of rare events in which a t quark is produced with a $\bar{b}$ instead of a $\bar{t}$, an indirect measure of the t-quark lifetime, which is thought to be too short to measure directly.

The difficulty of accumulating such numbers of top candidates at the present rate of 50 or fewer per year is the reason why University of Texas theorist Steven Weinberg says, "There is nothing more important to American high-energy physics right now than beefing up Fermilab's collider." As a step in this direction, the installation of the main injector at Fermilab is expected to increase the top production rate by about a factor of seven, beginning in 1998. Beyond that, one encounters many intriguing proposals for additional Tevatron upgrades, which could be operational before the end of the decade, and new accelerators, which could come on line in the first decade of the next century.

At present there are two proposals for upgrading the Tevatron, which could be implemented singly or in tandem. The Ditevatron proposal would use SSC magnet technology to double the Tevatron's energy and raise its top-production rate by another factor of seven. The Tevatron-Star proposal would build antiproton storage rings inside the main injector ring to increase the Tevatron's antiproton beam intensity and its top-production rate by a factor of 20 to 30. Both proposals pose technical challenges and are competing with other schemes for scarce funds.

According to SLAC director Burton Richter, the Next Linear Collider, a proposed 500-GeV e^+e^- collider, could produce thousands of t quarks per year, with relatively low backgrounds, beginning early in the next century.

CERN's proposed Large Hadron Collider dwarfs all of these proposals, in terms of its energy (14-TeV pp collisions), its luminosity (a hundred times the Tevatron's present capability), its ability to produce t quarks (800 000 per year) and its chances of finding the Higgs boson. Still, Fermilab theorist Stephen Parke sees a role for the Tevatron-Star, saying, "Fermilab is looking primarily at $q\bar{q}$ interactions, but because the gluon–gluon cross section rises so rapidly with energy, LHC will be a gluon–gluon machine. The two machines are complementary." However, in a time of fiscal austerity, many worry that even complementary proposals like the NLC and the Tevatron-Star divide the international particle physics effort and risk slowing the progress of the field as a whole.

—Ray Ladbury

ASTRONOMERS ARE POISED FOR THE 'CRASH OF 1994': BOOM OR BUST?

If comets are like "dirty snowballs," as Fred Whipple proposed in the early 1950s, then Jupiter is about to suffer the embarrassment of being hit by a boomerang snowball as astronomers around the world watch. Like many snowballs, Comet Shoemaker–Levy 9 broke apart in mid-flight. Comet SL9 was first seen, already in orbit around Jupiter, in March 1993, by a trio of avid comet hunters: Carolyn and Gene Shoemaker of the US Geological Survey in Flagstaff, Arizona, and David Levy, a contributing editor to *Sky & Telescope* magazine. By May of last year the comet's orbit had been determined. It was realized by Brian Marsden[1] (Smithsonian Astrophysical Observatory, Cambridge, Massachusetts) that in July 1992, SL9 had come within 95 000 km of Jupiter's center of mass, where it experienced tidal forces sufficient to rip it apart. On its next pass, SL9 will aim to come within 30 000 km of Jupiter's center of mass. Because the planet's radius is about 71 000 km, Jupiter will suffer a direct hit. Astronomers will be on hand to evaluate its injuries, if any.

This event is unprecedented—not the collision, but our advance knowledge of it. A mere glance at our Moon through a small telescope can attest to the importance of impacts in the solar system, but until now astronomers had no opportunity to tailor their observations to a particular event before it took place. Many impacts probably occur just as this event suggests: The target first captures a projectile into a bound orbit. The orbit is subsequently perturbed, and in some instances an impact occurs. SL9's highly eccentric orbit is perturbed mainly by the Sun's gravity.

The 21 known comet fragments of SL9 are inexorably moving in a lengthening train toward their separate encounters with the giant planet next month. (See the figure on page 20.) The first encounter will occur on 16 July around 20:00 universal time, and the last on 22 July around 8:00 UT. (UT is the same as Greenwich Mean Time; 20:00 UT is 4:00 pm Eastern Daylight Time.) The impacts will just miss being seen from Earth, occurring about 5–10° behind the morning limb (edge of the disk) of Jupiter. Because Jupiter rotates with a period of 9 hours 55.5 minutes, each impact site will rotate into Earth's view within 20 minutes.

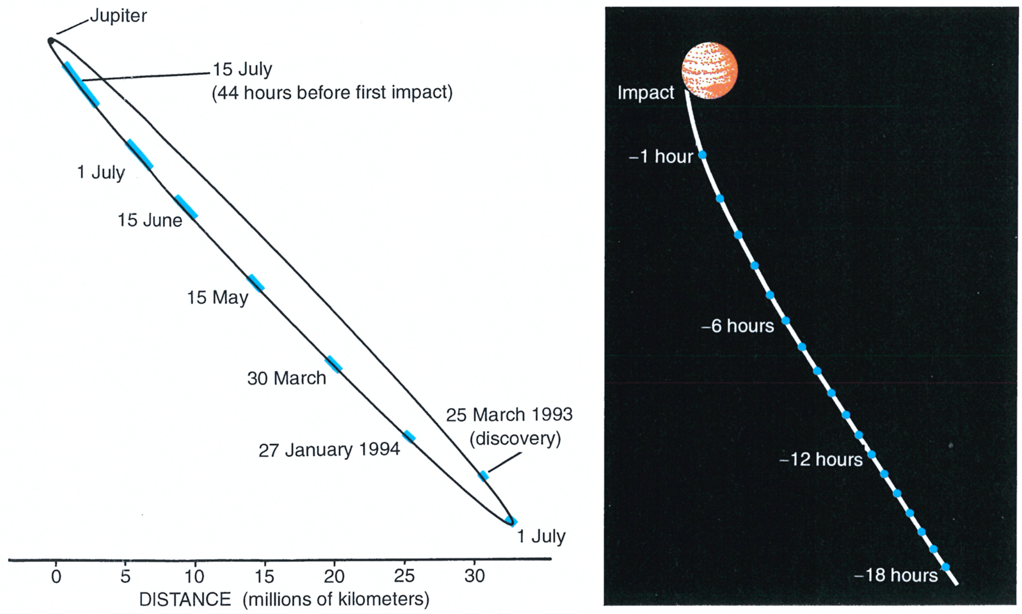
Paul Chodas and Donald Yeomans of the Jet Propulsion Laboratory in Pasadena, California, did the orbital and impact-time calculations, using a dynamical model that includes perturbations due to the Sun, the planets, Jupiter's Galilean satellites and the planet's oblateness. The uncertainties in the impact times currently range from 22 minutes to 1 hour, but they will decrease to about 15 minutes as the impacts approach, according to Yeomans.

Each fragment is a comet in its own right, with a coma of dust surrounding a bright core, which many researchers believe contains a solid nucleus. The refurbished Hubble Space Telescope (see PHYSICS TODAY, March, page 42) has been following the time evolution of the fragments. According to Harold Weaver and Keith Noll of the Space Telescope Science Institute in Baltimore, at least some of the fragments appear to be breaking up, and some are essentially disappearing. So "is there a solid nucleus or not?" asks Weaver. In addition, no gas has been detected, and the dust is distributed "unlike any other comet we've ever seen," he says. "The snowballs have no ice," says Alexander Dessler of Rice University in Houston, Texas. He adds that SL9 may actually be an asteroid, not a comet, although he admits that at Jupiter's distance from the Sun of 5 astronomical units, the volatile gases might be completely frozen. (An AU is the average distance of the Earth from the Sun.)

The world watches

According to Noll, the planned observations are driven by two main questions: What is the nature of the impacters, and what will Jupiter's response be?

Almost every observatory in the world, and many above the world, is expected to try to answer those questions during the third week of July.



Path of Comet Shoemaker–Levy 9 as viewed from Earth. The highly eccentric orbit (left) extends from Jupiter a distance about one-third that of the Earth from the Sun. Also shown are the length and orientation of the comet train on selected dates. The trajectory of one fragment (right) is shown for several hours prior to impact. (From calculations by Paul Chodas, Jet Propulsion Laboratory.)

Optical observatories from China to Ireland to New Zealand and radio observatories from Finland to Tasmania to Japan will be gathering data.

Given the wide range of possible effects in these encounters, a wide range of observations will be performed. Noll, who headed a working group on Jupiter's chemistry, says that there are many molecules to monitor in the infrared. H_2S will be closely watched for in particular, as this molecule is suspected to play a role in the coloring of Jupiter's atmosphere. A penetrating collision could dredge the H_2S up from below the cloud tops. Silicon is inaccessibly deep in Jupiter, but it should be abundant in SL9. Measuring either SiO or SiH_4 can constrain the fragments' masses and penetration depths. Astronomers will also closely monitor CH_4, an important temperature diagnostic. Far-ultraviolet observations will look for an enhanced aurora or other effects on the plasma environment of Jupiter. Radio observations will examine Jupiter's chemistry, watch its magnetosphere and monitor the planet's opacity, which is due almost entirely to ammonia at the cloud tops. Researchers scutinizing Jupiter in visible light will try to stay abreast of the changing weather patterns in the cloud tops as well as look for light from Jupiter's magnetosphere.

Many spacecraft are involved, but only Galileo, Ulysses and Voyager 2 will have direct views of the impacts. Because of a stuck and nonfunctioning main antenna, Galileo can transmit to Earth only at the glacial rate of 10 bits per second. Thus it will record images and later send back carefully selected frames. Ulysses, in a polar orbit around the Sun, will monitor Jupiter with radio instruments from a vantage point 2.5 AU below the plane of Jupiter's orbit and 5.3 AU distant from Jupiter. Voyager 2 is about 41 AU from Jupiter and will have its ultraviolet spectrometer pointed at Jupiter. (Its camera is turned off.)

The Hubble Space Telescope has dedicated 120 orbits (each of 51 minutes duration) to Jupiter observations, some of which have already been used to follow the progress of SL9. NASA's International Ultraviolet Explorer and Extreme Ultraviolet Explorer satellites also will be used, as will the Japanese Akebono and Geotail satellites.

Forecasts

In a sort of cosmic uncertainty principle, as the times and locations of the snowball "hits" are becoming known with greater accuracy, the predicted effects are becoming less and less certain. The greatest unknown is the size of any individual piece of solid matter within a fragment of SL9. Since last year, estimates for the diameter of the largest chunk have ranged from 15 kilometers down to much less than 1 km. All of the pieces will be moving at 60 kilometers per second (just less than Jupiter's escape velocity) at impact, but their sizes will determine how much energy is released. Stuart Weidenschilling (Planetary Science Institute, Tucson, Arizona) suggests[2] that each fragment may be merely a "pile of rubble." In that case the rubble might dissipate its energy high in Jupiter's atmosphere, above the visible cloud tops. On the other hand, a kilometer-sized chunk, with about 10^{28} ergs of kinetic energy, could have profound effects.

Predictions abound concerning the "crash of '94". The 1 June issue of *Geophysical Research Letters* is devoted to predictions; in addition, many predictions as well as details of the planned observations have been posted to an electronic bulletin board coordinated by Michael A'Hearn and Lucy McFadden at the University of Maryland in College Park. Only a sampling can be given here.

According to Gene Shoemaker, each fragment will certainly produce a burst of light as it blazes through Jupiter's upper atmosphere, just as the shock in front of a meteoroid heats the Earth's atmosphere to incandescence. For a small bit of comet debris, melting, vaporization and fragmentation may dominate the physics, so that the "shooting star" may be the only visible effect, unobservable except by the Galileo spacecraft or indirectly as a reflection off of one of Jupiter's moons. Currently, according to Chodas, the best candidate is a reflection from the moon Europa of an impact predicted for around 11:00 UT on 19 July; it will be best seen from Australia and New Zealand. Shoemaker adds that the dusty coma, perhaps 10 000 km across, may glow for about 15 minutes prior to impact and be directly visible from Earth.

A kilometer-sized piece would penetrate Jupiter's atmosphere to about the 10-bar level (100 km below the cloud tops), where it would explode, inducing a giant fireball.[3] Should material in the fireball rise a few hundred kilometers above the cloud tops, it might be directly observable from Earth.

There is much speculation about possible effects on Jupiter's magnetosphere of the comet's passage, and particularly the cometary dust. Unlike the solid nuclei of the comet fragments, much of the dust is expected to miss Jupiter. Jupiter's radio emission may decrease as a result of a decrease in energetic electrons as they collide with the dust.[4] A new Jovian ring may form in about ten years.[5] On the other hand, there may be almost no observable consequences in this region.[6] "The magnetosphere will probably swallow these things without even a burp," asserts Dessler.

Should solid material reach the dense atmosphere, it could make waves. What planetologists call a gravity wave (because gravity is the stabilizing force) propagates slowly like a water wave. Gravity waves may appear on Jupiter's surface as concentric rings of temperature fluctuations emanating from the impact site, may be observable for impacts with energies as low as 10^{27} ergs, and may last for one or two days.[7] Faster-moving, downward-launched acoustic waves could be refracted by density gradients within Jupiter and perhaps reach as deep as the interface between molecular and metallic hydrogen.[8] These acoustic waves would appear as a set of rings in one or two hours, much sooner than the gravity waves. Seeing any of these effects would provide researchers with their first empirical insight into Jupiter's interior.

Most important, as Dessler puts it, "glorious things may well happen that no one has predicted."

—STEPHEN G. BENKA

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EXPERIMENT REVEALS A NEW TYPE OF ELECTRON SYSTEM

In most metals, the electrons behave as if they were independent of one another. Although each electron really does interact with the other electrons and phonons, the net effect is felt only as a kind of molasses through which the otherwise freely moving electron must slog. Thus one can usually treat metallic systems as a low-density gas of weakly interacting particles, accounting for the average interactions simply by assigning an effective mass to the electrons. Such a model is commonly called a Fermi liquid. In one-dimensional systems, however, the Coulomb forces between the electrons intervene more strongly and produce quite a different behavior.

Theorists studied the one-dimensional electron system extensively in the 1970s, delineating the behavior that characterizes what is today called a "Luttinger liquid." But experimenters have been unable to find direct, conclusive evidence for such behavior in real-world conductors. Now signs of a Luttinger liquid have surfaced in a more exotic locale—in the excitations that develop at the edges of an electron system in a fractional quantum Hall state. At the March meeting of the American Physical Society in Pittsburgh, Richard Webb of the University of Maryland described the experiment he had performed with his colleagues Frank P. Milliken and Corwin P. Umbach of IBM in Yorktown Heights, New York.[1] At the same session, Xiao-Gang Wen (MIT) and Charles Kane (University of Pennsylvania) described the theoretical underpinnings of the experiment. (Kane has collaborated on this problem with Matthew Fisher of the University of California, Santa Barbara.) If confirmed, the evidence will not only substantiate years of theoretical work on the one-dimensional state, but might also open the door to further exploration of a fundamentally new interacting-electron system.

Luttinger liquids

In a Fermi liquid the Coulomb forces from other charges are treated, if at all, as a perturbation. But in one dimension, the electrons are effectively replaced by exotic new collective excitations, which can have spin and charge. One might picture the electrons in a Luttinger liquid as blocks connected by springs. The collective excitations are then oscillatory modes of this linear chain of blocks, which can carry a fraction of an electron charge. Whereas individual electrons get scattered off one another if they try to move in a particular direction, charged excitations can travel up and down the chain like a traveling wave, passing through but not scattering off one another.

The Luttinger-liquid picture produces predictions that differ from those of the standard Fermi-liquid model regarding the temperature dependence of measurable parameters. One example is the tunneling behavior of electrons: In a Fermi liquid an electron from outside the Fermi surface can always enter the system and occupy one of the single-particle states above the Fermi surface. But in a Luttinger liquid the states above the Fermi surface are collective modes and cannot be occupied by an individual electron. Thus, one hallmark of a Luttinger liquid is that there is no tunneling of electrons at zero temperature. More specifically, theorists have predicted that the tunneling conductance through a barrier between two Luttinger liquids will vanish as a power of the temperature, with the exact exponent depending on the details of the electron–electron interaction.

Interest in Luttinger liquids peaked 20 years ago when researchers were studying organic metals in the hopes of finding a high-temperature superconductor. An organic metal, such as TTF-TCNQ (tetrathiofulvalene-tetracyanoquinodimethane), consists of tight stacks of flat organic molecules and is closely approximated by a one-dimensional model. Joaquin Luttinger of Columbia University, working in the 1960s, defined the model that now bears his name.[2] It resembled the quantum field model developed in 1958 by Walter Thirring (University of Vienna). Sin-itiro Tomonaga had also published influential studies on the one-dimensional state around 1950. Subsequently, Daniel C. Mattis (now at the University of Utah, Salt Lake) and Elliott Lieb (Princeton University) correctly solved Luttinger's model.[3] In the 1970s theorists found that a wide class of one-dimensional models has the same behavior at low temperatures as the Luttinger model. Such models have been collectively called "Luttinger liquids" since Duncan Haldane coined the term in a 1981 paper proposing that a general low-