ON COLLISION OF SECONDARY NUCLEI OF COMET P/SHOEMAKER-LEVI 9 (1993E) WITH JUPITER

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ABSTRACT. In July 1994 the comet P/Shoemaker-Levi which in July 1992 split in the Roche lobe of Jupiter onto 21 fragments, then collided with Jupiter at the altitude near -45^o. The consequences of this collision in the form of outbursts of brightness of the Jupiter satellites/ emergence of new structures in the cloud layer of Jupiter (type of the Great Red Spot), generated of radiowaves and appearance of aurora, were observed at numerous world observatories, as well as from space probes. Since the moment of the split of comet P/Biela in 1846 onto two comets, astronomers have been already observing the 24th comets whose primary nucleus split onto secondary nuclei. The mechanism of destruction of the comet Shoemaker-Levi 9 was the tidal force of Jupiter which split the parental nucleus onto 21 icy pieces along one straight line. Prognosis of outbursts of brightness of Jupiter's satellites as a result of the light outburst in the atmosphere of the planet in the course of collision of the comet Shoemaker-Levi 9 with the latter is given. The Astronomical Observatory of Kiev University scientific program of observations of the collision of the comet Shoemaker-Levi with Jupiter is also presented.

Key words: Comet; capture; collision; Jupiter; bolide; satellite

Introduction

In July 1994 astronomers for the first time in the history of science will observe the unique event - impact of the 21st secondary nucleus of comet P/Shoemaker-Levi 9 (SL9) with giant planet Jupiter. Though the fragments of the split comet will fall on the night side of the planet, great energy generated as a result of colliding cometary nuclei with one another with Jupiter's atmosphere will yield a series of secondary events which will be registered at the ground-based observatories and from space probes.

Such secondary events may be short-period increases in the Jupiter satellites' brightnesses reflecting the light outburst of the impact, emergence of new structures in the cloudy atmosphere of Jupiter (type of curls similar to the Great Red Spot) formation of a ring around Jupiter, appearance of aurora in Jupiter's magneto sphere, generation of radio waves and other effects.

Statistics of Cometary Nuclei Splitting

The flight of space apparatus near the comet Halley nucleus on March 1986 is a bright evidence of the conception of the cometary ice origins of cometary nuclei: the content of water H_2O in the nucleus of P/Halley was 80 % from the total nucleus mass (Moroz 1987), Therefore, as has been expected earlier, cometary nuclei appeared mechanically low strength tensile bodies in the Solar System, This fact was known to astronomers at last since the moment of splitting of the primary nucleus of comet P/Biela in 1846 onto 2 secondary nuclei A and B. with then were observed in 1852 in the form of two comets with tails moving around close orbits. Since then nuclei splitting onto secondary fragments has been observed in other 23 comets.

Catalogs of the split comets were composed by Konopleva (1967), Pittich (1972), Golubev (1975), Sekanina (1982). The more detailed catalogue of the split comets is given in the work by Sekanina (1982). To the list of comets given by Sekanina, three more comets should be added. The Table contains the list of comets where splitting of nuclei was observed: 1 column - names of comets, 2 - a number of secondary nuclei N, the splitting moment τ_s, the heliocentric distance r_s and distance from the ecliptic plane z_s at the splitting moment, the time interval between moment of comet perihelion passage and the moment of splitting $\tau_s - T$.

Statistics of the split comets has led to the following results:

1. velocity of fragments escaping is linked with the heliocentric distance by the formula (Sekanina 1982)

$$V = B \cdot r^{-b} \qquad (1)$$

where $B = 0.70 \pm 0.09$ m/s and $b = 0.57 \pm 0.10$;

2. a tendency of the split of comets near the ecliptic plane is observed, tough there is no clear dependency, that might be explained by observation selection;

3. Physical mechanisms that lead to split of cometary nuclei may be tidal forces, chemical outburst of the nucleus, collision with meteor bodies, as well as centrifugal forces of the fast rotating nucleus. The influence of tidal forces is undoubted in the case of comets that had closely approached the Sun (comets 1882 II and 1965 VIII) and Jupiter (comets 1889 V and 1993e). Especially visible the action of tidal forces can be traced in the comet SL9, whose 21 secondary nuclei in the Roche lobe stretched along the straight line.

Discovery of the comet P/Shoemaker-Levi 9

The comet SL9 was discovered by Caroline and Gene Shoemaker and David Levi on the film obtained March 18, 1993 with the help of the 0.46-meter Schmidt telescope at the Palomar observatory. The object was located on the sky nearJupiter and was strong elongated in the east-west direction. As turned out, this elongation could be explained by the existence of 21st secondary nuclei were formed as result of the passage of the parental cometary nucleus inside the Roche lobe of Jupiter on July 1992. The nuclei were moving along similar orbits around Jupiter, and they were strong elongated ellipses. The rotation period of the 21-multiple comet around Jupiter was 2 years. As calculations showed, the next passage of the comet fragments through perijovion will occur during July 16-22; perijovion distance being less than the radius of the planet, from which it follows that the secondary nuclei will collide with Jupiter. Collision will occur at the latitude -45^o on the night side of the latter. During collision of the fragments with the planet energy from 10^{28} to 10^{31} ergs will be yielded that can be compared on the order with the energy of a solar outburst and $10^6 - 10^7$ times exceeds the energy which had yielded during the fall of the Tunguska meteorite in Siberia in 1908.

The secondary nuclei of the comet SL9 were designated by the Latin letters from A to W. The brightest nucleus is Q. The integral magnitude of the comet SL9 in 1883 according to the ground observations was $m_1 = 13.5 - 14^m$. Around each nucleus a dust coma and dust tails were observed comprising particles of micron sizes, submillimeter - size and meter - size boulders.

According to calculations (ESO Press Release 10/94, 1994) the first nucleus A will collide with Jupiter July 16, 1994 at 18:00 UT. The second nucleus B will fall in the morning July 17, 1994 at 03:00 ut. The nuclei A and B are rather small in size. And the first of the large nuclei E will collide with Jupiter July 17, 1994 at 15:00 Ut. The brightest nucleus Q (according to observations from the Hubble telescope HST it also split onto two nuclei) will fall July 20, 1994 at 20:00 UT. The last nucleus of the "comet train" W will collide with the planet July 22, 1994 at 8:20 UT. Error in these moments is $\pm 45^m$ tough near these events the processing of all obtained data will allow to improve them up to $\pm 15^m$.

Entry of large bodies into Jupiter's atmosphere

A problem of a separate large piece of nucleus of Shoemaker- Levy comet passing through Jupiter atmosphere is considered. It is assumed that: initial size (diameter) of a spherical body is 1 km, mean body density is 0.8 g/cm^3, velocity of entry is 60 km/s, zenith angle of entry is 45^o. Atmosphere density distribution with height $\rho(H) = \rho_0 \exp(-H/H^*)$, where $\rho_0 = 10^{-4}$ g/cm^3 at conventional height $H = 0$ (corresponds to atmospheric pressure of 0.5 atm), height of homogeneous atmosphere $H^* = 20$ km.

Shock wave is formed at height 400 km. Intensity of bolide radiation (of shock wave radiation) in integral light (by $T = 20,000$ K after Stefan's law) equals to $\approx 10^{24}$ ergs/s and during 10 s of the flight it will constitute quantity of order 10^{-3} as related to solar radiation at the distance of satellites Io or Europe.

Because of quick dissociation of sublimated parent molecules in near to the nucleus area of the comet (temperature here is 2600 - 3000 K), radiation in lines of oxygen and hydrogen is likely to be dominating one in visible region of the spectrum. Cyan is unlikely to contribute greatly to radiation, either.

The body is unlikely to reach the height of maximum deceleration $H_* = -100$ km, where the estimate of the velocity equals to 35 km/s, deceleration is - 27 km/s , because aerodynamic loads are too high there - 10^{10} N/m^2.

Explosion and flash of brightness should occur at aerodynamic pressure $10^7 - 10^8$ N/m^2, that is at about 100 km higher. We suggest that luminescence of the flash is due to stone fragments having mass of 0.1 - 1.0 g and density of 3 g/cm^3. Total mass of these fragments is assumed to constitute 10 per cent of comet nucleus mass which is left by the moment of flash, i.e. $\approx 10^{13}$ g. The short term flash of this kind ($\approx 10^{-2}$ s) can increase the satellites Io or Europe brightness in 0.2^m to 0.8^m.

Plans to Study the Event

Astronomical observatory of the Kiev University plans to realize the following program:

1. Patrol observations of the P/Shoemaker-Levy 9 (May-July 1994 near the Jupiter from the observational station of Kiev Astronomical observatory by means of telescopes AZT-8 (D=70 cm) and AZT-14 (D=50 cm), image converter tube and TV-equipment with narrow-band interference and polarimetric cometary filters in order to determine the parameters of gas and dust production rates from the secondary nuclei of the comet before the impact process. Attempt of TV-spectroscopy of the cometary nuclei with application of such telescopes as the 6-meter reflector of Special AO, 2.6-meter Shine reflector of Crimea AO and 2-m Zeiss reflector of Shemakha AO.

2. TV-observations of the equatorial zone of the Jupiter before and after the impact in order to find out the structure changes in the cloudy layer of the equatorial zone and in the southern hemisphere (down to -45°.): a) search for new vortex-like (type of the GRS) and other structures in the equatorial zone; b) search for a dark equatorial band that could be a shadow of the new dust Jupiter ring formed from the dust component of the secondary nuclei broken down in the Roche lobe; c) polarimetric observations of the equatorial and south tropical Jupiter zones in order to evaluate the mass of the dust substance originated from the secondary nuclei of the comet. d) photoelectric observations of the Jupiter satellites Europe and Ganymede about the moment of impact in accordance with the data of IJW/Aurora, v. 4, n. 4, p. 2 (1993).

3. Computer simulation of interaction of cometary plasma, originated from impact of cometary particles with the particles of planetary atmosphere, with the Jupiter magnetosphere.

4. Numerical simulation of the "fireballs" resulted from impact of the secondary cometary nuclei with the Jupiter atmosphere.

5. Investigation of the natural oscillations of the Jupiter magnetosphere. International comet SL9-Jupiter Watch: It is generally expected that nearly every observatory in the world will be observing events associated with the impact. These observatories will include several Earth-orbiting telescopes (Hub-

Table 1. The splitting comets

Comet/Name	N	τ_s	r_s	z_s	$\tau_s - T$
P/Biela	A-B	1840.05.25	3.59	+0.04	-2088
Liais (1860 I)	A-B	1859.09.18	2.49	+2.17	- 152
Great September Comet (1882 II)	A-D	1882.09.17	0.017	+0.003	+0.83
Sawerthal (1888 I)	A-B	1888.03.02	0.76	-0.28	-14.9
Davidson (1889 IV)	A-B	1889.07.30	1.06	0.00	+ 11
P/Brooks 2 (1889 V)	A-E	1886.07.21	5.38	+0.09	-1168
P/Giacobini (1898 V)	A-B	1896.04.24	2.36	+0.35	- 187
Swift (1899 I)	A-C	1899.04.25	0.48	+0.26	+12.09
Kopf (1905 IV)	A-B	1906.03.25	3.38	+0.04	+54
Campbell (1914 VI)	A-B	1914.08.25	0.82	-0.59	+20
Mellish (1915 II)	A-E	1915.03.23	2.09	+0.70	-116.6
P/Taylor (1916 I)	A-B	1915.12.08	1.65	-0.27	-53.4
Whipple-Fedtke-Tevzadze (1943 I)	A-B	1943.03.09	1.43	+0.44	+30.8
Southern Comet	A-B	1947.11.30	0.15	+0.07	-2.05
Honda (1955 V)	A-B	1953.07	8.2	-3.5	-740
Wirtanen (1957 VI)	A-B	1954.09.10	9.25	-4.97	-1087
Ikeya-Seki (1965 VIII)	A-C	1965.10.21	0.008	+0.005	+0.016
Wild (1968 III)	A-B	1968.08.03	2.92	+1.33	+125
Tago-Sato-Kosaka (1969 IX)	A-B	1970.02.09	1.20	+0.20	+50
Kohoutek (1970 III)	A-B	1970.04.29	1.79	+0.98	+38.9
West (1976 VI)	A-D	1976.02.27	0.22	+0.09	+2.27
Wilson (1987 VII)	A-B	1987			
P/Chernykh (1991o)	A-B	1991			
P/Shoemaker-Levi (1993e)	A-W	1992.07.09	5.2		

ble Space Telescope, International Ultraviolet Explorer, Extreme Ultraviolet Explorer) and several interplanetary spacecraft (Galileo, Clementine, and possibly others). Most observatories are setting aside time and resources but delaying detailed planning until the last possible minute in order to optimize their observations based on the latest theoretical predictions and the latest observations of the cometary properties.

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