Fact Sheet: Comet P/Shoemaker-Levy 9 and Jupiter

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Comet P/Shoemaker-Levy 9, heading toward collision with Jupiter in July, 1994 continues to show evidence of continuing fragmentation through changes in relative brightness and positions of some fragments as observed from both space-borne and ground-based telescopes. This great "spectacle of the century" will occur at the planet Jupiter at a distance of 400 million miles from Earth, a distance so far away that we will not be affected on Earth. Scientists continue to monitor the physical properties of the comet and theoreticians ponder how they expect these bodies to interact with Jupiter and its environment. Astronomers plan to observe the collisions between July 16-22, 1994.

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Comet P/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 the effects of the impacts will be sought after by both amateur and professional astronomers.

Significance

The impact of comet P/Shoemaker-Levy 9 into Jupiter represents the first time in human history that people have discovered a body in the sky and been able to predict the consequences to a planet more than seconds in advance. The impacts 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 processes within the solar system, impacts. The discovery has spawned scientific thinking about the frequency with which comets fragment and the implications related to the inventory of small bodies in the Solar System and how they modify the surfaces and atmospheres of the planets. Scientists interested in the planet Jupiter anticipate extracting new knowledge of the composition and structure of the largest, most massive planet in the Solar System.

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, Tucson, AZ 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. By the beginning of April, 1993, 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 ($\sim$30 million miles) from Jupiter, the sun causes significant changes in the orbit. Thus, when the comet again comes close to Jupiter in mid-July 1994 its fragments will actually impact the planet as they move almost due northward at 60 km/sec aimed at a point only halfway from the center of Jupiter to the visible clouds.

Twenty-one identified fragments as well as smaller debris in the orbit, will collide with Jupiter producing a series of explosions, one right after the other, like a 21-gun salute. The region of Jupiter at its southern latitude of -43 - 44 degrees away will be bombarded at intervals proportional to the distance between each fragment spread out over six days from 16 - 22 July 1994. The fragments will approach the atmosphere at an angle roughly 45 degrees from the vertical. If there is a continuous distribution of fragment sizes from the largest kilometer-sized ones to sand grain sizes, there will be a continuous rain of debris hitting the southern hemisphere of Jupiter.

The Nature of the Comet

Twenty-two fragments have been counted from observations in July, 1993 at Mauna Kea Observatory. We continue to find new fragments while previously known ones disappear from telescope-view. Images taken in January, March and May, 1994 by the Hubble Space Telescope (HST) and the 2.2- m telescope at Mauna Kea Observatory, Hawaii show changes in the relative positions of some fragments as well as in their brightness and morphology. The two fragments designated J=13 and M=10, which were seen in July, 1993 could not be seen with Earth's most powerful telescopes in January, 1994. The fragments designated P=8 and Q=7 are clearly resolved by the Hubble Space Telescope into multiple components, a consequence of the January repair mission to the telescope. Nine fragments are displaced significantly into the dusty side of the comet as seen in the January images. A schematic image of the January HST image, showing the nomenclature of the fragments accompanies this report.

Further evidence of fragmentation was observed in images acquired in March by the Hubble telescope. Fragment 8b is now resolved into two images. Fragment T=4 and 8a are barely discernible puffs. It is unclear when the splitting occurred in most cases. A brightness spur in the sunward direction at fragment S=5, seen in the January images, is not visible in the March images and there is no evidence of anticipated fragmentation.

Images acquired in May at the 2.2-m telescope in Hawaii and confirmed by HST revealed that fragment G=15 is double. This had been the brightest fragment for a time, until these recent observations.

Neither Earth-bound nor Earth-orbiting telescopes have been able to see through the immediate cloud of dust surrounding each fragment. Scientists wonder whether each fragment is a cohesive, solid body, or a rubble pile of small, round blobs of material. 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 (2-4) kilometers for each of the 11 brightest nuclei. Because of the uncertainties in these assumptions, the actual sizes are very uncertain.

No volatile gases, a primary component of comets, have 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 P/Shoemaker-Levy 9. The available sunlight at Jupiter is insufficient to produce an observable signal from glowing gases. Additionally the material from the comet is spread out, making the signal reaching a detector on a telescope very low. In addition to the individual condensations thought to represent solid fragments, a tail of dust is swept in the anti-sunward direction by radiation pressure predominantly from the Sun. A more diffuse fan of dust, but larger in extent than the tails was seen last year and is believed to be the remnant of the original fragmentation. This fan has diffused significantly in recent months.

Collision Parameters

The time of each of the major impacts is now known to within tens of minutes. They 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 each impact. The grains in the tail of the fragments will pass behind Jupiter and remain in orbit around the planet.

Interactions with the Jovian Magnetosphere and Rings

Interactions of cometary material with Jupiter's magnetic field have been predicted to lead to observable effects on Jupiter's radio emission, the injection of material into Jupiter's auroral zone, and to disruption or additions to the rings of 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 about ten years, form a new ring about Jupiter although there are some doubts whether this will happen.

Scientists at Goddard Space Flight Center predict that dust-plasma interactions generating charged particles could produce cyclotron radio emission. The break-up of fragments favors generation of these phenomena because the column density of dust increases the probability of producing an observable abundance of charged particles.

Due to huge uncertainties in the mass of dust associated with the tail of the comet, it is not possible to make reliable predictions of the effects of the dust impact on the rings. Observers will monitor the brightness of the rings for observable evidence of either brightening or darkening of ring particles.

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 both 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. 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, then nuclei could penetrate far below the visible clouds.

In any case, there will be an optical flash lasting a few seconds as each nucleus passes through the stratosphere much like the bright flash from a bolide or fireball as a meteor passes through Earth's atmosphere. 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.

A hot plume will rise in the atmosphere like the fireball after an 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, some estimates indicate that the rising hot plume of gas might be observable above Jupiter's limb as seen from Earth within about a minute after impact. Another theory predicts that the flashes may be bright enough to be observed from Earth in reflection off the inner moons of Jupiter. Europa is well-positioned for such an observation on July 19, though only Australia and the Pacific region will be in darkness at that time. 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 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. Carbon monoxide (CO) and silicon oxide (SiO) might be observable products from the comet. Emission lines of ammonia (NH_3) are expected to be observable. Water, believed to exist, but previously concealed by opaque clouds at higher altitudes, may rise to an altitude where they are observable. Di-hydrogen sulfide, (H_2S), highly sought after because it is an expected coloring agent of the atmosphere, is expected to be produced. Careful measurements of methane (CH_4) and molecular hydrogen (H_2) 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 shock waves produced by the impacts are predicted to penetrate into the interior of Jupiter at the speed of sound and produce something analogous to earthquakes. Because the speed of sound increases with depth, the propagating waves will refract and return to the surface possibly leading to a prompt (within an hour or so) enhancement of the thermal emission over a very large circle centered on the impact. Observations using several of the largest infrared telescopes, with the most sensitive thermal infrared detectors, will attempt detection of the interior oscillations. Larger estimates of the mass of the fragments favor detection of the predicted seismic waves. Observation 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.

Plans to Study the Event

Nearly every observatory in the world will be observing events associated with the impacts. These include Earth-orbiting telescopes (Hubble Space Telescope, International Ultraviolet Explorer, Extreme Ultraviolet Explorer), several interplanetary spacecraft (Galileo, Ulysses, and Voyager 2) and ground-based observatories located on every continent in the World including Antarctica.

Plans for observations of the chemistry of Jupiter's atmosphere as it is affected by the collisions will be carried out in the ultraviolet, visible, near-infrared and radio wavelength regions. Because the predictions are uncertain, it is important to observe for all predicted species. Molecules containing eight different elements are reasonably expected to appear.

Helium emission might be detected by the Extreme Ultraviolet Explorer and provide information about the amount of atmospheric heating in the upper atmosphere. Telescopes located in Hawaii, Texas, Chile, Australia and Russia will monitor near-infrared atmospheric chemistry. Ions of $H_3{}^+$ and H_3O^+ are observable near 3.5 microns and will be diagnostic of ionospheric processes.

The 7.8 micron band of methane is expected to yield the best measure of temperature changes in the atmosphere. Variations in abundance of ethane (C_2H_6) or ethylene (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. Infrared telescopes in Hawaii, Texas, and Arizona will be observing in this spectral region.

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 and at millimeter and centimeter-radio wavelengths. If material is transported to the stratosphere in a hot plume as predicted by hydrodynamic models, a temporary increase in molecules of phosphine (PH_3), phosphorous, (P_4), germane (GeH_4) and arsenic hydride (AsH_3), might be seen. Normally these species are depleted by photodissociation at the cloud tops.

The World's infrared telescopes located on five continents including Antarctica will be monitoring temperature changes induced by both surface waves and refracted internal waves. The small variations in temperature predicted to be induced by the collisions are just at the edge of our technical capability of detection. However, scientists have decided to attempt the observations in case the models are significantly in error.

At the workshop at the University of Maryland, in January, 1994, the rings study-group suggested monitoring of the rings at near-IR wavelengths for brightening induced by the impacting dust tails. The 5-m Hale telescope at Palomar Observatory will concentrate a significant portion of its observations measuring ring brightness before, during, and after the impacts. This team is headed by Phil Nicholson of Cornell University. Telescopes located atop Mauna Kea, Hawaii and at McDonald Observatory, Texas, will also support these ring studies.

High speed charged-coupled device (CCD) imaging and photometry will be used to detect flashes from the impacts reflected off of Jupiter's moons. Observatories in Australia, Hawaii, Texas, California, Chile, Brazil, India, Italy and Indonesia will be watching for these flashes, as will the Voyager 2 spacecraft located over 40 astronomical units (the distance between the Earth and Sun) from Jupiter and the Galileo spacecraft which is headed for a rendezvous with Jupiter in 1995.

Support for the studies of the event will be coming from many sources. Within the United States, support is provided by NASA, the National Science Foundation, 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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