released when the anion is hydrated. Without such cooling, the hydrated species are fluxional, likely sampling several isomeric structures, which results in diffuse infrared spectra carrying limited structural information. For complexes with an incomplete hydration shell, the spectra remain diffuse even when the complexes are cooled by Ar evaporation. In contrast, the OH stretching fundamental spectrum for the tetrahydrated O_2^- shows well-defined structure, in excellent agreement with that predicted for a highly symmetric hydrogen-bonded structure. As in the Nauta and Miller work, the OH stretch spectrum is particularly sensitive to the structural properties of the complex because of its strong dependence on the degree and cooperativity of hydrogen bonding.

If one neglects the possible difficulties of assembling superoxide tetrahydrate in liquid helium nanodroplets, the use of Ar is, in principle, less favorable than that of He because of the larger perturbations and the warmer temperatures present in Ar nanomatrices. Nevertheless, the observed line widths for the tetrahydrate were sufficiently narrow compared with those of the less hydrated complexes to enable reliable structural assignment. With improved spectral resolution, one can foresee observation of rotational or rotational-tunneling structure, which would allow a more detailed comparison of experiment with theory for these important molecular species that are the cornerstones of macroscopic aqueous solvation.

Little is known about the size and nature of chemical reaction barriers smaller than ~0.1 kcal/mol (*14*). HENDI spectroscopy may be useful here, as the low-temperature environment is expected to suppress almost all reactions with an appreciable barrier, leading instead to the formation of van der Waals complexes, the presence of which would be indicative of even a small barrier. The structural selectivity demonstrated above, may allow the detection of the angular dependence of reaction barriers by allowing for the control of the matrix orientation in bimolecular encounters, much as it is done in the gas phase (*15*). HENDI may also be used to study isomers of complex organic molecules. Lindinger *et al.* have shown (*16*) that the number of tyrosine and tryptophan isomers detected by HENDI is smaller than that detected in the warmer but still cold environment of a supersonic free jet (*17*). Photon-induced annealing of the isomers of these and other, larger, molecules should teach us a great deal about the intramolecular dynamics, and possibly the folding, of complex molecules.

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PERSPECTIVES: ASTRONOMY

Stars at the Edge of Stability

Norbert Langer

The most massive stars known today can, for short periods of time, erupt, shedding amounts of mass and energy comparable to a supernova. Such an eruption does not end a massive star's life but is key to its ultimate fate. For example, Eta Carinae, today invisible to the naked eye, erupted in the 19th century, making it the second brightest star in the sky for more than 10 years (*1*). The ejected matter now forms the strongly bipolar Homunculus nebula (see the left panel in the figure) (*2*). About a dozen such luminous blue variables (LBVs) are known today (*3*). Their radius and surface temperature can remain variable on time scales of months or more, for decades to centuries after the eruption. Intense recent research activity, fueled not least by the Hubble Space Telescope, has shed some light on the eruption mechanism, with possible clues for the formation of massive stellar black holes and gamma ray bursts (GRBs), for which massive stars are thought to be progenitors (*4*).

There is one main factor that destabilizes LBVs: their huge luminosity. Stars shine brighter the more massive they are. This trend is so steep that the most massive stars—comprising about 100 solar masses ($M_\odot$) but a millionfold brighter than the sun—extinct their fuel in less than a per mil of the sun's lifetime. The enormous luminosity is produced in the star's deep interior, and the huge number of photons carrying it exert a strong outward force while traveling to the surface. This causes two instabilities. First, the stellar interior becomes convectively unstable, leading to a millionfold acceleration in the transport of energy to the surface and relieving the star from an otherwise unbearable pressure. Second, the photons escaping from the star push on the ions in the star's atmosphere so vigorously that they drive a very dense and powerful outflow, which can reduce the star's mass substantially during its short lifetime and creates huge bubbles in the interstellar medium.

Both instabilities—convection and radiation-driven winds—already occur in stars more massive than 10 $M_\odot$ but do not lead to their destabilization. However, the most massive stars are 100 times more luminous than 10 $M_\odot$ stars. In the outer parts of such stars, the hydrostatic equilibrium may break down as the radiation pressure gradient overwhelms gravity: The star exceeds its Eddington limit, the upper luminosity limit that can be radiated by an object of a specified mass. This is thought to lead to the eruptions seen in LBVs (*5*).

The morphology of the eruption debris lends strong support to the Eddington mechanism. Recent imaging and spectroscopic studies found that all but one nebula around LBVs show a bipolar geometry (*6*). Whatever causes LBV eruptions is thus not spherical but axially symmetric. Axial symmetry is expected when a rotating star exceeds its Eddington limit, as the centrifugal force breaks the spherical symmetry otherwise maintained by the balance between gravity and radiation. This has been demonstrated by models for the formation of the Homunculus nebula (*7*).

On the other hand, the axial symmetry of the eruption debris may also be caused by a close binary companion. Such a companion could exert a force on the surface of the LBV and thereby trigger an eruption, or it could shape the debris through its gravitational field, its radiation, or its stellar wind. In the latter case, the symmetry axis of the debris would not go through the LBV but through the center of mass of the binary

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system. To obtain a perfect axial symmetry, the binary period should be short compared with the duration of the eruption.

The idea that binarity is relevant to LBV eruptions was recently revived by the discovery of a 5.5-year period in spectral properties of Eta Carinae (*8*). Spectroscopic and photometric variations on time scales of years are inherent to LBVs, but the very strict periodicity in Eta Carinae is striking and leaves little room for alternative explanations (*8*). The presence of a companion remains, however, difficult to relate to Eta Carinae's eruption or to the bipolar shape of its circumstellar matter. The observed period seems too long to generate axial symmetry and the orbital separation of the two stars too large to allow a companion to trigger an eruption.

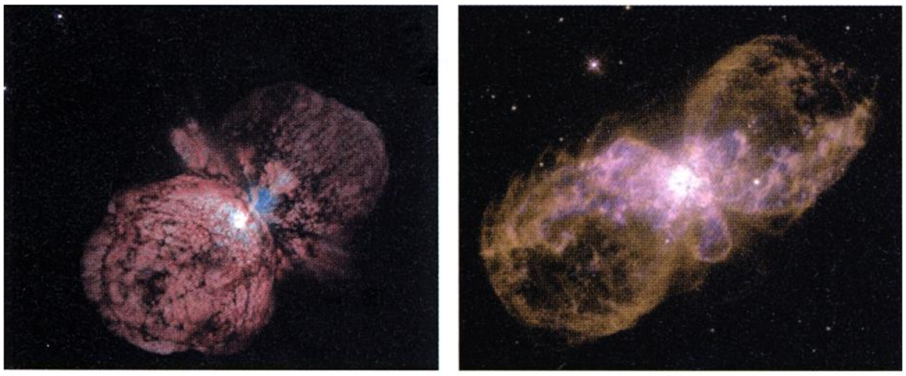
Clues may come from comparing the discussion about the mechanism of LBV eruptions and nebular geometry with the very similar debate on planetary nebulae, which form at the end of the evolution of low-mass stars (*9*). Planetary nebulae are mostly either axially symmetric (see the right panel of the figure) or spherical, indicating that the mechanism that produces the debris and the mechanism that shapes it are independent. In contrast, all known LBV nebulae are bipolar, suggesting that the LBV eruption mechanism is also responsible for their shape.

It thus appears reasonable to attribute particular features in Eta Carinae's debris—its knotty jets and streamers (*10*) and a massive cold torus (*11*), which are not known from other LBV nebulae—to binarity. This point of view is strengthened by the fact that similar features occur in some axially symmetric planetary nebulae. But the origin of the eruption is likely to be found in the erupting star itself, rendering the Eddington limit in rotating stars the most promising explanation.

The aftermath of an LBV phase is an almost bare stellar helium core, a so-called Wolf-Rayet (WR) star. WR stars have continuous winds so strong that they almost evaporate the star. It was recently found that their winds are considerably weaker than previously thought (*12*), but it remains true that the WR stars evolving from LBVs end up as objects of relatively low final mass (of 10 $M_\odot$ or less) (*13*).

The final stage of a massive star is determined by the mass of the iron core that it forms at the end of its life. Lower mass iron cores collapse to neutron stars, ejecting the stellar envelope in a supernova explosion. In contrast, massive iron cores collapse into black holes, which—if sufficient angular momentum resides in the core—may trigger an even more energetic event: GRB (*14*).

On average, stars with larger final mass develop more massive iron cores. It is thus conceivable that massive stars, which lose a lot of mass during an LBV and subsequent WR phase, end their lives in a supernova explosion, and that *only those that avoid the* LBV and WR stage may form GRBs. It then depends on the LBV eruption mechanism how many GRBs form. If the most massive single stars in the Milky Way become LBVs without the "help" of a binary companion, one may expect relatively few local GRBs. As the Eddington instability gets weaker when less heavy elements are present in the stellar envelope, one would expect most GRBs to occur in the early universe, which appears to be compatible with GRB observations (*4*).



A similar mechanism? The geometry of the Homunculus nebula ejected by the luminous blue variable (LBV) Eta Carinae **(left)** is strikingly similar to that of the planetary nebula Hubble 5 **(right)**.

CREDIT: RIGHT, oposite.stsci.edu/pubinfo/jpeg/EtaCarC.jpg; LEFT, oposite.stsci.edu/pubinfo/pr/97/pn/content/hb5.jpg

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PERSPECTIVES: MOLECULAR BIOLOGY

RNA Interference

Phillip A. Sharp and Phillip D. Zamore

The mechanical sounds of robots and the electronic hum of computers are features of 21st-century life. Despite the joys of increasing automation, simple experiments still produce wonderful new discoveries in molecular biology. The realization several years ago that double-stranded RNA (dsRNA) is a key player in one form of posttranscriptional gene silencing indicated that a new field of great importance was about to be created (*1*). The study of how RNA regulates gene expression—called RNA interference (RNAi)—has an exciting future, and the report by Grishok *et al.* on page 2494 of this issue (*2*) provides further support for such optimism.

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The RNAi phenomenon has been observed in a wide variety of organisms—plants, worms, flies, fungi, and vertebrates (including mouse embryos)—and is best considered a feature of nearly all eukaryotes. In most of these organisms, injection of dsRNA longer than 500 base pairs specifically suppresses the expression of a gene with a corresponding DNA sequence, but has no effect on genes unrelated in sequence. RNAi suppresses gene expression by a posttranscriptional process, although there is convincing evidence, at least in plants, that dsRNA can also regulate DNA methylation (another mechanism for silencing genes) (*3*). Thus, gene-specific regulation by RNA may also control transcription under certain circumstances.

The surprising nature of RNAi is highlighted by the recent discovery of small RNAs, about 25 nucleotides long, in plants displaying posttranscriptional gene silencing (*4*). These small RNAs are complementary to both the sense and antisense strands of the