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."

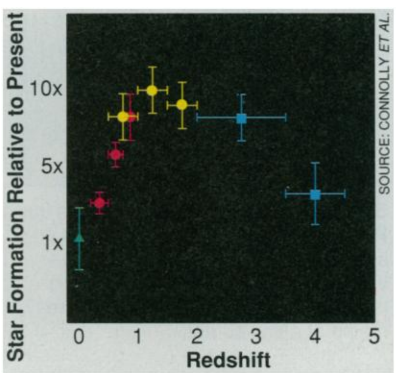
If the atmospheric holes aren't the debris of small comets, then what are they? The one-time critics don't know and aren't even ready to speculate. But Frank is now forming collaborations with Donahue, NRL's Meier, and others to, as Donahue puts it, "understand these things in a way that meets all the 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