lular structures collapse and bacteria are ejected from the safety of their compartments into the cell cytosol. Importantly, this nodule shutdown happens even when only a fraction of the local symbiont population is cheating, allowing the plant to solve the problem before it gets out of control, Sachs notes.

It’s not yet known how plants sense these cheaters. A simple hypothesis is that low nitrate concentrations could signal to the plant that nodule-living microbes aren’t doing enough fixation, Sachs says. But it’s probably more complicated than that. Experiments by his team have shown that even plants in nitrate-rich soil seem to know when their symbionts are shirking their responsibilities. “So [now] we are testing a hypothesis that there’s a private signal,” he says, “a very specific form of nitrogen that the host is getting from the symbiont” and nowhere else.

The need to keep out cheaters may also help explain one of the bobtail squid’s weirder behaviors. Like many animals with symbiotic organs, this species picks up its symbionts early in life—and then doesn’t acquire any more. But as an adult, the squid also blasts a large proportion of its symbiont population out through its siphon every dawn, before burying itself in the sand to sleep while the remaining bacterial population grows to full size again. “Ninety-five percent of the contents are expelled” in this mini-explosion each day, says Bongrand, “and then there is this five percent that is regrowing.”

The ostensible reason for this “venting” is to refresh the bacterial culture, which can otherwise cause a buildup of metabolic byproducts that harm the squid, Bongrand says. It affects the composition of seawater outside the squid, too, seeding the ocean with *V. fischeri* that may go onto colonize other squid. But some researchers suggest that the behavior might also offer the squid a way of jettisoning so-called dark mutants—bacteria that skimp on producing luminescent proteins. Research has shown, for example, that squid genes expressed in the light organ are regulated in response to the light produced by bacterial symbionts, not just by the presence of the bacteria themselves. This trick could provide the squid with a reliable mechanism to detect when cheaters might be sweeping through the population, Nyholm points out.

Despite such advances in understanding the biology of symbiotic organs, much about the intricacies of host-symbiont communication have yet to be worked out. Some symbionts, such as the bacteria living in tubeworms, are still impossible to culture in the lab, notes Cavanaugh, who also studies symbioses in bivalve mollusks and anemones. Other microbes are being sequenced and scanned for clues as to how they find their hosts, signal to those hosts that they’re performing their work, or interact with the host immune system to maintain their unusual relationship. Such studies could shine a light on microbial interactions across multicellular organisms, not just those that have developed separate organs for the purpose, Nyholm says.

For example, “by understanding how the innate immune system is used to tell the difference between symbiotic and pathogenic or not-symbiotic bacteria, we can really discover some evolutionarily conserved mechanisms by which all animals detect bacteria,” he explains. “This is an open question still in symbiosis, whether you’re talking about the human microbiome, or a mouse, or a squid, or a zebrafish, or a plant: How do the partners find each other, and what’s the language they use to talk to each other?”

**FARMING AIDS**

**Host:** Attine ants (*genera Atta and Acromyrmex*)

**Symbiont:** Genus *Pseudonocardia*

Fungus-growing ants use microbial symbionts to produce antibiotics to protect their fungus gardens from environmental pathogens. Microbes are stored and fed in crypts all over the ants’ bodies, and are easily transferred through contact between worker ants.

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Bacterial symbionts

Crypts

Crypt

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Bacterial symbionts

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