

First echoes from SN1987a... 87a... 87a



The first visible-light echoes from supernova 1987a—in fact, the first ever observed from a supernova—have been detected. The echoes, visible in this photo as arcs of rings surrounding the central star, are the light of the exploding star reflected from dusty clouds in the Large Magellanic Cloud. Although the clouds lie almost directly in our line of sight to the supernova, they are quite distant from the star. Arlin Crotts (University of Texas, Austin) reported finding a double echo on 4 March using the 40-inch Swope telescope at the Carnegie Institution's Las Campanas Observatory in Chile. Confirmation of Crotts's report came a week later from Michael Rosa (European Southern Observatory), who examined data he had taken in February with ESO's 3.6-meter telescope.

Crotts blocked out most of the direct light of the supernova with a disk, although some of that light is visible as a cloverleaf structure in the photo. The rings were 32 arcseconds and 47 arcseconds from the supernova in March, and they have been expanding at a rate of 2–3 arcseconds a month since then (or at an apparent linear expansion rate of 2–3 light years a month). According to Crotts, the light is echoed from dust clouds lying 440 light years and 950 light years away from the supernova, and may be visible for decades.

Three groups have independently compared the spectra of the rings with the changing spectrum of the supernova: Crotts; a group at the Cerro Tololo Inter-American Observatory, Chile, headed by Nicholas B. Suntzeff; and a collaboration

of ESO investigators at La Silla, Chile, and at Garching. As expected, the spectrum of the brightest light from the echoes is consistent with that of the supernova at its peak. Crotts notes that one expected feature of the echoes has not been observed. Each ring should have two components: a narrow outer ring bright in the uv, corresponding to the initial burst of light associated with the shock wave breaking through the surface of the progenitor star, and a broad inner ring, corresponding to the later brightening caused by the expansion of the supernova's outer layers. Crotts suggests that if the nearby dust clouds are thick, such finer structures may have been smeared out.

The echoes offer a unique opportunity to map the interstellar medium in this region. Roger Chevalier (University of Virginia) had predicted that supernova light echoes would appear as rings if the reflecting clouds occurred in sheets, and this may be the case with SN1987a. In addition, the rings are brighter in the region to the north of the star (top of photo), presumably because the interstellar medium is denser or thicker there.

The rings also represent a temporal record of the explosion, because light from the outer edges of the rings was emitted earlier in the explosion than light from the inner region. With sufficient resolution (not easily achieved), one could thus trace the evolution of the supernova across the width of the rings. "The rings give us a time sequence of photographs in the sky," Stan Woosley (University of California, Santa Cruz) told us.

Roberto Gilmozzi (European Space Agency IUE Observatory) reported in late June that a collaboration of IUE investigators has detected what may be an ultraviolet echo, some 40 arcseconds from the supernova. Such a signal would have originated in the first few hours of the explosion, during the shock breakout. Confirmation that the feature is indeed a uv echo awaits the observation of its expansion.

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direction), as expected from the Doppler principle. The large magnitude of the dipole vector seems to require a large-scale perturbation from smooth expansion of the universe (see *PHYSICS TODAY*, October 1987, page 17). An anticipated small-angle anisotropy of the CBR is potentially even more interesting to galaxy formation theorists. Observations so far have only placed limits on this, but we should now be near the threshold of its detectability, according to David Wilkinson (Princeton).

As yet CBR photons are the only means of directly studying the universe beyond redshifts of about 5, a value that bounds the highest-red-

shift quasars known. The fossil photons from the CBR give the most stringent constraints on conditions in the early universe, and so act as a damper on speculative scenarios of the formation of the inhomogeneous structure we see in the universe now.²

Finding fossil photons

From ground-based measurements of a relatively transparent part of the radio window at a wavelength near 7 cm, Arno Penzias and Robert Wilson (AT&T Bell Labs) in 1965 assigned a blackbody temperature of about 3 K to the CBR. Measurement of a blackbody's spectral intensity at only one wavelength defines its spectrum and

hence its temperature: Simply put, one blackbody curve cannot cross another. A 3-K blackbody spectrum has its peak intensity at about 1-mm wavelength, according to the Wien displacement law.

At longer wavelengths a blackbody (Planck) curve can be represented by the simple Rayleigh-Jeans power law approximation. Background contaminants must be subtracted from the measured sky brightness to yield reliable measurements of the CBR. Observers can easily avoid Galactic neutral hydrogen line emission at 21 cm, but continuum emission from bremsstrahlung in ionized hydrogen regions is more serious. There is also contam-