of a hot partly dissociated vapor cloud. Nevertheless, these observables are not sufficient to provide a definitive thermodynamic state of gas. Complete thermodynamic description requires pressure. The purpose of this study is to develop a technique to measure pressure of impact-induced vapor clouds. The basic approach is to measure the Lorentz broadening of hydrogen lines.

Experiments:

Since impact energy achieved by conventional laboratory launchers, such as 2-stage light gas guns, is not high enough to atomize hydrogen, we used a high-energy pulse laser (Nd:YAG, 1064nm) to produce hot vapor plumes. A hydrous mineral, gypsum (CaSO4 2H2O), was used as a target. Gypsum contains not only hydrogen, which has high pressure broadening efficiency, but also calcium, whose emission lines have been used to determine the temperature of impact-induced vapor in previous studies. Argon gas was used as the ambient atmosphere and the pressure was maintained to be 40 torr throughout the experiments. The energy of each YAG laser pulse is 240mJ. The laser beam was focused by a quartz lens on a spot with 0.5mm of diameter. The pulse width is 10ns. Generated vapor plume was observed with a spectrometer equipped with an intensified charge-coupled device (ICCD), which can control the exposure time down to 10ns. The exposure timing of the actual observation varied with an increment of 100 ns.

Results:

In order to measure the FWHM of the H_alpha line accurately we deconvolved the observed spectral line profiles into an instrument line profile and a 'true line profile'. Here the 'true line profile' is assumed to be Lorentzian because the contribution of Doppler broadening is negligible in the experimental conditions. When the obtained Lorentz width (W_L) is plotted as a function of time, it shows a very clear correlation with time. In fact, the scatter in this plot is much less than that in temperature-time diagram obtained from analysis of the same spectral data in this study. This demonstrates that the Lorentz broadening was measured very accurately.

Although Lorentz width (W_L) is a function of pressure (P), it also depends on temperature (T); W_L ~ P/T^0.5. In other words, the effect of temperature on W_L needs to be adjusted to obtain pressure. Since we could measure the emission temperature of hydrogen, we use this temperature for this adjustment. When the temperature-adjusted Lorentz width (i.e., relative pressure) is plotted as a function of temperature, the data points follows a power-law function: T ~ P^1.24. If both idal-gas and adiabatic approximations hold in the experimental conditions, the power-law index 1.24 indicates that the ratio (gamma) of heat capacities is about 1.3. Theoretical consideration indicates that the highly dissociated gas like the vapor plume in this study has gamma between 1.1 and 1.3 in general. Thus experimental result is consistent with the theoretical prediction. This strongly suggests that the method used in this study provides accurate pressure measurement.