Intensity of optical emission due to hypervelocity impacts

Seiji Sugita[1]; Peter Schultz[2]; Sunao Hasegawa[3]

[1] Dept. of Complexity Sci. & Eng., Univ. of Tokyo; [2] Dept. of Geol., Brown Univ.; [3] ISAS/JAXA

Introduction: Many precious experiments have shown that the intensity of optical emission during hypervelocity impacts is proportional to impact velocity raised to a power, which varies from 4 to 8, depending on impacting materials. It is not yet well understood, however, what controls this power-law exponent. Nevertheless, the exponent value is required for predicting the intensity of optical emissions from hypervelocity impacts. Such a prediction is particularly relevant when the Deep Impact mission produces a collision between a metallic projectile and a comet in July 2005.

One reason why the basic mechanism controlling the emission intensity has not been understood is the absence of spectroscopic observation with high time resolution and wavelength resolution. Time-integrated and/or spectrally integrated spectra are difficult to interpret. Thus, in this study, we conducted a series of impact experiments in order to obtain emission spectra of hypervelocity impacts with high resolution in both time and wavelength [1].

Experiments: The experiments were carried out at NASA AVGR with impact velocities ranging from 2 to 5.5 km/s by Cu projectiles at 45 degrees of impact angle. Two spectrometers with ICCD cameras are used [1]. We focused on the earliest component of the impact-induced luminescence, which contains the most intense atomic emission without a strong blackbody. The exposure time of the spectrometers were set to be 0.5 - 2.5 micro sec after the first contact of impact. This generally corresponds to the jetting phase of impacts.

Experimental Results: Little emission occurs at velocities lower than 2 km/s. Above 2 km/s, CaO molecular bands, Na atomic lines, and Cu atomic lines appear, but there is no observable Ca line. As impact velocity increases, many Ca atomic lines start to appear. The relative intensities of Ca with respect to Na and CaO increase strongly with velocity. The emission intensity integrated over the entire observed wavelength range (435 - 650 nm) follows a power-law function of impact velocity well with the best-fit exponent of 5.1. The intensities of individual emission lines as a function of impact velocity also are also well represented by power-law functions, but the power-law exponents vary over a wide range (2.1 - 9.1). The power-law exponents correlate with the excitation energy of the electronic transition associated with the emission lines.

Theory: In order to understand the observed power-law exponents, we theoretically assessed the effects of chemical equilibrium, partition function, and ionization. The calculation results indicate that the effects of chemical equilibrium and partition function are small but that the effect of ionization is very large. The plasma calculation indicates that the emission intensities of atoms (e.g., Ca and Na) with low ionization energies are reduced significantly at high temperatures, whereas those atoms with high ionization energy are not.

One implication inferred from this result is that the Cu is a very efficient element to produce the initial impact flash because it has both high ionization and low excitation energies for major emission lines. Combined with its high impact impedance and low cosmic abundance, this spectroscopic property makes Cu an excellent projectile material for probing an unknown planetary body.

Conclusion: The intensity of optical emission is strongly controlled by electronic excitation and ionization. The former controls the relative intensity ratio among emission lines from the same atom, and the latter does the intensity ratio of emission lines between different atoms. Such fundamental understanding of impact plasma process will help us predict the intensity of early-stage optical emissions from the Deep Impact collision.

Reference: [1] Sugita, S. et al. (2003) JGR, 108(E12), 14-1 - 14-17.