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Properties of the impact-produced lunar exosphere during Perseid 2009 meteor shower

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Abstract

Quick variability of brightness of Na lines in the lunar exosphere during maximum of Perseid 2009 meteor shower is detected and explained by impacts of Perseid meteoroids at the level of 10^{-16} g cm^{-2} s^{-1}. Non-detection of lines of atoms of Ca, Al, and Si is explained by formation of metal oxides and condensation of dust particles.

1. Observations and data reduction

The spectroscopic observations of NaI resonance lines (5890 and 5896 Å) in the lunar exosphere were performed on August 12-13, 2009 and August 13-14, 2009 during maximum of Perseid meteor shower (see Table 1) with echelle spectrograph MMCS (Multi Mode Cassegrain Spectrometer) at the 2-m Zeiss telescope (Terskol branch of Institute of Astronomy of Russian Academy of Sciences, Kabardino-Balkaria, Russia). The slit of the spectrograph has height of 10″ and width of 2″. We used the CCD with size of 1245x1152, where 31 spectral orders in the range from 3720 to 7526 Å were registered. The spectrograph resolution was R = 13 500; the signal to noise ratio in the spectra was about 50 at the position of NaI lines. Six echelle spectra were obtained at the distances of 50″, 150″, and 250″ (90, 270, and 455 km, respectively) from the lunar limb above the north pole which was bombarded by Perseid's meteoroids. The exposure time of each spectrum was equal to 1 800 s. The echelle package of the MIDAS software system was used for the spectroscopic data reduction: removing the cosmic trace, definition and extraction of echelle orders, the wavelength calibration using the spectrum of a Fe-Ar lamp, the flux calibration using standard star HD214923. As the result of reduction we have the spectrum in absolute fluxes. This spectrum is superposition of spectrum of lunar exosphere and solar spectrum reflected from the Moon surface and scattered in the Earth atmosphere. For extraction the spectra of lunar exosphere we use the solar spectrum taken as spectrum of daytime scattered light. The signal-to-noise ratio of obtained spectra is about 40. Spectral transparency of Earth's atmosphere at 600 nm was taken as 88 % at 45 degrees in accordance with [3]. Accuracy of measurements of Na line areas is about 2.5 %.

2. Results of observations

Brightness of Na lines at 270 and 455 km from the limb is 109 % and 93 % in comparison with that at 90 km on Aug. 12/13, 2009. Brightness of Na lines at 270 and 455 km from the limb is 89 % and 58 % in comparison with that at 90 km on Aug. 13/14, 2009. Height scale and temperature of Na atoms are estimated as 700±100 km and 3000±500 K on Aug. 13/14.

Temperature of Na atoms on Aug. 12/13 cannot be estimated because the column density of Na atoms changes significantly during observations due to meteoroid's impacts. Intensity of solar wind on Aug. 12/13 and 13/14 was comparable [4], and solar flares cannot explain significant difference between two sets of observations. Obtained results can be explained as evidence of quick variability of brightness of Na lines during maximum of Perseid meteor shower which is responsible for additional column density of impact-produced Na atoms of about 5×10^{8} cm^{-2} on Aug. 13, 2009 at 0-1 UT.

Table 1. Parameters of observations of the Moon.

Time of Observations, UT	Distance from the surface, km	Position angle, degrees	Intensity of Na D2 line, R
Aug. 12, 23:13 - 23:43	90	-19	146
Aug. 12, 23:54 – Aug. 13, 0:24	270	-19	159
Aug. 13, 0:43 -1:13	455	-19	137
Aug. 13, 23:22 – 23:52	90	-15	152
Aug. 13, 23:53 – Aug. 14, 0:23	270	-15	136
Aug. 14, 0:26 – 0:56	455	-15	89

Taking properties of Perseid's impacts from [5] our results can be explained by single impact of Perseid meteoroid with mass of about 15 kg or additional mass flux of meteoroids of about 10^{-16} g cm^{-2} s^{-1}. Upper limits of intensity of lines of other elements Fe (3859 Å), Si (3906 Å), Al (3962 Å), Mn (4033 Å), Ca (4227 Å), Ti (5036 Å), Ba (5536 Å), and Li (6708 Å), and are estimated as 14, 16, 12, 18, 11, 13, 14, 17 R, respectively, at 3 σ level.

5. Condensation and formation of molecules during Perseid's impacts

Elemental composition of impact-produced cloud is calculated as a mixture of CI chondrite and ferroan anorthosite with mass ratio of 1:50 [5]. Assuming temperature of impact-produced atoms of 3000 K and taking g-factors from [6] theoretical intensity of lines of impact-produced atoms is calculated without taking into account effects of condensation and formation of molecules as 3.1, 980, 580, 0.06, 4500, 4.8, 1.3, and 8.9 R for Fe, Si, Al, Mn, Ca, Ti, Ba, and Li lines, respectively. Thus, intensities of Al, Si, and Ca lines are at least in 50, 60, and 420 times less than expected based on stoichiometric model.

Main Al, Si, and Ca-containing species in the impact-produced cloud are AlO, AlO_2, SiO_2, SiO, $Ca(OH)_2$, CaO respectively [5]. Based on approach [5] and available molecular constants photolysis lifetimes of AlO, AlO_2, SiO, SiO_2, $Ca(OH)_2$, and CaO at 298 K are estimated as 6, 10^9, 320 000, 170 000, 90 000, and 6 s, respectively. Thus, formation of molecules and low photolysis rate of these molecules can explain low content of atoms of Al, Si, and Ca in the impact-produced cloud. Condensation temperatures less than 3700 and 2400 K for Al and Ca, respectively, [5] can explain also depletion of these refractory elements in the gas phase.

6. Summary and Conclusions

Based on spectral observations of Na lines in the lunar exosphere maximum of activity of Perseid meteor shower on the Moon is observed on Aug. 13, 2009 at 0-1 UT. These observations give strong support to formation of slowly photolysed Al-, Si-, Ca-bearing species and condensation of Al-, Si-, Ca-containing dust particles in the impact-produced clouds formed during Perseid's collisions with the Moon.

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