Fact Sheet: Comet Shoemaker-Levy 9 and Jupiter

Updated, April 1994

Comet Shoemaker-Levy 9, heading toward collision with Jupiter in July 1994 shows changes in relative brightness and positions of some fragments since measurements of July of last year. Are the changes due to active physical processes, geometric orientation or both? Astronomers plan to observe the collisions between July 16-22, 1994.

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Comet Shoemaker-Levy 9 and Jupiter

A comet, already split into many pieces, will strike the planet Jupiter in the third week of July of 1994. It is an event of tremendous scientific interest but, unfortunately, one which is not likely to produce a spectacular visual display for the general public. Nevertheless, it is a unique phenomenon and secondary effects of the impacts will be sought after by both amateur and professional astronomers.

Significance

The impact of comet Shoemaker-Levy 9 onto Jupiter represents the first time in human history that people have discovered a body in the sky and been able to predict its impact on a planet more than seconds in advance. The impact will deliver more energy to Jupiter than the largest nuclear warheads ever built, and up to a significant fraction of the energy delivered by the impact which is generally thought to have caused the extinction of the dinosaurs on Earth, roughly 65 million years ago. Earth-bound observers are taking this opportunity to observe and study the comet's collision with a planet to gain more understanding of one of the fundamental physical process within the solar system, impacts. The discovery has spawned scientific thinking about the frequency with which comets fragment and implications related to the inventory of small bodies in the Solar System and how they modify the surfaces and atmospheres of the planets.

History

The comet, the ninth short-period comet discovered by Gene and Carolyn Shoemaker and David Levy, was first identified on a photograph taken on the night of 24 March 1993 with the 0.4-meter Schmidt telescope at Mt. Palomar. On the original image it appeared "squashed". Subsequent photographs at a larger scale taken by Jim Scotti with the Spacewatch telescope on Kitt Peak showed that the comet was split into many separate fragments. Before the end of March it was realized that the comet had made a very close approach to Jupiter in mid-1992 and at the beginning of April, after sufficient observations had been made to determine the orbit more reliably, Brian Marsden found that the comet is in orbit around Jupiter. By late May it appeared that the comet was likely to impact Jupiter in 1994. Since then, the comet has been the subject of intensive study. Searches of archival photographs have identified pre-discovery images of the comet from earlier in March 1993 but searches for even earlier images have been unsuccessful.

Cometary Orbit

Because the orbit takes the comet nearly 1/3 of an astronomical unit (30 million miles) from Jupiter, the sun causes significant changes in the orbit. Thus, when the comet again comes close to Jupiter in 1994 it will actually impact the planet, moving almost due northward at 60 km/sec aimed at a point only halfway from the center of Jupiter to the visible clouds.

The 22 identified fragments and smaller debris in its orbit will all hit Jupiter in the southern hemisphere, at latitudes between 47-49 degrees between 16 and 22 July 1994. The fragments will approach in the atmosphere at an angle roughly 45 degrees from the vertical. The times of the impacts are now known accurately to within minutes.

The Nature of the Comet

Twenty-two fragments have been counted from observations in July, 1993 at Mauna Kea Observatory. Images taken by the Hubble Space Telescope in January, 1994 and from Mauna Kea Observatory in Hawaii showed considerable changes in the relative positions of some fragments, as well as their brightness and morphology. A dust sheet observed last July to extend to the northeast and southwest of the line of the nuclei has nearly disappeared.

Two fragments, designated J=13 and M=10, seen in the July, 1993 images were not present in late January, 1994. The fragments designated P=8 and Q=7, are clearly resolved into multiple components P1=8a, P2=8b and Q1=7a, Q2=7b, a consequence of the January repair mission to the telescope. Another fragment, S=5, is sending dust in the sun ward direction indicating that it may be in the process of ejecting dust, vaporizing, or fragmenting. Nine fragments are displaced significantly into the dusty side of the comet.

Examination of the most recent observations by the HST acquired in March indicate further fragmentation of fragment P2=8b. At the positions of fragments T=4 and P1=8a, a barely discernable "puff" appears. The dust sent in the sunward direction, described as a dust "spur" from fragment S=5, has decreased in intensity. All other fragments seem to have the same circular condensation about each fragment as appeared in earlier exposures in January and before then in July, 1993.

None of the observations to date are capable of resolving individual fragments to show solid nuclei though we expect each fragment to be a cohesive body at some size. The coma extends at least 400 km from the center of each nucleus and is symmetric out to 2400 km. Reasonable assumptions about the spatial distribution of the grains and the reflectivity of the nuclei imply diameters of a few kilometers for each of the 11 brightest nuclei. Because of the uncertainties in these assumptions, the actual sizes are very uncertain.

No outgassing has been detected from the comet. While measurement of gas production is routine for most comets, two factors make such an observation a challenge in the case of Shoemaker-Levy 9. Because of Jupiter's distance from the sun (5.2 AU), the rate of vaporization is slow thus less likely to be detected. Additionally the material is spread over a large angular distance projected on the sky reducing the amount of light projected onto each detector element making the signal very low.

The brightness of the major fragments continues to vary with time suggesting intermittent release of material from the nuclei.

Collision Parameters

The times of the major impacts are now known to within minutes. The impacts will occur on the back side of Jupiter as seen from Earth in an area that is also in darkness. This area will be close to the limb of Jupiter and will be carried by Jupiter's rotation to the front, illuminated side less than half an hour after the impact. The grains in the tail of the comet will pass behind Jupiter and remain in orbit around the planet.

The Impact into Jupiter

The predicted outcomes of the impacts with Jupiter span a large range. This is due in part to the uncertainty in the size of the impacting bodies and the state of Jupiter's atmosphere. An additional complicating factor is that planetary scientists have never observed a collision of this magnitude and they do not know which physical processes will be most important in absorbing the energy of the impactors. If the cometary nuclei have the sizes estimated from the observations with the Hubble Space Telescope and if they have the density of ice, each fragment will have a kinetic energy equivalent to roughly ten million megatons of TNT (10^{29} to 10^{30} ergs). If ablation (melting and vaporization) and fragmentation dominate, the energy can be dissipated high in the atmosphere with very little material penetrating far beneath the visible clouds. If the shock wave in front of the fragment also confines the sides and causes the fragment to behave like a fluid, then nuclei could penetrat $\sim$70 km below the one bar level if it is 1 km in diameter with a density of 1 g/cm^3.

In any case, there will be an optical flash lasting a few seconds as each nucleus passes through the stratosphere. The brightness of this flash will depend critically on the fraction of the energy which is released at these altitudes. If a large fragment penetrates below the cloud tops and releases much of its energy at large depths, then the initial optical flash will be faint but a buoyant hot plume will rise in the atmosphere like the fireball after a nuclear explosion, producing a second, longer flash lasting a minute or more and radiating most strongly in the infrared. Although the impacts will occur on the far side of Jupiter, estimates show that the flashes may be bright enough to be observed from Earth in reflection off the inner satellites of Jupiter, particularly Io, if a satellite happens to be on the far side of Jupiter but still visible as seen from Earth. The flashes will also be directly visible from the Galileo and Voyager 2 spacecrafts. The Ulysses spacecraft will be positioned such that the impact points are just on the edge or limb of the planet barely in view.

The shock waves produced by the impact onto Jupiter are predicted to penetrate into the interior of Jupiter, where they will be bent, much as the seismic waves from earthquakes are bent in passing through the interior of Earth. These may lead to a prompt (within an hour or so) enhancement of the thermal emission over a very large circle centered on the impact.

Waves reflected from the density-discontinuities in the interior of Jupiter might also be visible on the front side within an hour or two of the impact. Finally, the shock waves may initiate natural oscillations of Jupiter, similar to the ringing of a bell, although the predictions disagree on whether these oscillations will be strong enough to observe with the instrumentation currently available. Observation of any of these phenomena can provide a unique probe of the interior structure of Jupiter, for which we now have only theoretical models with almost no observational data.

The plume of material that would be brought up from Jupiter's troposphere (below the clouds) into the stratosphere where it is observable is expected to bring up material from the comet as well as from Jupiter's atmosphere. Emission lines of NH_3 are expected to be observable. Water, believed to exist in Jupiter's troposphere, but previously concealed by opaque clouds at higher altitudes, may rise to observable altitudes. Other chemicals that scientists hope to detect include H_2S, sought after because it is a highly probable coloring agent of the atmosphere. Careful measurements of CH_4 would provide indications of the stratospheric temperature changes resulting from the collisions. Much of the material will be dissociated and even ionized but the composition of this material can give us clues to the chemical composition of the atmosphere below the clouds. It is also widely thought that as the material recombines, some species, notably water, will condense and form clouds in the stratosphere. The spreading of these clouds in latitude and longitude can tell us about the circulation in the stratosphere. The grains of the comet which impact Jupiter over a period of several months may form a thin haze which will also circulate through the atmosphere. Enough clouds might form high in the stratosphere to obscure the clouds at lower altitudes that are normally seen from Earth.

Interactions of cometary material with Jupiter's magnetic field have been predicted to lead to observable effects on Jupiter's radio emission, injection of material into Jupiter's auroral zone, and disruption or additions to the ring of grains that now encircles Jupiter. Somewhat less certainly the material may cause observable changes in the torus of plasma that circles Jupiter in association with the orbit of Io or may release gas in the outer magnetosphere of Jupiter. It has also been predicted that the cometary material may, after ten years, form a new ring about Jupiter although there are some doubts whether this will happen.

Plans to Study the Event

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 (Hubble Space Telescope, International Ultraviolet Explorer, Extreme Ultraviolet Explorer) and several interplanetary spacecraft (Galileo, Clementine, and Voyager 2).

In this update we highlight plans for observations of the chemistry of Jupiter's atmosphere as it is affected by the collisions. Because the predictions are uncertain, it is important to observe for all predicted species. Molecules containing eight different elements are reasonably expected to appear. Ions of $H_3{}^+$ and H_3O^+ are observable near 3.5 microns and will be diagnostic of ionospheric processes. Helium emission might be detected by the Extreme Ultraviolet Explorer and provide information about the amount of atmospheric heating in the upper atmosphere. The CH_4 abundance in Jupiter's atmosphere is not expected to change as a result of the collisions. The 7.8 micron band of CH_4 is expected to yield the best measure of temperature changes in the atmosphere.

Variations in abundance of C_2H_6 or C_2H_4 might also be induced by the impact and could provide constraints on the physical processes operating during and immediately following the impact. Oxygen is essentially absent from Jupiter's stratosphere. Reaction network calculations suggest that most of the oxygen should eventually end up in CO, although the time scale is uncertain by orders of days and months. The challenge for interpreting the production mechanisms of CO lies in extracting the contribution of CO from the comet relative to that produced from Jupiter's atmospheric chemistry. CO and H_2O observations are observable near 5 microns. Though additional overtones and combination bands will also be studied at other wavelengths. An increase in the abundance of stratospheric ammonia is predicted if heated parcels of gas are transported in a rising plume. Multi-wavelength studies of the ammonia molecules will be carried out in the 5 and 8 micron region.

Detection of H_2S would be ascertained from absorption bands in the 8 micron region. Moderately high spectral resolution would be required to separate the signal from ammonia molecules. If material is transported to the stratosphere in a hot plume as predicted by hydrodynamic models, a temporary increase in molecules of PH_3, P_4, GeH_4 and AsH_3, for example, which are depleted by photodissociation at the cloud tops might be observed. Estimates of the mass of transported material could be derived from spectral measurements of these species in the near-IR. Additional constraints on the mass of the upwelled material would be provided from detection and measurement of SiH_4 and SiO in the mid-IR and UV.

Participants in the January Workshop at University of Maryland called for continuous spectral coverage of Jupiter from 1250 Å 20 microns. Far-UV and radio observations are also planned. Given the realities of astronomical observing, and limited availability of telescope time on the largest telescopes, and the limited numbers of mid-IR spectrometers, there will likely be gaps in temporal coverage of the collisions. Coordination of efforts in both data acquisition and data analysis and interpretation will be required.

Support for the studies of the event will be coming from many sources. Within the United States, support is being supplied by NASA, by NSF, by DoD, and by many observatories which operate under private or state-university budgets. Around the world, studies are being supported by national governments, by universities, by research societies, and by various international organizations such as the International Science Foundation, the European Space Agency, and the European Southern Observatory.

Further Information

People wanting further information about opportunities for the general public should contact *The Planetary Society.* Address inquiries to The Planetary Society, 85 North Catalina Ave., Pasadena CA 91106, telephone (818) 793 5100. Updated information will be published regularly in the monthly magazine *Sky and Telescope* and the monthly magazine *Astronomy.* These can be obtained at newsstands or libraries as well as by subscription. Accredited press reporters can contact the Press Officer of the *American Astronomical Society* (Dr. Stephen Maran, AAS Executive Office (202) 328 2010) or the Press Officer of the *Division for Planetary Sciences* of the AAS (Dr. Nadine Barlow, Lunar and Planetary Institute (713) 280 9021).

This fact sheet will be updated, perhaps once per month, as new developments dictate. It is distributed through the American Astronomical Society and other distribution mechanisms.

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