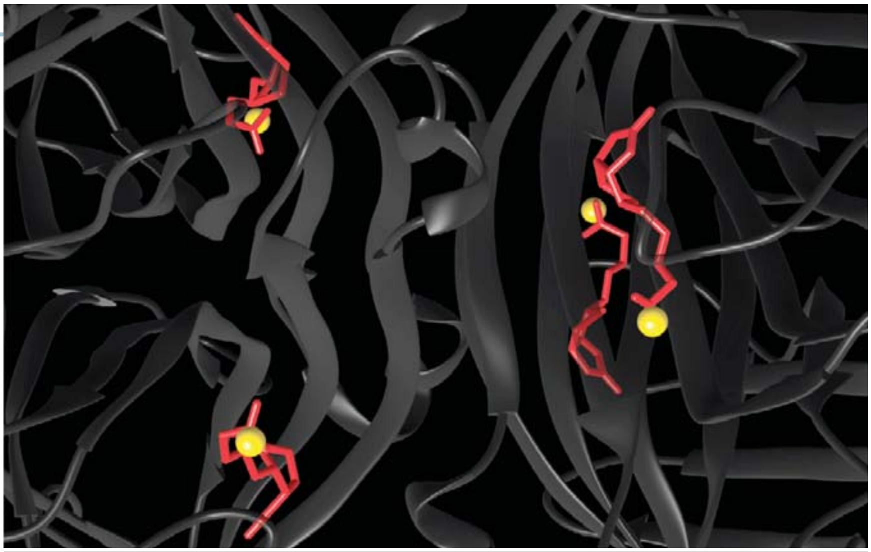

Figure 2. The crystal structure of the streptavidin–biotin complex, with the streptavidin protein structure shown in dark gray and the biotin molecules shown in red. The yellow spheres represent the AFM-derived positions of the ends of the biotin molecules—in agreement with their crystal-structure positions to within 0.2 nm. (Adapted from ref. 1.)

some DNA-bound biotin, incubated it with streptavidin molecules that they'd affixed to a solid substrate, and imaged the resulting complexes with their AFM.

From imaging a large number of randomly oriented complexes, the researchers found that the distances between DNA-labeled biotins in the same complex clustered around three values: 3.0 nm, 5.3 nm, and 6.0 nm. Three pairwise distances are what's expected if the four biotins form a tetrahedron with each pair of opposite edges the same length (as is known to be the case). Kim and Sahin calculated the shape of the tetrahedron, superposed it on the protein structure, and calculated where the molecules' ends must be, as shown by the yellow spheres in figure 2. The AFM-derived positions agree with those in the crystal structure to within 0.2 nm.

To make the best use of their method, Kim and Sahin would like to be able to apply a DNA label to any part of a protein molecule on demand. But that's no easy feat, in part because proteins are made up of many copies of the same amino acids, with little to chemically distinguish them. In the meantime, the researchers are turning their attention to naturally occurring biomolecular complexes between proteins and DNA or RNA. "The RNA strand that is part of the complex may provide the label that we need," says Sahin, "so they may be easier to study. We are exploring that possibility."

Johanna Miller

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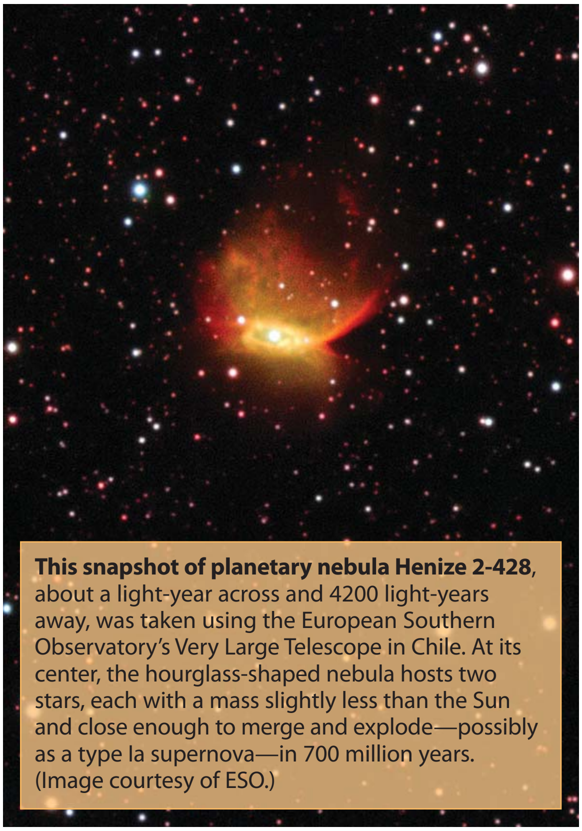
A newly found pair of stars appears destined to merge and explode

An analysis of their orbits and masses indicates that the pair is a plausible supernova progenitor.

As its nuclear fuel runs out, a Sun-like star balloons into a red giant whose outer layers are blown farther outward by the stellar wind. The naked carbon–oxygen core left behind contracts under gravity into a white dwarf, its surface becoming hot enough in the process to ionize its surrounding envelope of dust and gas. The glowing shells, known somewhat confusingly as planetary nebulae, are among the most beautiful sights in the night sky.

The vast majority of the thousands of such nebulae cataloged by astronomers have shapes that seem inconsistent with the stellar wind's spherical symmetry.



This snapshot of planetary nebula Henize 2-428, about a light-year across and 4200 light-years away, was taken using the European Southern Observatory's Very Large Telescope in Chile. At its center, the hourglass-shaped nebula hosts two stars, each with a mass slightly less than the Sun and close enough to merge and explode—possibly as a type Ia supernova—in 700 million years. (Image courtesy of ESO.)

For the past two decades, theorists have been trying to figure out why. Although the issue remains unsettled, most believe that the presence of a pair of orbiting stars is the most efficient way to generate sufficient angular momentum to break the symmetry and shape the wind into an outflowing equatorial ring, sometimes with bipolar lobes.[1] Orbital drag causes the stars—a soon-to-be white dwarf interacting with either another nearby dwarf or something else, such as a main-sequence star or red giant—to spiral inward toward each other as nebular jets are thrown outward. The sightings and analyses of some 50 close binary stars found in sky surveys of planetary nebulae have largely borne out that hypothesis.

As part of one recent sky survey, Miguel Santander-García of Spain's National Astronomical Observatory, Romano Corradi of the Institute of Astrophysics of the Canary Islands, and their collaborators have discovered an especially intriguing binary:[2] two pre-white-dwarf stars of virtually identical mass and size orbiting each other with a period of just four hours inside the planetary nebula Henize 2-428. What's more, the mass of each star is about 0.9 solar masses ($M_\odot$). When the two finally merge in 700 million years, their combined mass will exceed the Chandrasekhar limit of 1.4 $M_\odot$, above which electron degeneracy pressure cannot support a white dwarf against its own weight. According to theory, that "super-Chandrasekhar" merger will ignite a spectacular nuclear explosion—the runaway thermonuclear fusion of some 10^{30} kg of carbon into nickel—provided the merger sufficiently pressurizes the core of one of the stars.

Because the newly observed binary has the essential ingredients required for so ferocious an explosion, known as a type Ia supernova, it qualifies as a credible progenitor—the first ever observed. "Of the few dozen white-dwarf binaries found so far, all have been either too widely spread to merge within the age of the universe or their combined mass has been below the Chandrasekhar limit," says Corradi. Louisiana State University's Bradley Schaefer puts the claim in a broader perspective: "It's been a hard, 40-year-long slog searching for a type Ia progenitor." Those supernovae are responsible for much of the universe's iron and other trace elements and have long been standard candles for gauging cosmological distances (see the PHYSICS TODAY articles by Saul Perlmutter, April 2003, page 53, and by Mario Livio and Adam Riess, October 2013, page 41).

A weird system

Although finding a progenitor is reassuring, it is not unexpected. About 10% of all white dwarfs are born as close binary pairs, and 100 million such binaries are thought to populate our galaxy at the moment (see the article by Gijs Nelemans, PHYSICS TODAY, July 2006, page 26). Planetary nebulae have long been considered good hunting grounds. Indeed, the fraction of type Ia supernovae exploding inside planetary nebulae may be as high as 20%.[3]

Santander-García and company were not looking for supernova progenitors. Their challenge, finding new binaries, is its own difficult task. White dwarfs dim quickly and, while very young, much of their light may be obscured by the nebular gas and dust. The researchers pored over catalogs, looking for nebulae whose elongated, bipolar shapes seemed to best suggest the interaction of companion stars. The pair of extended lobes and ring-shaped waist of Henize 2-428, shown above, drew their attention. The nebula itself is a light-year across, but the stars at its center orbit within two solar radii from each other.

From our distant perspective 4200 light-years away, no telescope can spatially resolve so compact a binary. The usual tack, which the researchers followed, is to monitor the modulations in visible-light emission as the stars repeatedly cross in front of each other. Quasi-sinusoidal variations due to the stars' tidal distortions of each other confirmed the presence of the binary and provided a handle on its orbital dynamics. To measure the stars' radial velocities and extract the stars' masses, the researchers used the Gran Telescopio Canarias, whose 10-m mirror captured the Doppler shifts in the absorption-band frequency of helium as the stars orbited each other.

Aspects of the system are still mysterious. "Frankly, the identical masses, radii, luminosity [and thus temperature] of the stars is just weird," says Gijs Nelemans of Radboud University Nijmegen in the Netherlands. "Maybe one star has been transferring mass to the other." Or the stars may have started life in nearly the same state at the same time, a rare situation.[4] At about 0.7 solar radii, both are still large and hot.

Nelemans also questions the relevance of the Chandrasekhar limit as a forecasting tool for merging white dwarfs. The violent merging process is distinctly different from the situation in which one of the stars slowly accretes by siphoning off matter from a normal hydrogen-burning star until its mass exceeds the limit (see PHYSICS TODAY, May 2010, page 11). Three-dimensional hydrodynamic models have found complex structures that may explode in a way that resembles a type Ia supernova even when the total mass of the merger is below the Chandrasekhar limit.[5]

Two years ago Rüdiger Pakmor and colleagues from the Max Planck Institute for Astrophysics in Garching, Germany, showed that the thin shell of helium surrounding a white dwarf can become entrained onto its companion so rapidly during a merger's onset that the helium detonates and sends into the star's core a shock wave that ignites its store of carbon.[6] Yet other simulations suggest that a white dwarf rotating fast enough can also stabilize itself against carbon ignition. In short, modeling mergers is complicated, and theorists are not sure what initial conditions and evolutionary paths take a white dwarf from stable equilibrium to a supernova explosion.

Nonetheless, says Nelemans, "the companion stars in Henize 2-428 are so massive that something explosive is bound to happen. Their discovery is an important case to guide theory." The context of the discovery is likely to intrigue astronomers as well. As Noam Soker at the Technion–Israel Institute of Technology puts it, "Planetary nebulae are much more than just beautiful. They are the crossroads of many other astrophysical objects."

Mark Wilson

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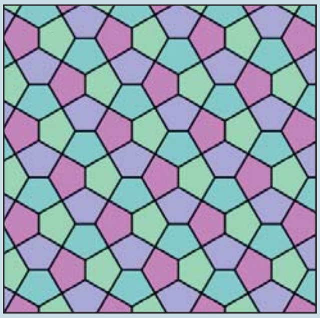
physics update

These items, with supplementary material, first appeared at http://www.physicstoday.org.

Modeling wind farms' influence on weather. The amount of electricity generated worldwide from wind has been increasing by roughly an order of magnitude per decade; in 2012 wind power generated 520 terawatt-hours, according to the US Energy Information Administration. The fast growth is prompting researchers to study not just how airflows affect the extraction of wind energy by wind farms (see, for example, the Quick Study by John Dabiri, PHYSICS TODAY, October 2014, page 66) but also how wind farms affect the atmosphere. That influence extends through the atmospheric boundary layer, a region of turbulent, well-mixed air that strongly couples to Earth's surface and whose height ranges from tens of meters to a few kilometers. Understanding the interactions between wind farms and the boundary layer is important for modeling weather and other large-scale atmospheric processes. Flows around individual wind turbines can't be spatially resolved in weather models, so they must instead be parameterized. One common approach is to treat wind farms as sinks of momentum and sources of turbulence at finite, realistic elevations. Mahdi Abkar and Fernando Porté-Agel of the École Polytechnique Fédérale de Lausanne now put that approach on an analytical footing that can take into account wind-farm densities, farm layouts, and wind direction. In particular, the researchers show the importance of various factors affecting the wind velocity inside wind farms. Incorporating those considerations into the parameterization produced good agreement with large-eddy simulations of the boundary layer for the vertical profiles of both the drag forces and the turbulent energy induced by wind farms in different configurations. (M. Abkar, F. Porté-Agel, *J. Renewable Sustainable Energy* **7**, 013121, 2015.) —RJF

Predicting pentagonal graphene. Symmetry precludes the use of regular pentagons to tile a surface. However, as the accompanying figure shows, you can tile with irregular pentagons in a pattern known as Cairo tiling, named after the paving on several streets in Egypt's capital. According to a new theoretical study by Qian Wang of Peking University and her collaborators, the same pattern can be realized on the atomic scale: in graphene-like sheets of carbon. Carbon structures that feature pentagons have already been synthesized. The archetypal fullerene, C_{60}, comprises 12 pentagons amid 20 hexagons; the smallest, C_{20}, comprises 12 pentagons. Despite those antecedents, the idea that carbon could be coaxed into forming pentagonal sheets arose not from fullerenes but from a new crystalline phase that was predicted three years ago. Known as T12, the phase has two repeating layers, one of which consists of a corrugated arrangement of Cairo-tiled pentagons. Working on the assumption that the buckled layer could be chemically exfoliated, Wang and her collaborators calculated its properties. Although the material, dubbed penta-graphene, turned out to be metastable, it withstands heating up to 1000 K. It is stronger and somewhat less stiff than graphene, and it can be rolled up to form nanotubes. Unusually, penta-graphene has a negative Poisson's ratio: If you stretch it longitudinally, it will also stretch laterally. And unlike pure graphene, pure penta-graphene is a semiconductor, whose nearly direct 3.25-eV bandgap might make it optically useful. (S. Zhang et al., *Proc. Natl. Acad. Sci. USA* **112**, 2372, 2015.) —CD



Evidence for primordial gravitational waves negated. On 17 March 2014, scientists working with the South Pole's BICEP2 telescope announced that they had seen characteristic twisted patterns, called *B* modes, in the polarization of microwave photons coming from a significant patch of sky. The team, after accounting for contributions from dust in our galaxy, interpreted its observations as arising from primordial gravitational waves, stretched by cosmic inflation and imprinted on the cosmic microwave background (CMB; see PHYSICS TODAY, May 2014, page 11). Several months later data from the *Planck* collaboration suggested that dust may have caused the BICEP2 result after all (see the Commentary by Mario Livio and Marc Kamionkowski, PHYSICS TODAY, December 2014, page 8). Now a joint paper by researchers from BICEP2, the South Pole's Keck Array collaboration, and *Planck* finds no solid evidence for primordial gravitational waves. At frequencies much above 200 GHz, the galactic-dust contribution to *B* modes dominates the gravitational-wave-induced CMB signal. The new joint work compared the *B*-mode distribution observed by *Planck* at 353 GHz, for which dust is surely the cause, with that observed by BICEP2, and later by Keck, at 150 GHz. The distributions were highly correlated, suggesting that dust is also responsible for the 150-GHz signal. The strength of gravitational-wave-induced CMB polarization is conventionally described by a dimensionless parameter, r. Last year's BICEP2 announcement cited $r = 0.2$, several standard deviations away from zero; the new work bounds r to be less than 0.12. Evidence for gravitational waves may yet be lurking in the original BICEP2 data; if so, it will take more work to tease it out. (P. A. R. Ade et al., BICEP2/Keck and *Planck* collaborations, *Phys. Rev. Lett.* **114**, 101301, 2015.) —SKB ■