FLOWERING PLANTS THAT COMPETE SUCCESSFULLY FOR POLLINATOR SERVICES OFTEN ADVERTISE THEIR COMMODITIES—NECTAR, POLLEN, AND OTHER NUTRITIOUS REWARDS—WITH DAZZLING COLOR DISPLAYS AND ALLURING PERFUMES. POLLINATOR ABUNDANCE AND PREFERENCE MAY LIMIT A PLANT’S REPRODUCTIVE SUCCESS, ESPECIALLY IF ITS REPRODUCTIVE WINDOW IS BRIEF (1). SUCH CIRCUMSTANCES PREDICT A “BUYER’S MARKET” FOR POLLINATORS, WHICH SHOULD ENGENDER FIERCE COMPETITION AMONG NEIGHBORING PLANT SPECIES FOR ATTRACTING POLLINATORS THROUGH QUALITY REWARDS AND TRUTHFUL, ENTICING ADVERTISEMENTS. FLOWERS THAT ABUSE THE GOOD WILL OF THEIR CONSUMERS WITH MEAGER OR DISTASTEFUL REWARDS SHOULD FAKE POORLY IN SUCH AN ARENA. ENTER NICOTIANA ATTENUATA, A TOBACCO FROM NORTH AMERICA’S MOJAVE DESERT THAT LACES ITS FLORAL NECTAR WITH NICOTINE (SEE THE FIGURE). WHY WOULD A PLANT ADOPT SUCH A STRATEGY WHEN ITS HAWKMOTH AND HUMMINGBIRD POLLINATORS ARE DEMONSTRABLY REPelled BY THE TASTE AND ODOR OF NICOTINE (2)? ON PAGE 1200 OF THIS ISSUE, KESSLER ET AL. ADDRESS THIS CONUNDRUM (3) BY COMBINING GENIE SILENCING, PATERNITY ANALYSIS, AND FIELD EXPERIMENTS. SURPRISINGLY, THE COMBINATION OF NICOTINE AND BENZYL ACETONE (THE MOST ATTRACTIVE SCENT COMPONENT) BEST SERVES THE REPRODUCTIVE INTERESTS OF THE TOBACCO PLANT. THOSE WITH THIS BLIND BLEND SIRE MORE SEEDS ON OTHER PLANTS AND PRODUCE LARGER SEED CAPSULES THEMSELVES.

ONE NOVEL ASPECT OF THIS STUDY IS ITS SELECTIVE MANIPULATION OF SPECIFIC SCENT AND NECTAR COMPONENTS. THE AMOUNT OF SCENT AND NECTAR CAN BE AUGMENTED (4, 5), BUT THEIR EXPERIMENTAL DELETION IS MORE DIFFICULT. KESSLER ET AL. SILENCED GENES ASSOCIATED WITH NICOTINE AND BENZYL ACETONE BIOSYNTHEsis IN N. ATTENUATA AND THEN PRESENTED POLLINATORS WITH ARRAYS OF SUCH PLANTS Whose FLOWERS EMITTED DIFFERENT NICOTINE-BENZYL ACETONE COMBINATIONS. THE PRESENCE OF NICOTINE DECREASED THE TIME HAWKMOTHS AND HAWKMOTHS SPENT DRINKING FROM INDIVIDUAL FLOWERS BUT INCREASED THE NUMBER OF FLOWERS VISITED, PRESUMABLY TO SATISFY THE CALORIC DEMANDS OF HOVERING FLIGHT. CONVERSELY, BIRDS AND MOTHS VISITED FEWER FLOWERS FOR LONGER PERIODS WHEN NICOTINE LACKED NICOTINE, WHICH SUGGESTS THAT THE POLLINATORS’ INTERESTS ARE BEST SERVED BY EXTENDED VISITS TO A FEW NECTAR-RICH FLOWERS (6). RESPONSES TO PLANTS LACKING BENZYL ACETONE WERE MORE AMBIGUOUS. THE TASTE AND/OR SCENT OF THIS COMPOUND ARE PREFERRED BY HUMMINGBIRDS AND HAWKMOTHS (2), AND PLANTS LACKING BOTH NICOTINE AND BENZYL ACETONE WERE IGNORED BY HAWKMOTHS, POSSIBLY BECAUSE OF REDUCED ODOR (7). FLOWERS WITH NICOTINE ABSOLUTELY DETERR FLORIVORY BY CAPTIVATORS AND NECTAR-ROBBING BY CARPENTER BEES, BOTH OF WHICH COULD DIRECTLY REDUCE REPRODUCTIVE FITNESS. THESE RESULTS, COMBINED WITH SEED AND SEED CAPSULE PRODUCTION DATA, SUGGEST THAT CHEMICALLY MEDIATED “PULL” AND “PUSH” STRATEGIES OPTIMIZE REPRODUCTIVE FITNESS IN N. ATTENUATA BY ATTRACTION POLLINATORS, PREVENTING THEM FROM LOITERING, AND DETERRING FLORAL ENEMIES.

THE STUDY OF KESSLER ET AL. HIGHLIGHTS A PARADOX IN FLORAL BEHAVIOR: FLOWERS MUST COMPETE VIGOROUSLY FOR POLLINATORS WITHOUT BEING SO ATTRACTIVE THAT THEY NEVER LEAVE. A PLANT MUST ENCOURAGE A POLLINATOR TO VISIT OTHER FLOWERS OF ITS OWN SPECIES WITHOUT FORSAKING IT FOR FLOWERS OF A COMPETITOR. IN N. ATTENUATA, NICOTINE FUNCTIONS AS A FLORAL FILTER (8) FOR ANTAGONISTIC VISITORS (CAPTIVATORS AND NECTAR-ROBBERS) BUT MANIPULATES POLLINATORS BY ALTERING THEIR MOVEMENT PATTERNS (AND POLLEN EXPORT) THROUGH A POPULATION. FOR THIS TO WORK, NICOTINE MUST BE SOMewhat TOLERABLE—IF DETERRENT—TO HUMMINGBIRDS, OR THE LOCAL NECTAR MARKET MUST BE POOR. IN EITHER CASE, NICOTINE WOULD FUNCTION MORE AS AN ECONOMIC HURDLE (9) THAN AS A FILTER, WHICH SUGGESTS THAT POLLINATORS SUPPLEMENT ADDITIONAL REPRODUCTIVE OPTIONS AT THE TOBACCO’S DISPOSAL. SUCH A SCENARIO IS AMENABLE TO A GAME THEORY APPROACH. Indeed, N. ATTENUATA FLOWERS ARE SELF-COMPATIBLE, CAPABLE OF MATURING SEED CAPSULES WITHOUT POLLINATORS.

IN THIS LIGHT, TESTING A POLLINATOR’S TOLERANCE FOR NICOTINE-SPKED NECTAR APPEARS LESS RISKY. YET, HOW MIGHT OUTCROSSING—WHEN A FLOWER IS FERTILIZED BY POLLEN FROM A DIFFERENT PLANT—BENEFIT A PLANT THAT CAN POLLINATE ITSELF, SUCH AS N. ATTENUATA? PERHAPS THE ANSWER LIES IN THE PLANT’S LIFE HISTORY. IT IS A FIRE-ADAPTED DESERT ANNUAL THAT CAN SPEND DECADES AS A DORMANT SEED, AWAITING A SMOKE SIGNAL THAT WILL TRIGGER GERMINATION. THIS LIFE-STYLE IS NOTORIOUSLY UNPREDICTABLE, AND BETHEADING STRATEGIES ARE COMMONLY INVOKED (10) IN STUDIES OF GERMINATION SUCCESS. EVEN A LOW PERCENTAGE OF OUTCROSSING MIGHT IMPROVE SEEDLING SURVIVORSHIP, ESPECIALLY IF SEEDS GERMINATE UNDER VARIABLE CLIMATIC CONDITIONS.

THIS STUDY ADDS TO A GROWING LIST OF RUSES BY WHICH PLANTS MANIPULATE POLLINATOR MOVEMENT TO OPTIMIZE GENE FLOW. NEARLY A THIRD OF ALL ORCHIDS HAVE NO FLORAL NECTAR (11). WHEN SUGAR SOLUTIONS ARE ADDED TO SUCH FLOWERS, POLLINATORS REMAIN LONGER AT INDIVIDUAL PLANTS, RESULTING IN INCREASED INBREEDING OR POLLEN WASTAGE (12). SIMILARLY, THE REDUCTION OF NECTAR BY EXTRINSIC FACTORS (SUCH AS MITES) MAY BENEFIT PLANTS BY ALTERING POLLINATOR MOVEMENT OR FLORAL CONTACT (13). ANOTHER FLORAL SCHEME IS TO TURN UP THE HEAT. DRAMATIC INCREASES IN TEMPERATURE AND ODOR CONCENTRATION COMPETE CYCAD POLLINATORS TO LEAVE MALE CONES (WHERE THEY FEED ON POLLEN) FOR FEMALE CONES ON DIFFERENT PLANTS, THEREBY.
Astronomy

Life After Death

Annalisa Celotti

In 1054 C.E., Chinese and Arab (~3) astronomers recorded the observation of a bright explosion in the sky. Now known to have been a supernova explosion, the remnant—the Crab nebula—still emits particles energized to extremely relativistic energies and radiates light at x-ray and gamma-ray wavelengths. On page 1183 of this issue, Dean et al. (4) report the discovery that the high-energy radiation (hard x-rays) from the Crab is polarized, yielding insights into the processes and mechanisms involved in making a dead star so active.

When a massive star exhausts its fuel for nuclear fusion, it collapses under its own gravity into a neutron star or black hole, releasing energy that heats and expels the outer star layers. The material expands at a speed as high as 1% that of light, sweeping through the interstellar medium and giving rise to a supernova remnant. The Crab nebula is such a remnant, resulting from the explosion of a star thought to have been 10 times as massive as the Sun. It is located in our galaxy, in the constellation Taurus, about 6500 light-years from Earth, and is about 10 light-years in size.

Inside the Crab, a relatively young neutron star (5, 6) of 1.4 to 2 solar masses is active as a pulsar. The neutron star rotates at about 30 times per second. As it slows down, at a rate of 38 ns per day, its rotational energy is converted in part to radiation collimated along the axis determined by the pulsar magnetic field. Because this magnetic axis is misaligned with the rotation axis, like the beam from a lighthouse, such emission is observed from Earth as pulses of light from radio- to gamma-ray wavelengths. But most of the neutron star spin energy goes into powering a wind of relativistic particles and electromagnetic fields. Highly energetic particles moving in such a field will emit radiation. The x-ray image (see the figure) reveals morphological features over a scale of about 5 light-years, comprising a narrow collimated “jet” and a doughnut-shaped “torus,” as well as ripples, wisps, and arcs.

Even 40 years after the discovery of the Crab pulsar and more than 20 years after the basis of the currently accepted interpretation was formulated (7, 8), key questions remain: How is the rotation power converted into the electromagnetic and the kinetic power of the wind? How are particles accelerated to emit high-energy radiation?

Understanding how the Crab system works will elucidate the late stages of stellar evolution, the physics of magnetized relativistic plasma, the conditions of matter at nuclear densities, and the mechanisms by which extremely relativistic particles are efficiently accelerated in the universe. Indeed, observations of radiation from the Crab at extremely high energies (9), up to ~100 TeV (1 TeV = 10^{12} eV), requires electrons (and positrons) to have been energized to 100 million times the energy associated with their own mass.

The spectrum of the Crab, from radio to gamma-ray frequencies, is well known. Its brightness in x-rays promoted it to the role of a flux (and time) calibrator for x-ray detectors. The high degree and direction of polarization at high energies reported by Dean et al. provide valuable information on the site of acceleration of the particles and on the structure of the magnetic field associated with the pulsar. Such information cannot be provided by the spectrum alone.

Electromagnetic waves oscillate in a plane perpendicular to their direction of travel. They are linearly polarized if the electric and magnetic field vectors oscillate along the same direction in such a plane. For that to occur, the emitting system has to be characterized by some order, or degree of symmetry. For synchrotron radiation, an elevated level of polarization thus indicates that the magnetic field (and possibly the radiating particles) is

References

How is a dead massive star still able to energize extremely relativistic particles?