Air and Space this Week

Item of the Week

COMET SHOEMAKER-LEVY 9 IMPACTS JUPITER

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Twenty-five years to the day after the launch of Apollo 11*, a train of debris from Comet Shoemaker-Levy 9, fragmented by Jupiter's gravity, began impacting that massive planet. It was the first time a planet was observed in real-time undergoing a strike by an asteroid/comet. Impacts are one of the major ways a planet's surface can be altered, and even though Jupiter's "surface" lay far below the impacts' locations, much was learned. The comet was named for its co-discoverers, neither of whom were formally trained as research astronomers. They were, however, extremely-successful finders of comets and asteroids, and were very adept at popularizing Science. This is their story.*

CAROLYN SPELLMAN SHOEMAKER, COMET HUNTER

Carolyn Spellman was born on June 24, 1929, in Gallup, New Mexico. Soon thereafter, her family moved to Chico, California, and that was where Carolyn spent her formative years. She attended Chico State University, and earned a BA and Master's degree in History, Political Science, and English Literature.

Her only sibling, Richard, attended Cal Tech, where his roommate was one Eugene Shoemaker. After graduating from Cal Tech, Gene entered the Ph.D. program at Princeton, but returned in the summer of 1950 to Chico to serve as Richard's best man, where he met Richard's sister. Gene and Carolyn hit it off, and maintained a distance relationship that grew until their own marriage, on August 18, 1951. Carolyn took a job teaching the seventh grade, but didn't care for it, opting to take care of her growing family.

Gene Shoemaker was on the way to becoming one of the most preeminent planetary geologists in history, deeply involved in the study of the Moon, impact cratering, and training the Apollo astronauts, based at what would become the U.S. Geological Survey's Astrogeology Branch in Flagstaff, Arizona. Carolyn found that the way Gene explained his work was much more interesting than the one geology course she'd taken at Chico State. [Gene will, no doubt, be the subject of a future Item of the Week!] Carolyn began studying astronomy with a student from Flagstaff's Lowell Observatory and serving as Gene's field assistant, helping him find and map terrestrial impact features.

Carolyn's abilities grew in such a rich environment, and by 1980, she was searching for asteroids, particularly ones that dangerously cross Earth's orbit, and comets, based out of

Palomar Observatory in southern California. Later that same year, she was hired at USGS Flagstaff as a visiting scientist, and then obtained a research professorship at Northern Arizona University in 1989, where she continued searching for comets and asteroids. She had found her first new comet on September 3, 1983, and by the time of her NAU appointment, she had 17 new comets to her credit.

Carolyn was a keen observer, and she mastered the famed 48" Schmidt Camera at Palomar, and the detailed techniques of using specially-treated photographic film to good effect. When she got to NAU, she met and began working with David H. Levy, whose education had, like Carolyn's, been heavy on English Literature. But, like Carolyn, his passion was searching for comets. He would eventually earn a Ph.D. in English Lit in 2011, but long before then he was racking up comet "finds" and using his English skills to write a number of books and articles about Astronomy.

The Shoemakers and David were working together at Palomar when they made their ninth discovery of a new comet. As is appropriate for such finds, they sent a telegram to Brian Marsden at the Harvard-Smithsonian Center for Astrophysics. He confirmed their discovery and calculated the orbit of the new comet, giving it the name, Comet Shoemaker-Levy 9.

Marsden was amazed to find that SL-9 was on course to hit Jupiter!

Gene was elated, because after studying impact craters and processes for years, he was actually going to be able to see impacts in real-time. Carolyn was happy for him, but sad, too. She was attached to her discoveries, and now she was going to lose one.

Carolyn continued working with the Palomar Asteroid and Comet Survey after the impact, and she, Gene, and David Levy continued searching after the PACS program ended at the end of 1994.

Then tragedy struck. Carolyn and Gene were in Australia scouting out and examining impact features in the Australian Outback. On July 18, 1997, they were in a horrible head-on crash. Gene was killed and Carolyn was hurt badly. Both were well-known in the Solar System exploration community, and I remember the shock we all felt when we heard the news. My dissertation advisor was particularly saddened, because he had worked closely with Gene on Apollo astronaut training and other projects.

Carolyn returned to Lowell Observatory after recovering from her injuries, continuing to hunt for new comets and asteroids. She remained active through 2002, and passed away on August 13, 2021.

Carolyn's work was recognized by a number of honors and awards. She received an honorary doctorate degree from NAU in 1996, and the NASA Exceptional Scientific Achievement Medal in 1998. The National Academy of Science awarded her and Gene jointly the James Craig Watson Medal for their contributions to Astronomy in 1998; their citation included, "For their painstaking research, which led to the discovery of more than 800 asteroids and 32 comets, including their co-discovery of Comet Shoemaker-Levy, the first comet observed colliding with a planet." Asteroid 4446 is named for her, as is the Carolyn Shoemaker formation (a phyllosilicate layer sampled by the *Curiosity*), in the Mt. Sharp Group in Mars' Gale Crater.

DAVID H. LEVY; SCIENCE WRITER

David Howard Levy was born on May 22, 1948, in Montreal. He was interested in Astronomy from childhood, but his educational path (B.A., M.A., and Ph.D.) was in English Literature. His dissertation had an astronomical bent, shown by its title, "A Study of Allusions to Celestial Events in Elizabethan and Jacobean Writings, 1572-1620."

David is arguably one of the most successful amateur astronomers on record. He discovered 23 comets, 13 of them with the Shoemakers, co-discovered the first Martian Trojan asteroid, and co-discovered 63 other asteroids. David was the sole discoverer of periodic comets 255P/Levy and P/199 L3. He also made copious observations of variable stars for the American Association of Variable Star Observers.

David has written 34 books, including a 2006 biography of Clyde Tombaugh (my childhood hero!), the discoverer of Pluto. He wrote a number of articles and blog notes for *Sky & Telescope* Magazine, and also has contributed to *Astronomy Magazine* and other pieces.

The Royal Astronomical Society of Canada gave David their C.A. Chant Medal in 1980, and the Astronomical Society of the Pacific gave him their Amateur Achievement Award in 1993. He also received the Smithsonian Astrophysical Observatory's Edgar Wilson Award for his discovery of comets in 2007. Asteroid 3673 was named in his honor.

COMET SHOEMAKER-LEVY 9

The Shoemakers and David Levy were using one of the smaller Schmidt cameras at Palomar Observatory on the night of March 18/19, 1993, when they found an unusual comet. It was not a long-period comet in a highly-elliptical orbit, it did not orbit the Sun at all. It was in orbit around Jupiter! That's not as weird as you might think; at least five other comets are known to have been (temporarily) captured by Jupiter.

Shoemaker-Levy 9 did have a highly-elliptical orbit, with a perijove right above Jupiter's cloud tops, and an apojove high enough to make the orbital period two Earth years long. Its last closest approach before discovery was on July 7, 1992.

Moving fast so close to Jupiter, just inside the Roche Limit, produced huge internal tidal effects, so much so that the comet was disrupted, broken into 21 observable pieces of sizes ranging to a few kilometers. They were still so close together that the discovery team saw them as one weirdly-shaped object, but in the coming days they slowly moved apart from one another. They were tracked closely to determine their fate, and astronomers were surprised and excited to realize that the pieces would impact Jupiter at their next perijove. This gave the astronomical community time to prepare an observing schedule using a variety of Space-based and ground-based assets. Gene Shoemaker wasn't the only one excited about the prospect of observing an impact in real-time!

The fragments were in the same orbit, just a little ahead or behind the others. If Jupiter didn't rotate, they would hit very near one another and make a tight cluster of craters. But Jupiter does rotate, and quickly, which caused the impacts to hit in a line, widely separated from one another. This wasn't the first time a comet break-up had been observed, and there was even a simple protocol for "naming" the fragments. A single letter would be assigned to each. The first fragment in the group became "A," the second, "B," and so one, omitting "I" and "O" to avoid confusion.

Abundant questions were posed prior to the impacts, among them: What are the comet fragments made of? It was given a comet name, but was pre-fragmentation body actually a comet? How would Jupiter's clouds be affected by the impacts? How would Jupiter's magnetic field be affected by the impact? And are there any other manifestations of the impact we haven't foreseen? Speculations were plentiful, and answers were just around the corner.

Well, just around the edge. The bad news was that the impact site was just over the limb of Jupiter, (just barely) not visible from Earth or even low-Earth orbit.

A full-court press of observations was planned meticulously. A number of Earth-based telescopes would be looking to see if any impact plume cleared the edge of Jupiter. The *HST* and the *RORAT* X-ray observing satellite were watching from LEO. The *Ulysses* solar polar orbiter and *Voyager 2* were watching, too; they could see the impact site but they were both very far away, and could make no meaningful observations (although they tried). Fortunately for all, however, there was one more spacecraft in position. The *Galileo* Jupiter orbiter was already *en route* to Jupiter, and would be able to see the impact sites relatively up-close, with a useful suite of imagers.

IMPACT ON JUPITER AND LESSONS LEARNED

Fragment A hit Jupiter 4:13 PM EDT on July 16, 1994, **thirty years ago this week**. The impact speed was on the order of 35 miles/second. The impact produced a fireball over 43,000 °F that expanded and cooled rapidly, rising over 2000 miles above the impact site, enough to be seen by *HST* first and ground-based observers very soon later. A dark mark at the impact site was imaged by *Galileo*'s cameras. The other 22 fragments impacted Jupiter over the next six days. The G impact was the largest, estimated to have released energy equivalent to 6 million megatons of TNT, leaving an Earth-sized dark spot on the jovian cloud deck.

Asteroid or Comet? The fragments did not break up further prior to impact, suggesting an internal strength more like a rock than a "dirty snowball." The *HST*'s Faint-Object Spectrograph detected silicon, magnesium, and iron close to the impact sites; either asteroid or comet nucleus would be a likely source of those elements. A lot of water was expected, derived from Jupiter's upper atmosphere, but that was not seen; perhaps the impact effect did not penetrate deeply enough. Cometary fragments would have been water/volatile rich and would likely have displayed the presence of some hydroxyl compounds, but they were not seen. Evidence points toward "asteroid," but is not enough to be conclusive. We've learned since then that the boundary between "comet" and "asteroid" is not sharply-drawn; perhaps the parent body was a water-rich asteroid or a volatile-poor comet; perhaps like 3200 Phaeton, the "rock comet."

Effect on atmosphere: Each impact sites in the jovian atmosphere showed a dark stain, in which could be detect unexpected sulfur compounds, including diatomic sulfur, carbon disulfide, and hydrogen sulfide. The stains weren't permanent, but they did last for several Jupiter days, changing shape as they were sheared east and west by atmospheric jets at the cloud-top level driven by sunlight and Jupiter's own internal heat. The *HST*'s UV imager showed the presence of fine-grained dust high above the dark stains that gradually diffused into the clouds below. The movement of the dust as it settled was primarily pole-ward, driven by winds created by high-energy particles in Jupiter's intense magnetic field.

Effect on Jupiter's magnetic field: The impact of the K fragment had a significant effect on Jupiter's magnetic field in the vicinity of the impact site. The disturbance moved along the magnetic field lines into Jupiter's giant version of Earth's Van Allen Belts, where charged particles are trapped by the magnetic field. At Jupiter, a LOT of charged particles were released from the belts into Jupiter's upper atmosphere, causing much more intense auroral displays than had been observed there previously.

Other observations: Radio emissions at 21 cm wavelength increased sharply after the impacts, attributed to synchrotron radiation caused by the acceleration of electrons released by the impact to extreme speeds by Jupiter's magnetic field. The dark splotches persisted for months, and elevated levels of disulfide and ammonia were detected for over an Earth year after the impacts. Surface temperatures were elevated over the impact sites, but quickly returned to normal within a week for larger impacts sites and two weeks for smaller ones.

The fact that the dark splotches that resulted from the SL-9 impacts, readily seen on Jupiter using Earth-based telescopes, had never been seen in the centuries of telescopes looking at Jupiter, means that the rate of SL-9 class impacts is relatively low.

The *Voyager* fly-bys of Jupiter years before had revealed long chains of impact craters, at least thirteen on Callisto and three on Ganymede (example). Seeing how Jupiter's gravity had disrupted SL-9's parent body confirmed how such things could form when the fragments of the disruption hit a solid body rather than Jupiter's atmosphere. Such pre-impact disruption of an incoming body could explain the production of two or more craters so close together that the movement of material ejected from each appears to have interfered with each other.

In my opinion, the most important thing that happened as a consequence of the impact of SL-9 on Jupiter was that it really increased awareness of the potential danger posed by a large impact event on Earth. Dying dinosaurs 65 million years ago may not put a scare in the public or decision-makers, but 6 million megatons of TNT in real-time was a different issue entirely!

And if SL-9 didn't get your attention, there was another event of late that might. When I was at NASM, I prepared a hands-on learning station about meteorites, where visitors could touch and handle a variety of different meteor types. After the Chelyabinsk event over Russia in 2012, I added a piece of that meteorite and the following to the station program.

I pointed out that Chelyabinsk happened almost exactly 50 years after the height of the Cuban Missile Crisis, the closest we've ever come to nuclear war. Further, Chelyabinsk lies less than 1000 miles from Moscow as the crow flies, and less than 700 miles from the Baikonur launch site in Kazakhstan. When I had a multi-generation group at the station, I'd casually mention the distances, and remark, "50 years is but a blink of the cosmic eye, and 1000 miles is nothing in Space. Reconnaissance technology 50 years ago was very primitive. Imagine what might have happened if Chelyabinsk happened 50 years earlier and a thousand miles away from where it actually came in. The remark would blow over the younger audience without notice, of course. But the looks on the faces of those at the station who lived through the "duck and cover" era was unforgettable.

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