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ASTRONOMY

More Supernova Surprises

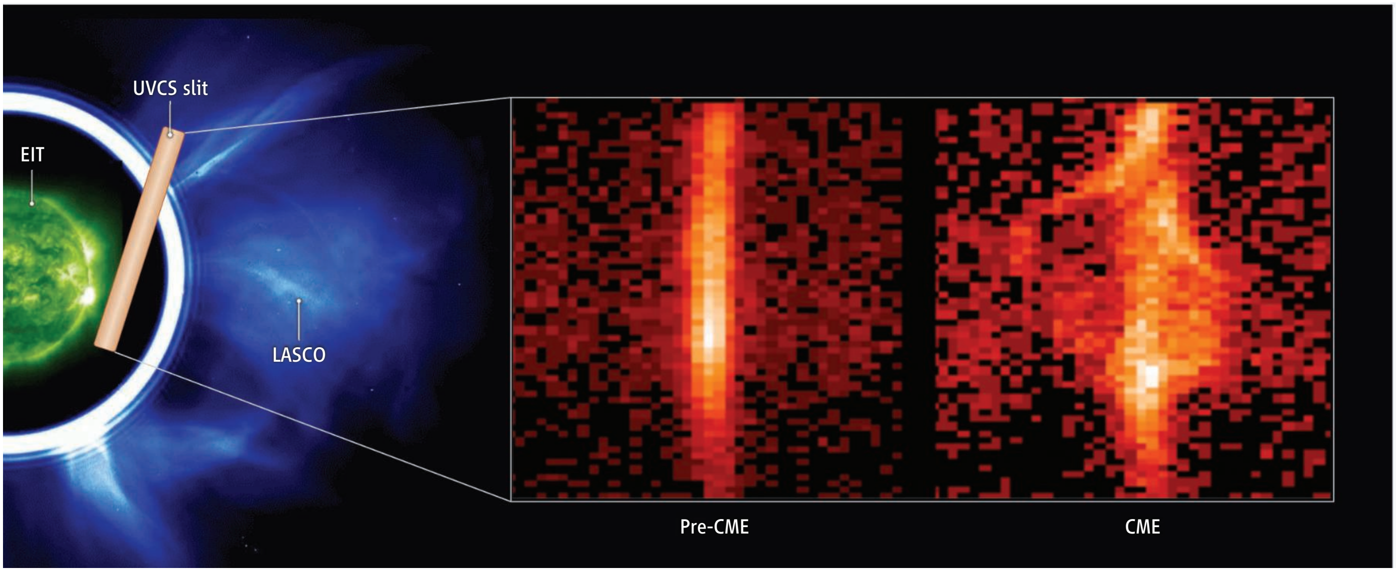
Spectroscopic observations of the supernova SN1987A are providing a new window into high-energy shock physics.

J. Martin Laming

The explosions produced when the central region of a massive star ceases nuclear burning and collapses to a neutron star (a core-collapse supernova) have stretched and motivated research that has expanded our knowledge of astrophysics. The brightest such event in modern times was the explosion of the supernova SN1987A on 23 February 1987. As SN1987A evolves from supernova to supernova remnant (SNR) and interacts with its external medium, it continues to reveal new insights into unexplored areas of physics. On page 1624 of this issue, France *et al*. (*1*) discuss how ultraviolet spectroscopy can provide new insights into the nature of shock waves associated with SN1987A.

The explosion of a supernova sends a forward shock out into the surrounding medium, driven by the motion of the explosion products (the ejecta). As the forward shock sweeps up more material, it decelerates. This deceleration must be communicated to the expanding ejecta, and in supernova remnants this usually occurs through a second backward-pointing (or reverse) shock (*2*, *3*). Spectroscopic emission line intensities and profiles (through the distribution of Doppler shifts of emitting atoms or ions) tell us important things about the condition of the explosion products and their interaction with the reverse shock. Observations with the Space Telescope Imaging Spectrograph onboard the Hubble Space Telescope (HST-STIS) reveal UV lines from neutral hydrogen and quadruply ionized nitrogen, with the distinct possibility of several more line detections with the new Cosmic Origins Spectrograph (HST-COS).

A crucial property of the shock is that it is "collisionless" (*4*). In hydrodynamics, a shock is a discontinuity in fluid properties, occurring over an infinitesimally small distance. Simple considerations of the kinematic viscosity suggest that this transition should occur over a distance similar to the collisional mean free path of a fluid particle (*5*, *6*). However, in the dilute plasmas encountered in astrophysics, the mean free path of shocked fluid particles in many SNRs is typically larger than the size of the object itself. The shock transition must occur on a length scale much smaller than the collisional mean free path. This can occur as the plasma particles interact not through the emission and absorption of virtual photons, as would be the case in vacuum, but through the emission and absorption of the quanta of oscillating electric and magnetic fields associated with collective motions of the plasma. In low-energy (or nonrelativistic) shocks, these quanta are usually Alfvén waves (low-frequency traveling waves of oscillating ions and magnetic field) and can be generated by stimulated Cerenkov radiation emitted in instabilities. Thus, if such a mode is allowed to grow by the plasma conditions, it can overwhelm the more usual Coulomb collisions (between charged particles). Hence, thermal equilibrium is no longer enforced, and phenomena associated with collisionless shocks such as particle acceleration may occur.



Shocking images. Observation of the 21 April 2002 CME by instruments onboard SOHO, with speed of 2400 km s^{-1}. The left panel gives context images: the solar disk observed in the light of Fe XII (11 times ionized, Fe^{11+}) by the Extreme-Ultraviolet Imaging Telescope (EIT) and a white-light image of the CME taken by the Large Angle Spectroscopic Coronagraph (LASCO), with the position of the UVCS slit shown. The center and right panels show "before" and "after" images of the O-VI (quintuply ionized oxygen) spectral line profile as the CME goes by, detected by the UVCS instrument. The horizontal dimension is the spectrometer dispersion direction; the vertical dimension gives spatial imaging.

Neutral atoms, such as hydrogen, do not "see" these collective oscillations and penetrate right through the shock, emitting photons as they are excited by collisions with gas particles on the longer length scale. Thus, their spectral line profiles are determined by Doppler shifts associated with their preshock velocity distribution. Quadruply ionized nitrogen, along with other ions expected to be detected with HST-COS because they are electrically charged, will react to these collective oscillations, and their line profiles (also excited by collisions) will reveal information about the scattering processes that form the shock.

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Similar ground is being broken in studies of shocks in the solar system (*7*, *8*), where phenomena related to particle acceleration have more than just academic interest. The figure shows a spectroscopic observation by the Ultraviolet Coronagraph Spectrometer (UVCS) instrument onboard the ESA/NASA Solar and Heliospheric Observatory (SOHO) of a 2400 km s^{-1} disturbance driven by a solar coronal mass ejection (CME) based on images published in (*9*). The line profile in the post-CME gas (right panel) is broader than in the pre-CME image (center panel), possibly implying through the Doppler shifts that the post-CME gas is hotter. However, the broadening is distinctly nonuniform in the spatial direction, for reasons that are currently not completely understood, but which may relate to the upstream medium or whether the disturbance has fully transitioned to a shock. To date, most work in this area has concentrated on in situ observations of planetary bow shocks, although some higher-speed shocks driven by CMEs have also been observed. The nonlocality of the collisionless shock problem often stymies quantitative understanding, as the whole shock is not observed at once; only shock parameters along the spacecraft line of flight can be detected. The four spacecraft of ESA's Cluster mission go some way toward ameliorating this, but, as can be seen in the figure, four in situ observation points instead of one do not necessarily solve the whole shock problem.

We can anticipate similar data when HST-COS observes the somewhat faster shocks in SN1987A. One might consequently expect the broadening to be even more dramatic. We are doubly fortunate in that SN1987A not only exploded at a time when ideas about the core-collapse explosion mechanism were beginning to reach a degree of maturity that could really be informed by observations, but did so in a part of the sky accessible to ultraviolet observations, thereby allowing us to study the shock waves associated with its remnant in detail.

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BOTANY

The Rise of Sunflowers

A new fossil suggests the family that includes sunflowers and daisies originated in South America.

Tod Stuessy

Everyone appreciates the beauty of daisies, chrysanthemums, and sunflowers, and many of us enjoy eating lettuce and artichokes. These cultivated plants, along with 23,000 other wild species, make up the sunflower family, also known as Compositae or Asteraceae. Today, members of the family are found on every continent except Antarctica, especially in temperate or higher elevation areas in the tropics. Where the sunflower family first evolved and how it spread, however, is not well understood, in part because researchers have found relatively few fossils. On page 1621 of this issue, Barreda *et al*. (*1*) describe an unusually well-preserved new fossil that sheds light on the history of this successful plant family and adds to evidence that it originated in southern South America about 50 million years ago.

The family Compositae is a distinct group characterized by the combination of several morphological features. The most conspicuous is flowers that are closely aggregated into heads (an arrangement that botanists call an inflorescence). The well-known sunflower has two types of flowers in the head, disc and ray flowers, but the common dandelion and many other species contain only one. In all cases, the flowers are surrounded by leaflike structures called involucral bracts or phyllaries. Another important feature is the pappus, which is a modified calyx attached to the apex of the ovary. In dandelions, the pappus extends into a parasol as fruits mature, which aids dispersal. Laterally fused pollen sacs (anthers) that form a tube, through which the female style pushes upward and presents pollen, is also a diagnostic feature for Compositae.

Despite its enormous size, broad geographic distribution and distinct features, there is a weak fossil record for this group. Most reports have been of fossil pollen (*2*, *3*), from Africa, Australia, and South America. Although variations in pollen grains exist in the family, a lack of broad diversity limits researchers' ability to determine relationships and derive evolutionary insights. The paucity of larger macrofossils has also been a problem. There are some macrofossils from the very recent Pleistocene (~2.6 million to 12,000 years ago). An older fossil, *Viguiera cronquistii*, came from western North America and is dated to the Oligocene-Miocene (~34 million to 5.3 million years ago) (*4*). Critical investigations (*5*), however, have cast doubt on the fossil plant's relationship to Compositae; it may not even be a flowering plant.

Roots. The sunflower and other members of its large family appear to have evolved from a common ancestor living in southern South America more than 50 million years ago.

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