things nice and neat," she says.

Regardless of where the new fossils fit in the family tree, Wolpoff and others hope the site will eventually reveal what kind of technology or behavior allowed these early humans to persist in the hostile European climate before 500,000 years ago. So far, it's hard to tell, because the tool kit found with them included only simple cutting flakes, not the more sophisticated tools found elsewhere at this time. One additional, bizarre clue is that the bones were covered with cut marks, indicating that their bodies were defleshed and processed like those of animals killed for meat (*Science*, 19 January 1996, p. 277). Bermúdez de Castro and his colleagues have suggested that this could be cannibalism, but researchers such as Peter Andrews of the Natural History Museum, London, warn that cut marks alone don't prove cannibalism.

So although the fossils give paleoanthropologists a new view of an obscure time in history, they also raise a whole crop of new questions. "That's the main contribution of the Atapuerca fossils," says Hublin. "They give us an idea of the amazing variation in *Homo*." And that diversity, notes Arsuaga, shows "that human evolution is like that of other groups. We're not so different."

–Ann Gibbons

PLANETARY SCIENCE

Spots Confirmed, Tiny Comets Spurned

Lou Frank isn't the only one seeing spots anymore. More than 10 years ago, the University of Iowa space physicist proposed that house-sized comets are pummeling Earth 20 times a minute. Frank estimated that since the planet formed, these tiny comets have dumped enough water into the upper atmosphere to fill the world's oceans.

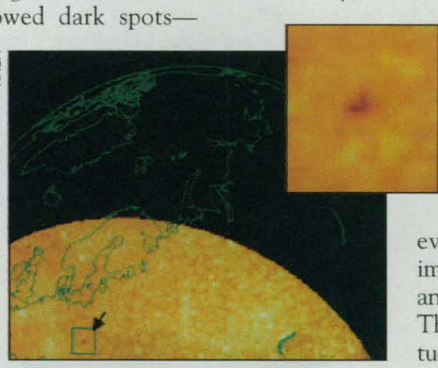
It was a provocative hypothesis from a highly regarded researcher, but the whole idea drew scorn from the rest of the earth and planetary science community. Researchers couldn't imagine where all that water could be hiding in the inner solar system, which in all other measurements seems pervasively dry. And only Frank could see the traces of these tiny objects: The dark spots formed, he said, as gassy clouds of water dispersed in Earth's high atmosphere (*Science*, 10 June 1988, p. 1403). Other researchers looking at the same satellite images, however, saw only meaningless instrument noise.

Now, in a stunning turnabout, Frank has used a satellite camera with sharper resolution to produce more detailed images that confirm the existence of these dark spots to the satisfaction of other scientists. The new data even seem to show an influx of water. "Now, you're faced with overwhelming evidence," says Frank. "We've verified [the spots] from five different viewpoints."

Even Frank's more vocal critics agree. "He's clearly seeing something, but I don't know what," says space physicist Robert Meier of the Naval Research Laboratory (NRL) in Washington, D.C. "We're all going back to the drawing boards to figure out what's going on here."

Although Frank's observations are being vindicated, he has a long way to go toward persuading the community that these black dots are actually the remains of midget comets. "There are two quite separate questions," says atmospheric physicist Donald Hunten of the University of Arizona, another early critic. "One is, are the spots real? Okay, they're real. The next question is whether Lou's explanation is valid. No, it certainly isn't valid. It is very easy to put forward five objections to the small-comet explanation, any one of which rules it out."

Frank's new data, reported this week at the spring meeting of the American Geophysical Union, come from the Polar satellite, launched in February 1996 to study magnetic fields and charged particles over the poles. This spacecraft carries ultraviolet cameras far better than the one aboard the Dynamics Explorer satellite, which took Frank's first images in the 1980s. Images from the older ultraviolet camera showed dark spots—Frank calls them "atmospheric holes"—no larger than a single picture element or pixel. Everyone except Frank and his University of Iowa colleagues John Sigwarth and John Craven, who is now at the University of Alaska, thought the single-pixel spots were instrumental noise, like snow on an ultraviolet television. Frank and his colleagues, though, interpreted them as places where 80 tons of water had absorbed enough ultraviolet to darken the UV glow of the upper atmosphere.



NASA

Seeing spots? Lou Frank believes this Polar satellite image of a dark spot (inset) against the atmosphere's ultraviolet glow (seen here in false color) marks a gassy cloud of water, the remains of a tiny comet.

Other researchers are now accepting the reality of the spots, if not Frank's explanation, because the ultraviolet images taken by the Polar satellite have much smaller pixels, and in these views the 50-kilometer-wide spots are 10 to 20 pixels across. The odds that so many randomly darkened pixels could come together to form a spot, all researchers agree, are nil. What's more, the spots show up under different imaging conditions, bolstering the case for their existence. In some cases, Frank and Sigwarth found, the Polar ultraviolet camera caught the same spot in consecutive exposures as the spot moved across the field of view. In other images, spots appeared doubled—as they should have—because Polar wobbled enough that the same object was recorded twice in one exposure. A random dark pixel would appear only once. And one particular spot, says Frank, was caught by both his ultraviolet camera and another on Polar of a different design.

Frank also presented observations of a new phenomenon high above the atmosphere that is presumably linked to atmospheric holes: bright trails of water debris. "I just happened to be looking through the images," says Frank, "and all of a sudden saw these bright oxygen trails. We were shocked." About 10 times a day, Frank concludes, an incoming small comet between 5000 and 50,000 kilometers leaves enough water in its wake that sunlight dislodges a trail of oxygen atoms from the water.

Frank's final line of evidence is visible-light images showing hydroxyl, another fragment of water. These trails appear at altitudes of 2000 to 3000 kilometers, just above where small comets are supposed to disrupt to form atmospheric holes, and the trails seem to be about as abundant as atmospheric holes, says Frank. "That's totally independent verification of the ultraviolet measurements," he says.

"It's very impressive observational work," acknowledges atmospheric physicist Thomas Donahue of the University of Michigan, "that I don't think leaves us much room for doubt. There are little somethings releasing a lot of oxygen, and they show the signature of hydroxyl in emission. It's hard to imagine what other than water" they would be. But Donahue has by no means come around to the idea that these clouds of water were left by Frank's small comets. "I still have all the problems I ever had with the amount of water involved," because no one has seen it elsewhere. He ticks off the problem areas: Venus is dry, Mars is dry, Earth's upper atmosphere is dry, and the space between the inner planets is "dry" in that it has no excess of the hydrogen that small comets would leave.

Indeed, if these midget comets exist, they are surprisingly well cloaked. If a grain of sand enters the uppermost atmosphere, for example, it burns for all to see as a shooting star. "The idea that a 10-meter meteoroid could enter Earth's thermosphere at night without causing a big flash is very difficult to accept," says Arizona's Hunten. Plunging in at 65,000 kilometers per hour, "it would light up the whole sky." Similarly, seismometers left on the moon by the Apollo astronauts have detected no trace of the 1500 small comets that Frank predicted should hit its surface every day.

Space physicist Alexander Dessler of the University of Arizona sees these and other problems as overwhelming. "The small-comet hypothesis fails to agree with physical reality by factors that range from a thousand to a billion," he says. Dessler was the *Geophysical Research Letters* editor who, against reviewers' advice, boldly published Frank's first papers, only to become one of Frank's most persistent critics later (*Science*, 31 July 1992, p. 622).

In response to such criticisms, Frank has suggested over the course of the debate that small comets have various properties that would minimize some of these anomalies. For example, comets with extraordinarily pure interiors would create less flash on atmospheric entry; a fluffy, snowdrift structure would enhance their disruption at high altitudes and help create the atmospheric holes. "I think there'll be lots of objections," says Frank, "but they're all based on a knowledge of rock [rather than low-density] impacts or the desire to not have our planet be exposed to a continual cosmic rain." Frank's colleagues are still not persuaded. "Lou has of course proposed rebuttals to all these criticisms," notes Hunten, "but I don't believe they're valid."

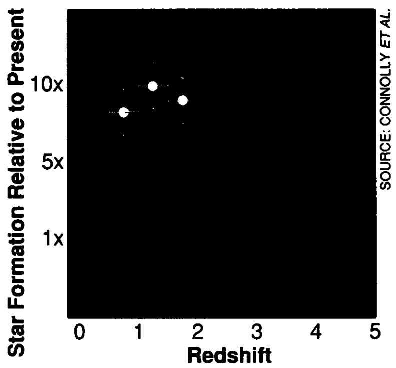
If the atmospheric holes aren't the debris of small comets, then what are they? The one-time critics don't know and aren't even ready to speculate. But Frank is now forming collaborations with Donahue, NRL's Meier, and others to, as Donahue puts it, "understand these things in a way that meets all the constraints," such as a dry inner solar system. Researchers also will be looking at other means of detecting and quantifying the high-altitude water and its source, including high-tech telescopes that ought to be able to pick up even dark bodies 10 meters in size. Most encouraging, says Donahue, is that Frank and the rest of the community are no longer at odds. "Last time, Lou was taking on the world," he says. "This time, he seems to be asking the world for help."

–Richard A. Kerr

ASTRONOMY

Gap in Starbirth Picture Filled

Like historians trying to piece together events from fragmented records, astronomers attempting to reconstruct the story of the stars and galaxies in the universe must rely on observations that only reveal bits and pieces at a time. Take their efforts to trace the history of star formation. Because of a quirk in the way astronomers measure galaxies' distances to learn where each one fits in cosmic history, their picture of the starbirth rate over time has had a crucial gap: the middle section, when the universe was turning gas and dust into stars at top speed.



Stellar birthrate. The peak—at a redshift of 1.25—falls two-thirds of the way back to the big bang. (Higher redshifts correspond to earlier times in cosmic history.)

Now, a team of astrophysicists has made a first stab at directly charting the stellar baby boom. New observations, combined with a new trick for estimating a galaxy's distance from its colors, have allowed Andrew Connolly and Alexander Szalay of Johns Hopkins University, Mark Dickinson of the Space Telescope Science Institute (STScI) in Baltimore, and their colleagues to calculate that starbirth peaked at about 12 times the current rate when the universe was about a third of its current age. Because this peak is both higher and later than many astronomers had suspected, it's sending the theoreticians back to revise their models of galaxy formation.

Still, astronomers are pleased to see this filling in of history. The result, which the team presented at a symposium last month at STScI, "connects the other two sets of data in a nice, smooth way," says Simon White of the Max Planck Institute for Astrophysics in Garching, Germany. "It's nice to actually see the peak now."

Previous work had traced the two slopes of the peak. By measuring ultraviolet (UV) light—the hallmark of newborn stars—from galaxies in a census they compiled, astrophysicist Simon Lilly of the University of Toronto and his colleagues had estimated starbirth from the present back more than halfway to the big bang. The data suggested that the universe is winding down—that star formation has been decreasing for at least the latter half of the universe's lifetime. But farther back, galaxies become very dim, making it difficult to detect the spectral signatures—the so-called redshift—that astronomers commonly use to measure distance.

Another stratagem allowed Piero Madau of STScI and his colleagues to identify some galaxies at much greater distances. The light from those galaxies must travel through so much hydrogen gas on its way to Earth that the ultraviolet end of its spectrum is essentially erased. The expansion of the universe shifts this UV decrease—called the Lyman break—into the blue part of the spectrum. That made the break easy to identify in the galaxies of the Hubble Deep Field, an image from the Hubble Space Telescope that includes some of the farthest reaches of the universe. This analysis added two more points to the graph, showing a steady increase in star formation from the time when the universe was only 10% of its current age until it was almost a quarter of the way through its history.

Combined with Lilly's data, that increase suggested a peak somewhere in the middle, when the universe was one-quarter to half its present age. But galaxies in that middle range are too close for the break to be displaced into visible wavelengths.

To fill in the gap, Dickinson and his colleagues took another look at the Deep Field. Examining galaxies in the Deep Field with the 4-meter telescope at Kitt Peak National Observatory in Arizona, they captured the infrared light that the Hubble's cameras had missed. The extra data helped Connolly and Szalay derive a mathematical formula for how a galaxy's colors should shift as it gets farther away—a formula they used to identify the galaxies in the middle range. They then determined the rate of starbirth in those galaxies, picking up the expected peak. A good indication that the new data are correct, Szalay says, is that their lowest point is a "spot-on" match with Lilly's highest.

In fact, the newly charted peak also matches some earlier predictions, based on theoretical models and on observations of gas and heavy elements in galaxies. But birthrates give only limited information; astronomers would now like to know where and how the stars were born. The rate of starbirth is "a step along the road toward understanding star formation and galaxy formation," says astrophysicist Michael Fall of STScI. But it cannot tell astronomers what kind of galaxies spawned these stars. "This is a valuable average over all the details," Dickinson says. "The challenge now is breaking it down again."

–Gretchen Vogel