Plant Life’s Boxy Heart

There’s not always more than one way to skin a cat. Take the way plants use sunlight, water, and CO₂ to synthesize the sugars they need to grow and multiply. Early in the process, an essential protein called photosystem II (PSII) uses solar energy to split water into hydrogen and oxygen atoms, then pairs oxygens into the O₂ molecules we breathe. Despite billions of years of evolution, PSII in all photosynthetic organisms shares almost the same catalytic core. Without it, a few ecosystems near undersea hydrothermal vents would be the only life on Earth.

Researchers in Germany got the first close-up look at PSII in 2001 by making a crystal of millions of copies of the protein and bouncing x-rays off it to probe its structure. Such crystallography experiments can map complex proteins in near-perfect atomic detail. But the early maps of PSII were too fuzzy to show the exact arrangement of atoms in the core.

The maps got better in 2009. And this year, researchers in Japan captured the protein in full, exquisite detail—including its heart of four manganese atoms, five oxygen atoms, and a calcium atom. The snapshot revealed that these core atoms form a cube with a short tail hanging off one end. That shape, it turns out, is critical for holding pairs of oxygen atoms close enough together to be knitted into O₂.

This structure isn’t just essential for life; it may also hold the key to a source of clean energy. Today’s societies rely almost exclusively on fossil fuels for energy because we can’t match plants’ ability to convert sunlight into chemical fuels. Yes, we can use solar cells to make electricity—but electricity is tough to store in mass quantities. Researchers around the globe are racing to come up with catalysts to do the job. One option is splitting water to generate O₂ and molecular hydrogen (H₂), which can be burned or run through a fuel cell to produce electricity. Researchers have created numerous catalysts to split water and generate O₂. And so far the best ones have nearly the same cubic arrangement of atoms at their core as PSII. Knowing the structure of nature’s catalyst may help scientists design better synthetic ones.

Researchers nailed down crystal structures of several other important proteins this year. But PSII’s structure offers a window into a catalyst that is essential not only for past and present life on Earth but also perhaps for the future of civilization.

Areas to Watch

The Higgs boson
We’ve said this before (in 2008), but this time we’re sure: Next year, particle physicists will either find the long-sought Higgs boson or prove that it does not exist, at least not with the properties ascribed by the standard theory. That’s not so much a prediction as it is a matter of fact. The world’s largest atom smasher, the Large Hadron Collider at the European particle physics laboratory, CERN, near Geneva, Switzerland, is cranking out data at such a stupendous rate that—barring breakdown—the Higgs must either make an undeniable appearance or be deemed an unequivocal no-show. It’s all but a mathematical certainty.

Faster-than-light neutrinos
This year, physicists with the OPERA particle detector rocked the world when they reported that subatomic particles called neutrinos made the 730-kilometer trip between CERN in Switzerland and Italy’s subterranean Gran Sasso National Laboratory at slightly faster than light speed. Researchers with the MINOS experiment, which shoots neutrinos from Fermi National Accelerator Laboratory in Batavia, Illinois, to the Soudan mine 735 kilometers away in Minnesota, say they will try to reproduce the result by early 2012. Don’t be surprised if it takes a little longer—and if neutrinos do not really fly faster than light.

Stem-cell metabolism
The way stem cells use energy and intermediate metabolites seems to help determine when they differentiate and what kinds of cells they become. In 2012, look for researchers to use large-scale studies of stem cell metabolism to gain new insights into how stem cells regulate themselves in the body—and how scientists might tweak the process in the lab or in patients.
Glimpses of a Simpler Time

The universe was born thrashing and flailing. You’d think that exploding stars and other cataclysms would have roiled every corner of the cosmos within a couple of billion years. But it turns out that pockets of tranquility persisted. This new insight, based on two discoveries reported this year, is making astronomers rethink the details of star formation in the young universe.

One discovery, reported in November, is the sighting of pristine clouds of hydrogen. The clouds match the chemistry of much older primordial gas from the first few hundred million years after the big bang, before stars formed. The other discovery is a small star in the Milky Way’s halo whose concentration of “metals” (elements heavier than helium) is about 1/10,000 that of the sun. This star is practically devoid of metals, just like the universe’s earliest stars, which are believed to have been hundreds of times as massive.

The results add a twist to the story of the universe’s chemical evolution. When the universe began, researchers believe, it was made up of gas containing light elements, mostly hydrogen and helium. The first stars formed from this material, some 300 million years after the big bang. As these early stars burned their fuel, they fused the lighter atoms to produce heavier elements like carbon and oxygen. These so-called metals spewed into interstellar space when the stars exploded as supernovae. The birth and death of later generations of stars, made from gas polluted with these heavier elements, added even more heavy elements into the mix, making the overall chemistry of the universe increasingly metal-rich. Today, the stars and planets and interstellar gas around us are laced with heavy elements.

Astronomers used the Keck telescope to probe the faraway universe, dating back to a mere 2 billion years after the big bang, for relatively pristine gas clouds. To figure out the clouds’ chemical composition, they studied the spectrum of a background quasar whose light had traveled through the gas on its way to the telescope. They searched for signs of oxygen, carbon, nitrogen, and silicon but saw only hydrogen and its heavier isotope deuterium.

The star discovered by the other team was equally surprising because astronomers thought low-mass stars could form only from material with a certain concentration of metals. The reason is that metals are considered necessary for helping to cool a gas cloud enough to condense into a star.

The two results suggest that the first few generations of exploding stars did not scatter heavy elements throughout the universe like a captive squid filling its tank with ink. Instead, pockets of pristine gas lingered for billions of years, and some may have seeded a late crop of small, metal-free stars.

Genomic epidemiology

Not long ago, sequencing a single bacterium’s genome took years; now the job takes less than a day. Scientists are beginning to harness that power to track pathogens’ movements in more detail than ever before. Whole-genome sequences will help to determine quickly where newly emerging diseases come from, whether microbes are resistant to antibiotics, and how they are moving through a population; they will also shed light on historic epidemics.

Treating intellectual disability

The cognitive deficits and behavioral problems caused by Rett, Fragile X, and Down syndromes have long been considered irreversible. In each syndrome, a genetic glitch causes brain development to go awry even before birth. But recent work with mouse models of these conditions suggests, remarkably, that some cognitive and behavioral symptoms may be reversible. Treatments that target growth factors or neurotransmitter receptors in the brain are now in human clinical trials, and preliminary results should start to emerge in 2012. Meanwhile, expect preclinical researchers to keep coming up with new targets.

Curiosity to Mars

NASA will have more than the $2.6 billion cost of the Mars Science Laboratory (MSL) mission riding on a successful landing on the Red Planet next August. MSL’s new “entry-descent-landing” system—designed to lower the 900-kilogram nuclear-powered Curiosity rover gently onto the martian surface—is essential to NASA’s ambitious plans to return rock samples to Earth. It is engineered to achieve the pinpoint landings on Mars needed to collect specific samples and return them on a later mission. Failure of the landing system on its first voyage would be disastrous for much more than Curiosity.