RADIATION FLASHES DURING METEOROID PENETRATION THROUGH ATMOSPHERES OF GIANT GASEOUS PLANETS. I.B.Kosarev, I.V.Nemchinov. Institute for Dynamics of Geospheres, Russian Academy of Sciences, Leninsky pr., 38, bld.6, Moscow, 119334, kosarev@idg.chph.ras.ru

Giant gaseous planets are ideal targets for detection impact generated flashes and determination size-frequency distribution of small bodies in the outer parts of the Solar System and their chemical composition.

First, the cross-section of these planets are very large. Second, due to huge mass and gravity of these planets the velocities of impactors are also very large, thus the specific kinetic energy of the impactor (per unit mass) is much larger than in the case of impacts onto Earth. That increases the optical energy of flashes for the same influx. Third, the upper layers of the atmosphere above clouds almost completely consist of hydrogen and helium which weakly radiate in the visible. Thus lines and molecular bands being detected in the spectrum should be attributed to meteoroids vapor and may be used to determine their chemical composition. Only for large and deeply penetrating bodies the shock wave becomes opaque and clouds begin to influence the radiation impulse. The rate of impacts and spectra got from observations of flashes may give insight into the structure and composition of the outer parts of the Solar System. Though impact processes for all giant gaseous planets are similar in their main features we shall give examples only for Jupiter.

Kuiper Belt consists of a large number icy objects - planetesimals remaining from the moment of the Solar System formation [1]. Some of the these Kuiper Belt Objects (KBO) are processed by collisions with other planetesimals and form a steady source of Jupiter-family comets. These collisions may produce small fragments with sizes down to meters and even millimetres and microns. The distribution of these fragments by sizes is not known as yet. A large number of small fragments of these KBO’s with sizes down to meters may hit Jupiter each year and each month and even several times each day.

Satellite based observations of bright flashes in the atmosphere of Earth, including day-time bolides caused by meter-sized meteoroids give the number of such impacts 25 per year [2]. As the Earth is 12 times smaller than Jupiter that may give a rough estimate of impacts on Jupiter 3000 per year or 10 times per day. But source of Jupiter impactors is quite different, as well as the velocity of impacts, and chemical composition of the atmosphere.

Estimates of the number of impacts onto Jupiter are based on the number of observed comets and power laws approximating the size frequency distribution, that is \( N( > r) \sim r^{-b} \), where \( N \) is the cumulative number of fragments with radii larger than \( r \) and \( b \) is the index assumed to be constant in a wide range of \( r \). These power laws allow to extrapolate from km-sized KBO down to tens of meters and meters. Indexes in the power law used by different authors are different.

The changes in the index from 3 to 2 produces uncertainty in the number of impacts by several orders of magnitude. Observation of flashes may make more certain these values and answer if the collision cascade in the Kuiper Belt reaches its steady state and if some physical process, e.g. sublimation of easily evaporated volatiles install a lower limit of surviving fragments sizes, even at such large distances from the Sun as 5-40 AU.

There may be other types of impactors (asteroids from the main belt, Trojans etc.). To discriminate we should use spectral data.

The kinetic energy of a 1 m in diameter icy object (with density of 1 g/cm\(^3\) and mass of about 0.5 \( \times 10^6 \) g) impacting Jupiter with the velocity of 64 km/s is 10\(^{12} \) J. The intensity of light depends on luminous efficiency which has not been determined for such small objects in the Jovian atmosphere as yet. For similar objects in the Earth’s atmosphere and velocity of 30 km/s at the altitude of 50 km luminous efficiency is about 10\% [2]. So the energy of the radiation impulse is about 10\(^{11} \) J. That exceeds the greatest energy of lightning flashes detected in the Jupiter’s atmosphere by Galileo Spacecraft [3] by an order of magnitude and the lowest detected flashes by two orders of magnitude.

To obtain quantitative estimates of the radiating gas volume spectrum we have chosen a 1 m in radius meteoroid moving with the velocity 64 km/s in the Jovian atmosphere above the clouds of \( NH_3 \) (\( H = 40\text{-}50 \) km), i.e. nearly at the pressure level 0.1 bar. The effective width of that volume is approximately 5 times of a meteoroid diameter, but its length is twice a width according to semiempirical model of [4]. So we have the approximate value of radiating surface \( S \) to be equal to 200 m\(^2\). Assuming the area to be perpendicular to the line of sight we have the total intensity \( F(\lambda) = S \cdot I_\lambda \) where the specific intensity \( I_\lambda \) is a solution of radiative transfer inside the meteor volume. As the cold meteor size is small relative to the entire radiative volume, the meteoroid can be neglected. With
a constant effective temperature $T_{\text{eff}}$ the radiative transfer equation can be easily integrated.

In calculation of optical properties of the radiating medium we have assumed the chemical composition of the meteoroid vapor admixture is that of H-chondrite [5] and $T_{\text{eff}} = 5000 \text{ K}$. The chemical composition of the mixture consisting of chondrite vapors mixed with the atmospheric gas was modeled on the base of 16 elements: H-He-C-O-Fe-Mg-Si-Al-Ca-Na-K-Cr-Mn-Ti-Ni. The number of meteoroid vapor atoms in the unit volume is 5% and of the atmospheric gas is 95% (according to semiempirical model by [4]).

Results for the total intensity $F(\lambda)$ (expressed in kW ster$^{-1}$) are presented by the graph. The total number of photons emitted in steradian is near of $10^{32}$ per sec. For the black body approximation their number must be in ten times more, but obviously that approximation isn’t valid, only spectral line tops are fully black. Spectral line widths are of the order of 0.01-0.1 $\text{km}/\text{s}$. The background continuous spectrum is dominated by photodetachment of the negative hydrogen ion which is optically thin. Only three lines of hot atmospheric gas are seen in visible spectra. These are Balmer lines 6562.8, 4861.32, and 4340.46 $\text{nm}$.

The solar radiation flux at Jupiter is 52 W/m$^2$. For the albedo $\lambda = 0.41$ the unit surface of Jupiter reflects 21 W/m$^2$. The number of solar photons reflected by a unit surface is $10^{20}$ photons/m$^2$ per sec. A meter-sized meteoroid moving in the Jovian atmosphere with the velocity of 64 km/sec at an altitude of 70 km above a 1 bar level emits $10^{26}$ photons per sec. At an altitude of 40 km this number increases to about $10^{27}$ photons/sec and at the altitude of 100 km to about $10^{29}$ photons/sec.

That gives the size of the area seen by telescope at the sunlit side to detect the flash of course, at night side it is much easier to detect small by spacecraft sensors flashes. The duration of the flash is about 1 sec.

Impacts of the Comet Shoemaker-Levy 9 fragments onto Jupiter with radii of 0.15 to 0.7 km were detected by various spectral instruments on board of Galileo spacecraft [6,7] at the distance of 240 $10^6$ km. Light flashes from fragments as small as 10-20 m [8] have been detected by ground based and Hubble Space telescopes [9].

Analysis of the meteor data on the Earth, of the historic SL 9 Comet fragments impact onto Jupiter, of lightning flashes on Jupiter and a single example of a small meteor (created by a meteoroid with mass of about several kg) detected on Jupiter at the distance of $0.5-10^6$ km [10] shows that detection of small bodies impacts on Jupiter is quite possible, using spacecrafts with such optical instruments as Galileo imagers and even the photoelectric sensors (used nowadays on satellites at geostationary orbits) and (for large impactors) even through ground based telescopes and Hubble Space Telescope. It seems reasonable to include detectors of intensity and spectra of meteor flashes into the scientific packages of future space missions to giant planets and beyond, and additionally analyze data already obtained by previous missions, e.g. to reveal how many flashes detected on Jupiter are really meteors and not lightnings.