P136-P002 Room: Poster Session Hall Time: May 27

Development of a pressure measurement method of impact-induced vapor clouds using atomic emission spectroscopy

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Introduction

Impact vaporization and chemical reaction in the vapor cloud may have played an important role in the formation and evolution of planetary atmospheres. We need to know thermodynamic values, such as temperature and pressure, to study chemical reactions in impact vapor clouds. Although a method to measure the temperature of impact vapor cloud has been developed [1], a pressure measurement method has not been studied well yet. One possibility is to use stark broadening effect [2, 3]. However, these pressure estimation methods have several problems.

In this study, we conducted experiments to develop a pressure estimation method that uses emission lines expected to be easily observable in impact experiments and not influenced self-absorption sensitively.

Experiments

We used high-energy pulse laser (Nd:YAG, 1064nm) to produce vapor clouds and also used calcium hydroxide ($Ca(OH)_2$) as a target. It contains calcium (Ca), whose emission line intensity can be used for temperature measurements. The widths of its ion (Ca^+) emission lines and hydrogen atomic lines can be used for measuring electron density. H line cannot be observed in laboratory-scale impact vapor clouds because of its high excitation energy. However, electron density using H line width is reliable because it is widely used in plasma science field. So it can be used to judge whether electron density measured by Ca^+ line is valid or not.

A vacuum chamber was kept about 10^{-3} mbar. The energy, width, intensity of each YAG laser pulse was 400 mJ, 13 ns, and $1.5x10^9$ W/cm, respectively. The generated vapor plume was observed with a spectrometer equipped with an ICCD. The exposure time of the observations was varied with an increment of 100 ns.

Results

We measured Ca^+ 373.69 nm line and H 486.13 nm width, both of which are free from strong self-absorption because of the high energy levels of their lower states. Observed spectrum is composed of a 'true line profile' and an instrumental line profile. Thus we generated line profiles by a conboluting Lorentz function with the observed instrumental line profile. Then we searched for the optimum line width of the Lorentz function to fit the observed line profile best using the least squares method. Based on the best fit line width, we obtained the electron density using the formula by [4].We found that estimated electron density in vapor clouds using Ca^+ 373.69 nm line and H 486.13 nm line agree with each other within the range of error bars and that both decrease with time at approximately the same rate.

To estimate vapor pressure, we calculated the ionization ratios of Ca, H, and O from electron density and temperature, which is estimated with the method by [1], using Saha's equation. Then, from the obtained ionization ratio and electron density, we calculated atomic number density, which allows us to estimate pressure using the equation of state of ideal gas.

The estimated pressure also declined with time and follows a power-law function: $P\tilde{~}T^{3.83}$. If both ideal-gas and adiabatic approximations hold, the power-law index 3.83 indicates that the ratio of specific heat is about 1.35. This ratio is between actively dissociated gas (~1.1) and monoatomic gas (1.67). This result and the agreement between electron density derived from H line broadening and that from Ca^+ line broadening strongly suggest that the electron density (i.e., pressure) estimated from Ca^+ in this study is accurate. Thus, the line width of Ca^+ at 373.69 nm may serve well as a reliable pressure indicator of impact vapor plumes.

References

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